2005 Range Field Day Progress Report

Papers presented at Union, Oregon
June 28, 2005

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Mike McInnis, Editor
Front cover photo: Cattle grazing riparian area of Catherine Creek on the Eastern Oregon Agricultural Research Center. Photo by Cory Parsons.

History of Rangeland Research on Catherine Creek

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Oregon State University acquired the Hall Ranch in 1941 and has maintained it as a forested rangeland research center since. The early studies on the Hall Ranch included classification of the soils and vegetation and mapping range use patterns of the University cattle herd. Forest grazing integrated with forest harvest practices was the early rangeland research focus of the station. The meadow associated with Catherine Creek was grazed heavily season long. Range surveys in the 1960's consistently indicated utilization was very heavy and range condition was poor. Some attempts were made to improve the forage production mostly through fencing and mechanical control of hawthorne (*Cratagus douglasii*) in 1958 and again in 1974 and 1975. Even though condition was poor the productivity of the forage in the meadow was much higher per acre than any of the upland sites. In 1971 Dr. Martin Vavra began working at the Eastern Oregon Experiment Station. In the middle 1970's, he collaborated with Dr. Ralph Phillips in a study of nutrition and production of cows and calves on the upland pastures and the meadow in pasture C, which is the riparian pasture dissected by Catherine Creek. In those studies, they discovered that grazing the meadow (riparian zone) in late fall improved cow and calf productivity over leaving them on the uplands as the forage began to mature in mid-August. Cows grazing the Catherine Creek meadow maintained their weight while the cows on the forested uplands were losing weight. At the same time the calves on the meadow gained 1 to 1.5 pounds per day more than calves on the uplands. Consequently, the cows in the meadow went into winter in better condition, and total calf weights were 25 to 40 pounds greater for calves grazing the meadow compared to those grazing the uplands in the late season. The distinct livestock production advantage of late-season grazing in the Catherine Creek meadow precipitated a change in management to using it exclusively in mid-to late August for about three weeks depending on the year and forage availability. We anticipated that this change in management would also improve the range condition of the riparian meadow.

When the change in management was made in 1977, there was no evidence whether there were positive or negative impacts to a variety of environmental aspects that could relate to late season grazing in the riparian zone. So Dr. Vavra and Dr. Bill Krueger developed a research program to evaluate the impacts of the late-season cattle grazing on the soils, vegetation, and wildlife associated with Catherine Creek. In 1978, a series of five exclosures were constructed along Catherine Creek so that approximately half of the stream banks along the 1.6 miles of the creek and the riparian zone within the adjacent 50 yards were excluded from cattle grazing (Figure 1). Since 1977 the grazing program has been maintained with grazing by cows and calves from mid-August to mid-September, usually for three weeks. Duration of grazing has been adjusted based on forage growth each year. Cattle are removed when the stubble height of Kentucky bluegrass (*Poa pratensis)* is at 1 inch. The only deviation from this grazing strategy was in 1992, when the pasture was grazed most of May, and again in early August for about two weeks. The same stubble height criteria was observed in the fall grazing.

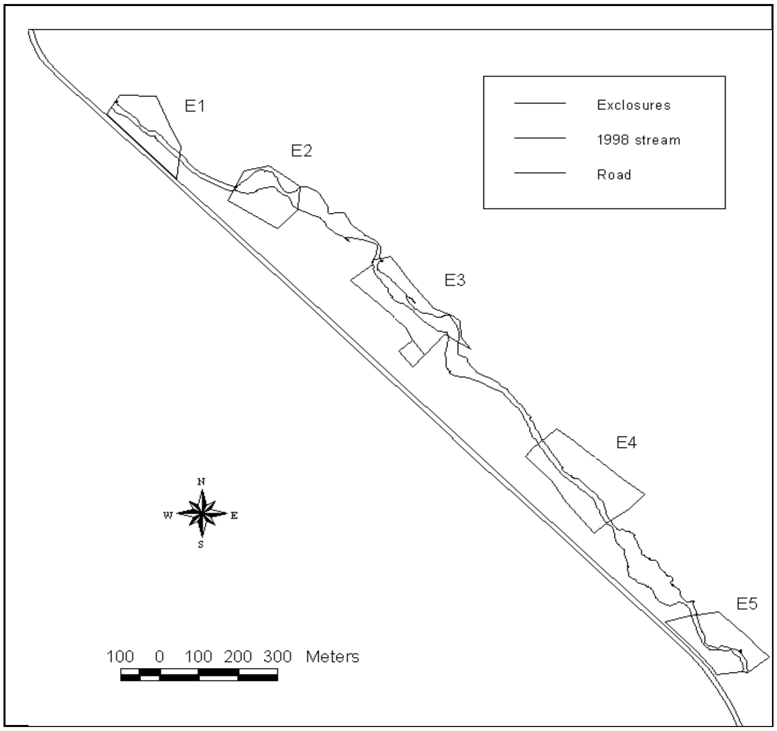

Figure 1. Layout of the study area locating the five exclosures and outline of Catherine Creek in 1998.

Much of the field research on Catherine Creek has been conducted by graduate students, beginning with John Boone Kauffman who finished an MS thesis in 1982 with major professor Dr. Krueger. He was followed by Douglas M. Green, who finished a PhD thesis in 1991 with major professor Dr. Kauffman; Edwin J. Korpela, who finished a PhD thesis in 1992 with major professor Dr. Krueger; Teena Ballard, who finished an MS thesis in 1999 with major professor Dr. Krueger; Mark P. Reynolds, who finished an MS thesis in 1999 with co-major professors Drs. Johnson and Krueger; and Andrea Laliberte, who finished an MS thesis in 2000 with Dr. Johnson as major professor.

The initial studies from 1978 to 1980 were the basis for Kauffman's thesis. The initial survey of the pasture, in a band 50 meters wide along the stream, indicated there were 256 individual stands of plant communities representing 60 discrete plant communities. Twenty species of mammals and 81 species of birds were found in the study area. Ten plant communities representing the range of community types were intensively sampled to contrast changes between areas excluded from cattle grazing and those grazed with the late season grazing strategy. Three of the 10 plant communities studied developed differently in the grazed areas compared to exclosures. There was substantial variability among and within community types. Wet meadows tended to increase the relative abundance of mesic forbs and sedges in the excluded areas compared to grazed areas; drier meadows with hawthorne tended to increase productivity, especially in abundance of Kentucky bluegrass, under exclusion; shrubs were grazed sufficiently on gravel bars to significantly reduce their rate of growth compared to those in exclosures. No differences in productivity were found for the other 7 plant communities studied in detail. Biodiversity was measured with standard indices including richness, species diversity, and equitability. No differences were found in biodiversity between grazed and excluded areas after two seasons of study. We also noted that the most productive meadow types would cycle in productivity between years when they were not grazed because of the heavy mulch left from about 7,000 to 8,000 kg/ha of vegetation residue in the exclosures. The reaction of individual species was dependent on the plant community they were in. For example, Kentucky bluegrass declined in exclosures in wet meadows and increased in exclosures in hawthorne types.

The impact of cattle grazing on short term erosion rates was significant. In 1979, after the first winter, streambanks were protected from cattle grazing in the exclosure. There was more total bank erosion in grazed areas compared to excluded areas during the grazing season. There were no differences in erosion losses based on vegetation types or for position on the meander bends. Over-winter erosion was not different between grazed and ungrazed locations, so erosion losses occurred during the grazing season and did not carry over into winter runoff losses. The experimental design, fencing out half of the streambanks, doubled the number of animal days per length of streambank from 48-50 meters of available streambank/animal unit month to 25-30 meters of available streambank/animal unit month. Grazing the pasture at 48-50 meters of available streambank had few impacts on the vegetation and, we suspected, would have much less impact on the streambank as well. When the status of streambank erosion, morphology, and bank undercuts are important considerations in making management decisions, it may be more useful to measure intensity of use with the numbers of animals per length of streambank rather than density of animals per unit area.

The third aspect studied was difference in abundance of birds and small mammals in exclosures compared to late season grazing by cattle. There were few short-term impacts on birds and a significant decrease in small mammals following the late season grazing. By the year following grazing, the small mammals had fully colonized the grazed areas to yield essentially the same species composition and densities.

In 1987 and 1988 the initial work was followed up by Doug Green to evaluate changes in 8 of the major plant communities under grazing exclusion or grazed with the late season strategy. He found that species diversity was similar after 10 years. Woody vegetation on gravel bars was less under grazing compared to exclusion. Most of the parameters studied did not change differently in grazed or excluded areas, but what did change resulted in more uniformity within the exclosures compared to the grazed areas. It may be that prior to historical introduction of livestock, diversity and species richness was lower than occurs under livestock grazing now. The vegetation in this riparian zone probably requires some level of disturbance to maintain optimum diversity.

This study also had a focus on the underground aspects of plant community ecology, including depth to water table, soil temperatures, and a variety of soil chemical attributes. The soils under *Glyceria* communities were anaerobic with high levels of nitrates. These wetter sites are efficient at denitrification of the soil and may be important to maintaining water quality parameters. The soil chemistry was distinct for each plant community, indicating that the plant soil associations were important in determining what will grow at any particular area.

In 1998, Dr. Douglas Johnson supervised evaluation of the changes over 20 years which was the basis for Andrea Laliberte's MS thesis. This approach used remote sensing and geographic information systems techniques to evaluate changes in the vegetation and morphology of Catherine Creek and to determine if the changes that occurred were a result of cattle grazing, topography, or climate.

Aerial photos from 1979 and 1998 (scale of 1:4000) were geo-referenced with ground control points, and various stream features were digitized using a GIS. Stream length, stream width and areas of change were identified for both years. Although stream length remained the same, stream width decreased in both grazed and exclosed areas (Table 1). The area of change (3.65 ha) was slightly larger than the area of no change (3.2 ha). The number of islands and island perimeter decreased, while the island area increased. Exclosures and grazed areas responded similarly, and it was concluded that the topography and stream dynamics had a greater influence on ecological change than the grazing regime in this study of 20 years of change in Catherine Creek and the riparian zone associated with the creek.

Table 1. Catherine Creek mean stream widths excluding islands for 1979 and 1998 in exclosures (E) and grazed areas (G). Stream width was measured every 0.5 m.

	1979	1998	Change
	(m)		(%)
E2	18.91	14.36	-24.06
E3	19.43	12.33	-36.54
E4	15.04	12.38	-17.69
E5	20.35	8.65	-57.49
G1	17.30	10.56	-38.96
G2	16.54	13.32	-19.47
G3	15.82	13.68	-13.35
G4	16.83	14.26	-15.27
Mean E	18.67	11.85	-36.54
Mean G	16.62	12.96	-22.06

These three studies of ecological changes over time illustrate the extreme complexity of riparian and stream systems. It is difficult to look at short-term changes and then predict what will happen in the longer term. In every period, the changes that were related to the grazing program were small or there were no differences between grazed and ungrazed study sites. As more time progressed some level of change, especially related to biodiversity, became more obvious. The increased biodiversity after 10 years of late-season grazing compared to exclusion of grazing suggests grazing increases biodiversity. This was the case, but this may not be satisfactory to all management objectives since in some plant communities there was an increase of plant species that tend to be more suited to disturbed areas. In some other areas, there was essentially no difference in vegetation between grazed and excluded sampling units. The response of vegetation and physical attributes of the riparian zone and creek after 20 years seems to be more a function of the weather patterns and natural attributes resulting from the topography. From this, we conclude that Catherine Creek is functioning for producing sustainable levels of production of both cattle and natural products that depend on a properly functioning ecosystem.

In 1984 and 1985 we decided to evaluate the riparian meadow specifically as it related to cattle use and production. This was the basis for Ed Korpela's PhD thesis. Productivity and seasonal trends of the five major plant community types were modeled using correlation and path analysis techniques. Wet meadows produced the greatest amount of biomass followed by moist bluegrass meadows, gravel bars, forests, and dry bluegrass meadows in descending order. Production was related to soil moisture in the dry meadows and depth to the water table in the wetter sites.

Streamflow levels had the greatest influence on production of the gravel bars. Preference for each plant community type was monitored and then modeled to evaluate forage preference, intake, and vegetative and nutritional characteristics of available forage. Relationships among variables were evaluated and the cattle behavior indicated they initially favored plant communities with highly digestible forage, specifically Kentucky bluegrass. Late in the period, in early September, cattle preference was less specific and communities were grazed at random. At the end of the season, daily grazing time declined. Intake was related to digestibility and the amount of time spent grazing but not related to amount of available forage. The key to livestock production on riparian zone at Catherine Creek is highly associated with the distribution and production of Kentucky bluegrass.

We conducted a methods study in 1996 and 1997 to evaluate the use of GIS technology for measurement of shrub utilization. This was the basis of Mark Reynolds' 1999 MS thesis. A point frame, photographs, and a canopy analyzer to evaluate obstruction of light were used to define level of utilization. Black cottonwood (*Populus trichocarpa*) and Douglas hawthorne were artificially defoliated and level of defoliation was determined for each technique. Analysis of photographs was the most reliable, followed by point frame analysis. The canopy analyzer was least reliable of the three techniques. Time invested in the point frame and photographic measurements (about 2 hours) were equivalent while the canopy analyzer was rapid (about 5 minutes). The photographic technique was determined to be the most useful of those tested.

Since chinook salmon (*Oncorhynchus tshawytscha*) spawn in the research area and they are listed as threatened, we decided to evaluate the long-term effects of cattle grazing on the spawning habitat in Catherine Creek and the direct relationships between cattle grazing and salmon behavior. In 1997 Dr. Bob Ellis (Fisheries Biologist) and Drs. Johnson and Harris in the Department of Rangeland Resources collaborated on an extensive study evaluating the long term (19 years) changes in spawning habitat in Catherine Creek and comparing it to conditions in the Little Minam River in the Eagle Cap Wilderness area that has been ungrazed for decades. The physical and biological attributes of both streams are similar.

Stream bank stability was similar between the grazed and exclosed plots after 19 years of application of the late-season grazing program on Catherine Creek (Table 2). Overall, the reference reach in the wilderness had about 20% more stable banks than either the grazed or exclosed areas on Catherine Creek. Vegetation cover and canopy density were not different for the grazed areas compared to the excluded areas on Catherine Creek. The canopy density and cover was significantly higher on both the grazed and ungrazed areas of Catherine Creek when compared to that on the Little Minam River in the wilderness.

Table 2. Percentage of streambank in each of four stability categories for both grazed and excluded areas of Catherine Creek and the Little Minam River.

Treatment	Covered and Stable	Uncovered and Stable	Covered and Unstable	Uncovered and Unstable
Exclosed	71.8	2.3	14.0	11.7
Grazed	61.5	9.7	20.6	8.1
Reference (L. Minam R.)	89.0	5.0	5.9	0.1

Most of the differences that were calculated from total inventories of the study area (i.e. streambank cover, pool quality, pool quantity, and spawning habitat area) were small (Table 3). The major unexpected exception was spawning habitat area, which was much larger in the grazed treatment. Pool frequency was higher in the grazed treatment primarily because grazed plots G-2 and G-4 had relatively long lengths of side channel habitat, where pools occurred more frequently than in the main channel. Most differences between means determined from transect data (i.e., width/depth ratio, mean bankfull channel width, mean low flow channel width, and percent fine sediments) were found to be non-significant.

Overall, the combined results indicate that variability within treatments was high and that any detrimental effects attributable to grazing impacts were small and probably biologically insignificant with respect to fish use. When compared with the pristine conditions of the Little Minam River reference reach, Catherine Creek habitat appears to be moderately degraded with respect to residual pool depth, width to depth ratio, undercut bank cover, and density of large woody material. However, little difference was found between the Little Minam River and Catherine Creek with respect to percentage of fines in potential spawning substrate. The Catherine Creek study area had better canopy cover and better bank cover than the Little Minam River meadow reach.

This case study demonstrated that after 19 years of cattle grazing under a late-season grazing management program, grazing impacts on stream habitat were minimal and within the range of natural variation compared with areas where cattle grazing was excluded. In conclusion, it appears that the relatively low intensity of cattle grazing on the riparian shrub/tree vegetation has allowed plant succession to advance similarly in both grazed and excluded areas. The stream channel throughout the study reach appears to be in a long-term process of recovery from historic effects of land use.

Table 3. Summary of habitat measurements for grazed and exclosed treatments, difference between treatments, direction of change relative to the grazed plots and consistency of the direction of change with that expected for grazing related impacts.

Habitat Characteristic	**Grazed**	**Exclosed**	**Difference**	**Direction of Change**	**Consistent with Expected Direction of change (yes or no)**
Streambank Cover					
%Undercut Bank	9.4%	5.3%	4.1%	+	No
%Overhanging Veg.	5.3%	7.4%	2.1%	–	Yes
Pool Quality					
Pool Rating Score	3.8	3.6	0.2	+	No
Residual Pool Depth	0.38m	0.47 m	0.09m	–	Yes
Pool Quantity					
% Channel Length	20.7%	28.5%	7.8%	–	Yes
Pool Frequency	52/mile	42/mile	10/mile	+	No
Width/Depth Ratio	58.2	50.2	8.0	+	Yes
Mean Bankfull Width	24.7 m	22.3 m	2.4 m	+	Yes
Mean Low Flow Width	13.5 m	12.4 m	1.5 m	+	Yes
Spawning Habitat					
Area of Medium + High Quality Habitat	267 m^2	120 m^2	147 m^2	+	Yes
% Fine Sediments	3.8%	3.6%	0.2%	+	Yes

The behavior of cows and calves in riparian pastures and their direct interaction with spawning chinook salmon was studied by Teena Ballard in 1996 and 1997. Cattle were stocked in the Catherine Creek pasture when salmon began to spawn each year. She followed individual cows and recorded thirteen different activities during the three weeks they grazed in the middle of August and early September. During the same period, she observed individual salmon redds and recorded nine different activities of the salmon.

Cattle spent approximately 94% of their time in the terrestrial habitats (meadow, disturbance, low shrub, tall shrub, and trees) that supported herbivory-type activities (travel, graze, and rest); the remaining time was spent in stream habitats, which consisted of gravel bar (5%) and in aquatic (<1%) habitats (Table 4). Cattle spent approximately 88% of their time on nonherbivory-type activities while in the aquatic habitat. Individual cows were observed during the daylight hours for 18 of 28 days each year they were in the pasture and were never observed in direct contact with a redd. Cattle spent over half of their time drinking and <0.01% of their time defecating while they were in the aquatic habitat. Defecation was proportional to time spent in each habitat; so about 2% of the manure was directly deposited in the stream.

Table 4. Percent of time cattle occupied each terrestrial and stream habitat in 1996 and 1997 compared to the area of the habitat.

Habitat	Dominant Species	Pasture % of Area	1996 Percent Time	1997 Percent Time
Meadow	Kentucky Bluegrass	38	26.9**[1]	28.2**
Disturbed	Cheatgrass	2	1.4	0.1
Low shrub	Snowberry	8	17.1*	12.3
Tall shrub	Black Hawthorn Thinleaf Alder	16	32.8**	26.1**
Tree	Grand Fir Ponderosa Pine Black Cottonwood	13	14.7	27.9**
Gravel bar	Willow Black Cottonwood Thinleaf Alder	8	5.4	5.0
Aquatic	Not Applicable	15	1.5**	0.4**

[1]Significant differences between the availability of the habitat and time spent in each habitat in each year are noted for P≤0.05 as * and P≤0.01 as **.

The second part of the study addressed the occurrence of spawning in the study area and two potential impacts of cattle behavior during chinook salmon spawning: 1) disruption of spawning behavior by the presence of cattle near the redd, and 2) the frequency of actual cattle contact with redds. Frequency of salmon redds was not significantly different in the stream reaches accessible to cattle compared with excluded reaches. The selection of spawning sites was proportional to the relative occurrence of suitable spawning gravel in the exclosed and grazed areas of the riparian area and creek. Salmon continued preexisting patterns of behavior while cattle were within visible range of a redd (Table 5). Cattle were seldom close to a redd (12% of the time) and the chance for direct interaction to occur was minimal. When cattle were visibly near an active redd, cattle remained greater than 3.0 m from the active redd 84% of the time. Of the total time redds were observed, cattle contacted the redds <.01% of the time. Previous studies have shown salmon that are harassed during spawning can retain eggs and even go completely unspawned. All salmon fully spawned in the study area in both years of the study.

Table 5. Percent time spring chinook salmon spent on each activity in the presence of cattle visible to a human observer and in the absence of cattle, averaged over years. There were no significant differences between time spent on activities when cattle were present compared to when cattle were absent.

	CATTLE PRESENT	CATTLE ABSENT
SALMON ACTIVITIES	% of time	% of time
Spawning	0.90	0.66
Working	4.45	8.36
Swimming around redd	5.92	10.32
Under cover	34.70	30.54
Resting in redd	52.31	43.47
Darting to cover	0.37	0.12
Protecting the redd	0.30	0.19
Absent from redd	1.13	6.41

Summary

These studies of the various aspects of ecology, cattle grazing, salmon spawning and behavior, and effects of management were case histories of a typical riparian zone found on private land in northeastern Oregon. The meadow is larger than most of the riparian meadows adjacent to streams in the National Forest. The applicability of the results of this study to other riparian areas is unknown. We conducted the research with stocking densities and utilization levels that are similar to those of private lands in the area and much heavier than those on public lands. Since most of this research is related to specific interactions of cattle with salmon and their redds and specific aspects of ecology and stream geomorphology, use of the information from these case studies in other areas should consider the grazing behavior of cattle. If cattle are not forced to spend time in the aquatic zone because of topography and availability of forage more than 3 meters from the creek, they would probably behave similarly to those in this case study. If topography, lack of usable forage, or other factors concentrate animals near the stream edge or in the stream for long periods, the conditions of the interactions of cattle and salmon, plant succession, or stream geomorphology as affected by cattle grazing could be different and the results would not be applicable. The early short-term studies indicated some grazing influences that we would expect to have a long-term cumulative effect on structure of the vegetation and geomorphology of the stream. However, as the study continued, the short-term impacts of cattle grazing were insignificant as the natural forces of weather and succession overwhelmed the system and determined the structure and function of Catherine Creek and the riparian area adjacent to the creek.

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Catherine Creek riparian pasture near peak production. The foreground is a Kentucky bluegrass site, middle is a wet meadow, and a corner of an exclosure is visible as the site transitions to a tall shrub community dominated by hawthorne.

Catherine Creek at high flow.

Soil Compaction by Grazing Livestock

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Soil compaction is a well-known concern on agricultural and forest land where heavy equipment traffic can form dense soil layers that retard soil water movement, root penetration, and reduce plant growth. It has also become apparent that human foot traffic can crush plants and compact soil where travel is concentrated along recognized trails and other frequently traveled rights-of-way. Although over half of all land in the U.S. is rangeland (Holechek et al. 2004), most of which is grazed by livestock or similar big game animals, surprisingly little is known about the impacts of this more diffuse animal impact on soil physical properties.

It is important to recognize that soil compaction is a natural and dynamic process. Gravity is the major cause of soil compaction. The weight of a layer of soil compacts the soil beneath it. The downward force of gravity applied to the soil surface by any object in contact with it compacts the soil. For instance, the weight of a tree is transferred down to the soil, which is compacted by the load. Interestingly, trees and other woody vegetation also compact soil through root expansion. It is not unusual to see trees that have formed a pronounced mound under their trunk by simple expansion of roots over many years pushing the soil up and away from the trunk. This lateral compression compacts nearby soils. The current compactness of soil is a dynamic equilibrium between these compactive factors and restorative processes that decompact soils. Restorative processes are very poorly understood and documented. Shrinking and cracking of vertic clay soils; freezing and thawing; activities of ants, worms, and other soil animals; and the formation of fine root channels by plants are frequently cited restorative forces. Livestock grazing may potentially influence these forces through impacts upon the litter layer that both insulates the soil surface and serves as food and habitat for soil surface organisms. The ability of these restorative forces to reform soil pore space and to increase water infiltration rates during periods of non-grazing is largely unknown.

I conducted a study in western Oregon during 2002-2004 to document the effects of 11 years of sheep grazing on soil water infiltration, soil bulk density, and soil porosity and to observe the rate of their change following cessation of grazing. These 3 characteristics, along with soil strength, are often used to measure soil compaction.

Methods

The study was conducted on the western edge of the Coastal Mountain Range near Corvallis, Oregon latitude (44.4^{o}North, longitude 123^{o}West). Elevation is approximately 120 m above sea level. Soil is a Philomath silty clay (*Vertic Haploxerol*), which is a shallow (<35mm deep), cracking clay developing above a basalt lava flow (Knezevich 1975). Prior to research, the entire 20 ha site was managed as a single pasture. The research area was plowed and harrowed in summer 1988. Agroforest plots were planted with 20 kg/ha of rhizobium innoculated subclover (*Trifolium subterraneum*) seed in September 1988. Three replications (plots) of forest and agroforest (Fig. 1) were established in 1989. Both forests and agroforests were planted with 568 low-elevation Douglas-fir (*Pseudotsuga menziesii*) bare root seedlings (2-0 stock) per hectare in February 1989. Forest trees were planted 4 m apart in a rectangular grid pattern. Agroforest trees were planted in rows with 2.5 m between trees within rows and 4 m between rows, as suggested by Sharrow (1992) to optimize tree and pasture production. Each plot was individually fenced with portable electric fencing and grazed as a single unit. Grazing occurred in early April and the accumulated result of 11 years of livestock grazing. Soil in the agroforests was more dense (higher bulk density) and somewhat less porous than those in adjacent forests. Most of the difference in total porosity was air-filled pores, whose total volume was over 40% less in agroforest than in forest soils. Water-filled pore volume was similar among treatments in 2002.

Table 1. Physical characteristics of the top 7 cm of soil in Witham Hill forests and agroforests in spring 2002.

	Bulk Density* (g/cc)	% Porosity* (cc/cc)	% Water-filled Pores* (cc/cc)	% Air-filled Pores* (cc/cc)
Forest	0.93 [a]	64.8 [a]	37.4 [a]	37.3 [a]
Agroforest	1.05 [b]	60.4 [b]	39.6 [a]	20.8 [b]
MSE	***0.007***	***0.26***	***0.86***	***0.74***

*Means not sharing a letter differ, $p<.05$, Tukey's W Procedure

Differences in porosity were reflected in infiltration rates (Fig. 2). Average water infiltration rate was 35% less in agroforests, being 1104 vs. 714 liters/m^2/hour for forests and agroforests, respectively. However, total water stored in the top 6 cm of soil at field capacity was similar being approximately 18 and 17.7 liters/m^2 for forests and agroforests, respectively.

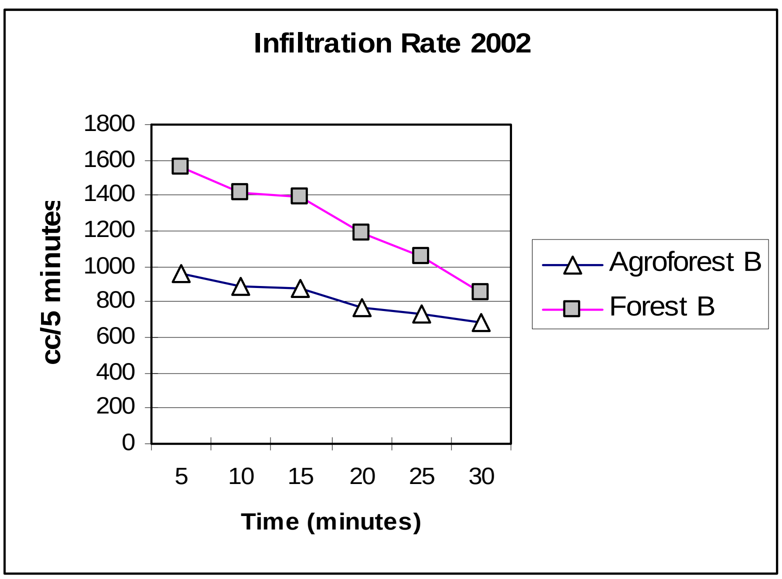

Figure 2. Witham Hill plot water infiltration rate, June 2002.

These observations are most easily understood by considering the nature of soil physical structure. Soil is similar in construction to a piece of bread. It is mostly a series of holes (pores) joined by a matrix of mineral soil and organic matter. The holes are squeezed together as soil is compressed by gravity, animal foot pressure, or equipment wheels or tracks. The largest, air-filled pores are the first to crush and be lost; while smaller, water-filled pores are much more stable under pressure. Only very severe compaction will crush the small pores where water is stored and actually squeeze water out of the soil. Movement of water and air into the soil is immediately reduced by loss of the large interconnected pores during initial compaction. This reduces water infiltration and soil aeration even under moderate levels of compaction. The loss of pore connectivity may be more important than the reduction of total large pore space in reducing water and air movement through the soil. Generally, once these large pores are crushed, they do not spring back after the pressure is removed. As air is squeezed out of soil, what remains is the heavier mineral soil and soil organic matter. So, the weight of soil per cubic inch of volume (soil bulk density) increases. It is unusual to compact soils to the point that even the smaller pores are crushed. So compaction usually does not reduce soil water-holding capacity. To the extent that larger, air-filled pores are squeezed down to become smaller water-holding pores, water-holding capacity of soil may even increase with moderate compaction. Because roots must now try to grow through denser soil with fewer interconnected pathways to follow, soil resistance to penetration (soil strength) increases with compaction.

It is logical to assume that the sheep grazing agroforest plots were responsible for the evidence of compaction seen in Table 1. Livestock can exert considerable downward force through their feet. The issue of how much pressure is placed on the soil by animal hooves is surprisingly complicated. The simplest approach is to just divide the weight of an animal by the area of its foot-print. A more refined calculation takes into account that moving animals may have one or more feet off the ground as well as having a downward and forward motion of their body weight as they travel. The general result of such calculations is that cattle, sheep, and humans can easily exert as much downward pressure on soil as do agricultural tractors, and unloaded forestry harvest equipment. However, the total amount of pressure exerted is not the whole story. The area over which the pressure is applied is also important. When the pressure is exerted over a very small area, such as a cattle or sheep hoof, some of the soil can respond by moving to the side as well as downward. This helps to dissipate the load near to the soil surface. Larger pressure sources, such as a broad agricultural tire or a caterpillar track, predominately transfer their loads downward and can compact soil to a much greater depth. Therefore, soil compaction by livestock is generally concentrated in the top few cm of soil, while heavy equipment compacts soils to a depth of well over a half meter. I limited the study to the top 6 cm of soil, which is the zone in which soil compaction by livestock should be most evident.

Infiltration data generally have very high spatial variability. My study area was certainly no exception to this rule. Agroforest soil infiltration rates in 2002, for example, varied from approximately 19 $cc/cm^2/hr$ to 632 $cc/cm^2/hr$ for individual infiltrometer runs. Visual examination of infiltrometer cores during 2002 suggested that high infiltration rate was not generally the result of large channels, such as gopher tunnels or worm holes, either in or under the core. It resulted from a large number of small pores <1 mm in size, presumably formed by small soil fauna. One of the striking differences between forests and agroforests or pastures was the relatively well established layer of both standing and soil surface grass litter present on forests. Pastures and agroforests largely lacked this layer. Sharrow and Ismail (2004), working in these same research plots, estimated that forests had over 800 kg/ha of herbaceous litter, while pastures and agroforests had less than 100 kg/ha of litter, some of which was shed conifer needles. This led me to consider the hypothesis that grazing management effects on soil physical properties may be as much from their impact upon the development of a persistent litter layer as they are from direct hoof impact upon the soil. The presence of a litter layer could change soil surface dynamics by insulating the soil surface and reducing opportunities for frost heaving and shrink/swell during wetting/drying cycles. On the other hand, the food source and physical habitat within the litter layer and underlying surface soil could greatly favor pore formation by soil organisms. If soil organisms were responsible for establishing and maintaining soil pore structure, changes with different management could be much more rapid than if physical mechanisms (frost heaving or shrinking/swelling) must be relied on. This prompted me to see if 2 years of non-grazing could again in June each year from 1990-2001. Agroforests were grazed with sufficient sheep to consume approximately half of the forage standing within 4 days on each entry. This generally resulted in a stocking density of 200-400 ewes/ha. Forests were not grazed. Following planting to subclover, all plots went through a successional process as local grasses and other forbs reestablished. Within two years, forests were almost entirely tall oatgrass (*Arrhenatherum elatus*) and annual grasses (*Bromus mollis* and *Vulpia myurous*), while agroforests and pastures were approximately half subclover and half a mixture of perennial ryegrass (*Lolium perenne*), meadow foxtail (*Alopercurus pratensis*), and annual grasses.

Figure 1. Agroforests were silvopastures, that combined conifer forest with improved grass/clover pasture.

Standard techniques were used to evaluate soil compaction. Soil samples and infiltrometer data were collected from forest and agroforest plots in June 2002. All forest, agroforest, and forest plots remained ungrazed during 2002-2004 and were then sampled in June 2004. Soil infiltration was assessed from a sample of 12 randomly placed 15 cm diameter single-ring infiltrometer (Bouwer 1986) runs per treatment plot. Infiltrometer rings were driven approximately 8 cm into the soil, filled to a depth of 8 cm with water, then allowed to drain for 1to 2 hours before measurements began. Infiltration was measured as the amount of water required to maintain 2 cm of head within the ring. Infiltration was recorded every 5 minutes for 30 minutes. Plots were then allowed to thoroughly drain. The entire infiltrometer and soil core was lifted and its top and bottom structure visually assessed. A wet (field capacity) soil sample was then obtained by excavating 8 cm diameter x 6 cm tall metal ring which was driven into the center of each infiltrometer plot. Wet soil samples were weighed to the nearest 0.1 g in the field, then dried in an oven at 105^{o}C. The dry weight of these samples provided an estimate of soil bulk density. Soil moisture holding capacity was calculated from the difference between sample wet and dry weights. Total soil porosity was calculated from bulk density and soil particle density (2.65 g/cc) as described by Danielson and Sutherland (1986). Since water weighs 1 g/cc at room temperature, area occupied by water-filled pores can be calculated from weight of water stored at field capacity. Air-filled pore volume was then estimated as the difference between total pore volume and water-filled pore volume. The soil immediately under each infiltrometer was probed to a depth of approximately 20 cm to find any soil channels or other large voids. All low density areas were excavated to identify their cause.

Results and Discussion

Because the entire research location was a single large pasture at the beginning of the experiment, differences in soil properties between agroforest and forest plots in 2002 (Table 1) were logically impact soil infiltration. Unfortunately, tree growth can also compact soils, and trees in agroforests grow faster than in forests. It was unclear how much of the greater soil compactness in agroforests was due to the larger trees there. Pastures (no trees) were sampled in 2004 in order to sort out this “tree growth effect.”

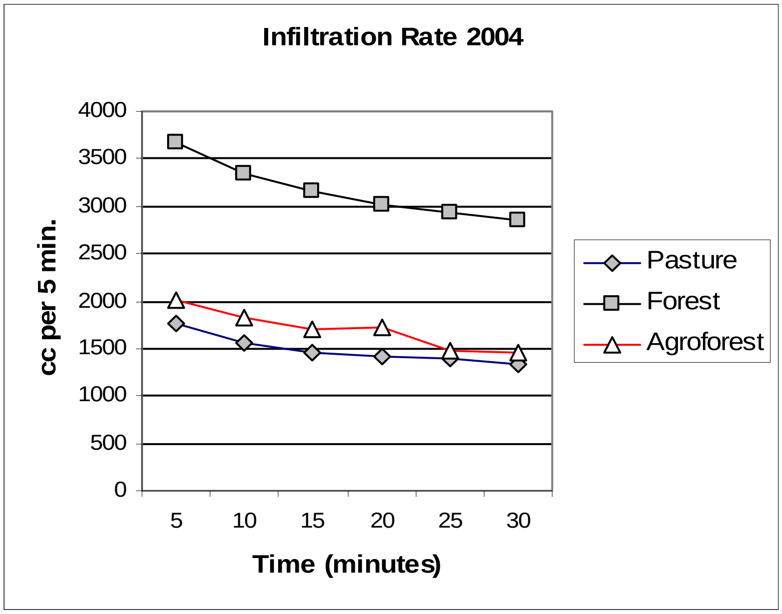

Figure 3. Witham Hill plot water infiltration rate, June 2002.

Similar to 2002, average soil water infiltration rates of agroforests in 2004 were substantially less than those of forests (Fig. 3). However, agroforest infiltration rate in 2004 (1080 liter/m^2/hr) was over 60% greater than the 2002 rate (710 liter/m^2/hr) and was very similar to those measured for forests in 2002 (1100 liter/m^2/hr). Infiltration rates on forest plots during these two years almost doubled to 2010 liter/m^2/hr in 2004. Clearly things had improved on both the forest and agroforest plots. Average pasture infiltration in 2004 (950 liter/m^2/hr) was similar to that of agroforests, suggesting that there was no significant “tree effect”.

Table 2. Physical characteristics of the top 7 cm of soil in Witham Hill forests, agroforests and pastures in spring 2004.

	Bulk Density* (g/cc)	% Porosity* (cc/cc)	% Water-filled Pores* (cc/cc)	% Air-filled Pores* (cc/cc)
Forest	0.97 [a]	63.5 [a]	34.4 [a]	29.1 [a]
Agroforest	0.97 [a]	63.5 [a]	36.3 [b]	27.2 [a]
Pasture	0.94 [a]	64.7 [a]	36.8 [b]	27.9[a]
MSE	***0.035***	***1.33***	***0.78***	***1.64***

*Means not sharing a letter differ, p<.05, Tukey’s W Procedure

Soil physical characteristics of pastures, agroforests, and forests were similar in 2004 (Table 2). The single exception was slightly lower water filled pore volume in forest soils compared to pasture or agroforest soils. Total water holding capacity of the top 6 cm of soil was similar among treatments, being approximately 16.4, 15.4, and 16.2 liters/m^2 for pastures, forests, and agroforests, respectively. The higher infiltration rates of forest soils in 2004 coupled with their lower total air-filled pore space that year compared to 2002 suggests that pore connectivity must have improved, increasing the effectiveness of the available pore space to conduct water.

Conclusions

Eleven years after establishment, soils in agroforests were denser, had lower water infiltration rates, and less air filled pore volume than those in forests. These all suggest soil compaction. Since pasture and agroforest soil properties were similar, soil compaction in agroforests was from either the direct (hoof impact) or indirect (litter reduction) effects of livestock grazing rather than from increased tree growth compared to forest plantations. Of these two, the indirect effects of grazing on litter appear to be more important. Grazing had little impact on soil water holding capacity. Soil infiltration rates and pore space rapidly improved when grazing ceased.

Practical Implications

Results of this study are consistent with the extensive review of published literature reported by Greenwood and McKenzie (2001), grazing does indeed compact soil. However, moderate livestock grazing on rangelands often has little real impact on water infiltration (Gifford and Hawkins 1978), and it is unusual for livestock treading on drained soils to sufficiently compact soils to hinder plant growth. Indeed, many of the studies that showed increased soil strength and increased bulk density after grazing failed to show any associated reduction in plant growth. Unless soils are very compact to start with, it takes considerable compaction to make them dense enough or poorly aerated enough to hinder plant growth. In my case, pastures and agroforests consistently produced more herbage than forests, and agroforest trees grew faster than forest trees. Clearly, "soil compaction" had not hindered plant growth, even though grazing occurred at high densities, on clay soils, during wet weather.

It is important to point out here that I avoided grazing when soils were saturated with water. The water filled pores of saturated soils are less easily compressed than the air-filled pores of drained soils, so pressure is more fully transferred from the hoof to the soil matrix. When soil is saturated, even moderate pressure expels water from the larger flooded pores. The lower structural strength of wet soils, particularly those with considerable clay content, along with the expelled water that serves as a lubricant, allows even relatively small pores to collapse and the soil to flow around the hoof. The resulting creation of deep hoof prints in wet pastures has been called poaching or pugging. Pugging is generally very undesirable because it reduces soil water infiltration, soil aeration, soil water storage capacity, and increases soil strength, all of which depress plant growth. The many small holes punched into pasture soils during pugging tend to collect water making the soil surface wetter and more susceptible to continued pugging.

The large increase in soil water infiltration rate of forest soils during the two years of this study demonstrates the potential for rapid change in infiltration rates. It also points out the importance of continuous channels through water may quickly move (pore connectivity) rather than just total porosity or soil bulk density when trying to describe and understand effects of management practices on soils. The reason for such a large change in infiltration or pore connectivity is unclear. Research often generates as many new questions as it answers old questions. It is possible that the soil fauna are going through a successional process of orderly change and have reached a stage at which their members are producing more connected pores. This may continue or may change with time. We will revisit the plots again in 2006 and see what the situation is at that time.

The relatively rapid "recovery" of soil porosity and infiltration rates with non-use in pastures and agroforests is most likely related to the rapidity with which a litter layer and its micro-fauna can be established. It offers considerable opportunities to use rotational grazing or hay cutting strategies to manipulate soil structure and water infiltration, especially on high producing sites.

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Will the Creek Flow Again:
The Camp Creek Paired Watershed Study

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Abstract

Western juniper's (*Juniperus occidentalis)* dominance on eastern Oregon's rangelands has increased 5 fold since 1934. The result of this significant vegetative change has been reduced forage production, increased soil erosion and reduced infiltration rates. Based on individual tree water use models and field observations it has been speculated that the expansion of western juniper has been, at least in part, responsible for the desertification of these landscapes. In 1994, a paired watershed study was implemented in the Camp Creek drainage, a tributary of the Crooked River (Deschutes River Basin). Two 300-acre watersheds were identified and calibrated. Baseline data for channel flow including duration and intensity of flow, along with channel morphology, hillslope soil movement and vegetative cover have been collected since 1994. GIS has been utilized to compare geomorphological characteristics of the two watersheds. Precipitation for each watershed has been continually recorded. In 2004, monitoring parameters were expanded to include weather, snow depth accumulation, spring flow, soil moisture and depth to ground water. Analysis of baseline data indicates similarities and differences between the two watersheds as it relates to their water cycles. In the fall of 2005, the juniper will be cut in one watershed and both watersheds will be monitored and data analyzed to determine changes in water.

Introduction

According to U.S. Forest Service publication PNW-GTR-464, *Western Juniper in Eastern Oregon*, western juniper's dominance in eastern Oregon has increased 5 fold since 1934 (420,000 acres to 2,200,000 acres). Based on water use models for individual trees, the U.S. Forest Service estimates that mature western juniper tree densities, ranging from 9 to 35 trees per acre, are capable of utilizing all of the available soil moisture on a given site. Research has shown that soil loss from sites with higher than the natural variation of western juniper cover is 10 to 100 times greater than similar sites that are still within their natural range of variation. Previous monitoring studies have been limited in their scope of monitoring to water quality impacts following western juniper control.

Water quantity and timing are the primary factors being monitored with this project. The project involves the use of a paired watershed study. The project consists of the treatment (cutting juniper) of one of the paired watersheds totaling approximately 300 acres with the other watershed serving as the untreated control. Scheduled for fall 2005, the Prineville BLM District will cut approximately 300 acres of western juniper in one of the watersheds and post-treatment monitoring will occur in both watersheds in order to compare responses and document impacts. The paired watershed project is located approximately 60 miles southeast of Prineville, Oregon. In 1993, two watersheds (Mays and Jensen) were identified in the Camp Creek Drainage, a tributary of the Crooked River. The average elevation of the site is 4,500 feet with an average annual precipitation of 13 inches. The historic vegetation type was mountain big sagebrush - Idaho fescue. The site is currently dominated by western juniper with a sparse understory of shallow rooted perennial grasses and forbs.

The Prineville District Bureau of Land Management manages ninety percent of the treatment area while the remaining 10 percent is owned by the Hatfield High Desert Ranch. The BLM, in cooperation with Crook County Soil and Water Conservation District, the permittee (Hatfields) and OSU Department of Rangeland Ecology and Management identified the paired watersheds as areas of interest because of the opportunities they provided to monitor changes in water yields as a result of juniper control. Access to the site is from the Camp Creek/Bear Creek road.

Since 1994, the two watersheds have been monitored for similarities and differences. Precipitation, vegetation composition and cover, erosion rates, changes in streambed morphology and surface flows have been monitored annually. Stream flow is monitored continuously and changes in streambed morphology are measured twice a year.

Situation

Junipers are known to increase soil loss with runoff water; intercept rain and snow before it reaches the ground making it unavailable for plant growth, stream flow or groundwater recharge; and consume large amounts of soil moisture. Previous monitoring of juniper control projects have focused on changes in vegetative composition and production. With this project we are monitoring the effects – on a watershed scale – of juniper control on the availability of water (quantity and timing) for other beneficial uses. Water yield over time will be measured, demonstrating the relative ability of the paired watersheds to catch and release water.

This project is unique in that it involves a paired study approach to monitoring changes in a system's water budget following western juniper control. Monitoring water yield following juniper control has not been done in the western juniper vegetation type. The value of a paired watershed study is that the impacts of the treatment can be compared to the untreated watershed. This study is also unique in that it is the only long-term study of its type in the Northwest. Because of the time and expense in monitoring watershed level activities, such watershed comparison studies are rarely undertaken. Similar studies in different ecological and climatic zones have been conducted in Idaho, Utah, Colorado, Arizona, and now Montana but no paired watershed studies have been implemented in western juniper ecosystems.

As per an agreement between Oregon State University, Department of Rangeland Resources and the Prineville District BLM, the treatment phase will take place only after an adequate amount of baseline data has been collected. Baseline data has been collected in both watersheds since 1994 and has included the following parameters: 1) stream flow measurements including duration, intensity and volume recorded on a continual basis, 2) changes in stream channel morphology, 3) understory vegetative composition, 4) cover and juniper tree density, 5) soil comparisons and differences, 6) side hill erosion activity, and 7) precipitation. The value of this constant monitoring over the last 10 years is that annual variation in precipitation, vegetation expression, soil movement and storm activity has been documented. Initial data collected also included an ecological site description and analysis of the two watersheds based on vegetation, soils, topography, geology, channel morphology, streamflow, local climate and erosive processes. In 1996, six piezometer wells per watershed were established to monitor subsurface water in areas adjacent to the flumes. Average depth of these piezometer wells was 5 feet.

As a result of these initial monitoring activities, additional monitoring needs were identified and included soil moisture, sub-surface water, on-site weather data and timing of water use by juniper (timing). Grant monies from the Bureau of Land Management, Application of Science Program were secured in the spring of 2004 and are being used to: 1) instrument soil moisture measurements so that continuous soil moisture data can be collected, 2) install and instrument additional piezometer wells to capture water data below the soil surface, and 3) purchase and install on-site weather stations.

Ground Water Monitoring

During 2004, 12 piezometer wells were drilled with the assistance of the Ochoco National Forest. Each well is 2 inches in diameter and they vary in depth from 20 to 27 feet. Monitoring of depth to water has yielded very useful information. In Jensen, the channel is located at the far west edge of the valley bottom and all wells are located east of the channel (well 1 closest to the channel, well 6 farthest from the channel). In Mays, the channel is more centrally located and 4 of the wells (wells 1 – 4) are west of the channel and 2 (wells 5 – 6) are located east of the channel. In 2004, Mays' depth to water was at its lowest value (nearest to the surface) in mid-March, while in Jensen the lowest values did not occur until mid-April. Following each drainage's peak in ground water, depth to ground water continuously dropped throughout the remainder of the year. On average, this drop was approximately 6 inches per week.

Aerial Photography

Low level, aerial photographs, both color and color IR were taken in spring of 2004. Additional flights were flown in August 2004. Photographs will provide the basis for GIS analysis. Additional GIS layers will include soils, vegetation, slope, aspect, elevation and treatment locations.

Channel Profiles and Sediment

Continual monitoring of channel cross sections and sediment movement is occurring. Cross sectional data is measured twice a year, after spring run-off and after the summer thunderstorm activity. Data is being compiled using Reference Reach software provided by Dan Mecklenburg, Ecological Engineer Ohio Department of Natural Resources Division of Soil and Water Conservation. This software allows the data to be looked at in a graphical representation of a cross-section while providing numerical output of parameters such as total cross-section area, deposition, and scour. Additionally, this software provides an approach for comparing between the two study areas by comparing the differences from one season to the same parameter of the data collection period preceding it.

Analysis of current channel cross-sectional area did not appear to change dramatically between seasons except for the periods of 1994-1996 and 2000-2001. The largest difference occurred during the winter of 1996. This change in area is represented primarily by loss (scour) of channel material. Spring of 1997 and 2001 show a dramatic decrease of cross-sectional area in both watersheds (in 1997 in particular), whereas summer of 2001 shows a decrease of the cross-sectional area in Mays watershed and only a slight change in cross-sectional area in Jensen represented by a positive change (p-value < 0.10). A decrease in area is representative of channel deposition or aggregation whereas an increasing value in area is representative of scour or channel degradation.

Regression analysis (Figure 1) demonstrates a strong linear relationship between the two watersheds (r^2=0.9665). The variation in data can be adequately explained with a p-value of less than 0.05.

The resulting equation suggests that for every 1cm^2 change in Jensen cross-sectional area there would be an expected change of 1.852 cm2 in the Mays watershed channel cross-sectional area. It should be noted that the regression equation is strongly influenced by the outlier data of spring of 1997. When this data is removed the regression equation and associated correlation coefficient change substantially.

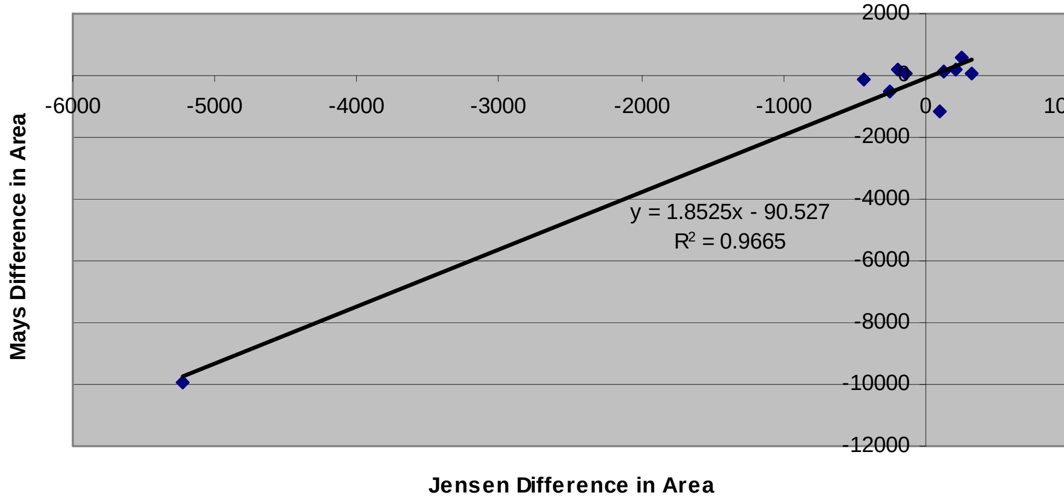

Figure 1. Regression graph of the difference in channel cross-sectional area with a correlation coefficient of 0.9665 and a best fit line equation of y=1.8525x-90.527 (p-value= 0.027464)

Weather Stations and Spring Developments

Installation of weather stations was completed in mid-November of 2004. Following completion, the sites received almost 2 inches of rain from mid-November through December. Early snow pack turned to ice (approximately 4 inches thick) and then was capped by another 10 – 14 inches of dense snow. Web site access to weather station information is: http://nopro.com/ifpnet. This web site is maintained by Automata Inc. and Wy'East RC&D. To view weather data, click on "change map" and highlight Crook County. Flags on map represent each weather station, Mays and Jensen.

Monitoring of spring flow began in September 2004 and is ongoing. Flow is read approximately every 2 to 3 weeks. Flow in Mays was lowest in November at 1.2 gpm, Jensen with .2 gpm. Spring output in mid-March 2005 was 20 gpm for Mays and 10 gpm for Jensen.

Depth to ground water is also measured every 2 to 3 weeks. Ground water in 2005 is not following a similar pattern to the winter of 2004. Ground water accumulation in Jensen and Mays wells in 2005 are approximately one-half of the accumulation in 2004.

Partnerships in Project

As this project progresses, the number of organizations, agencies, and individuals involved continues to grow. The current list of partners includes:

Prineville District, BLM	Deschutes Resource Conservancy	OSU Extension Service
Ochoco National Forest	Crook Co. Natural Resources Ad. Comm.	Doc and Connie Hatfield
OSU Rangeland Resources	Crooked River Watershed Council	COCC Forestry Dept.
Crook Co. Cattlemen's Assoc.	Crook/Wheeler Co. Farm Bureau	Crook County SWCD
Oregon Dept. DEQ	Western Juniper Work Group	McCormack and Sons
Malheur Co. Experiment Station	Congressman Walden, Senator Wyden	Larry Swan, U.S.F.S.
Ochoco Irrigation District	Oregon Watershed Enhancement Board	Wy'East RC & D

The Prineville District of the BLM has been a major cooperator and continues to support this project. Their cooperation and active participation in this project will assure that the results of this study are applied appropriately throughout the western juniper range. Special thanks to them for their support.

The Effects of Herbivory and Timber Harvest on Understory Production in Northeastern Oregon

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Introduction

Forested rangelands comprise a significant portion of the public land in the western U.S. Within the northwestern United States (Idaho, Montana, Oregon, and Washington) forested rangelands comprise approximately 35 percent of the total land area, and public ownership comprises 69 percent of these forested rangelands (Smith et al. 2002). Ponderosa pine (*Pinus ponderosa*) and grand fir (*Abies grandis*) are two forest types that are commonly found within the region. These forests are valuable for providing habitat and forage for livestock and wildlife, as well as wood products for human consumption. However, over the last 100 years, many of these forests have developed into dense stands consisting of more fire-sensitive and disease-susceptible species (Belsky and Blumenthal 1997), thereby reducing the overall productivity of the area. Many areas with high potential for timber harvest and forage production have the low output due to dense canopy cover (Hedrick et al. 1969).

In order to restore productivity in terms of forage and timber production to these dense stands, it may be necessary to open the canopy. Forage production response to overstory canopy cover is well documented (Young et al. 1967, Miller et al. 1986) and suggests that as overstory canopy cover decreases understory production (kg/ha) increases. Clary et al. (1975) also documented this relationship between canopy cover and forage production, but noted that there was an economic optimum between increasing forage production for cattle grazing and increased timber growth for harvest.

Although canopy cover influences understory structure and production, grazing or herbivory may also influence plant community structure and diversity within forested environments. Hobbs (1996) and Riggs et al. (2000) documented that herbivory can influence plant community structure and composition. Ungulate herbivory directly affects vegetation through selective feeding and the ability of a plant to recover from herbivory (Augustine and McNaughton 1998). However, plant species diversity was not consistently affected by grazing (Riggs et al. 2000), but individual species, at the local level, were affected by herbivory and logging. Herbivory had the greatest effect in altering plant community structure within clearcuts (Riggs et al. 2000).

As stated earlier, much is known about how quantity of vegetation responds to canopy cover and how herbivory can affect plant community structure. However, little is known about how plant communities are influenced by timber harvest, herbivory, and fuels reduction. Therefore, the objectives of these studies were to document the effects of timber harvest, herbivory and fuels reduction on individual species, plant community structure, understory production, and botanical composition of cattle diets.

Study 1. Hall Ranch Timber Harvest and Herbivory Study

The study area is located at the Eastern Oregon Agriculture Research Center's Hall Ranch, which is approximately 16 km east of the city of Union in the Wallowa Mountains of northeastern Oregon. Elevation ranges from 1050 to 1250 m and annual precipitation averages 66 cm with about 60 percent coming in the winter, whereas summers are usually dry.

The study was conducted as a replicated design. Three *Abies grandis*/*Pachistima myrsintes* (grand fir), habitat types, 22.5 ha each in size, and three *Pinus ponderosa*/*Symphoricarpos albus* (ponderosa pine) habitat types, 15 ha each in size, were selected to analyze the effects of herbivory and overstory canopy cover on understory plant community structure. Sites were randomly selected within areas of relatively homogeneous stand structure. The grand fir sites had three timber harvest treatments applied: 1) clearcut, 2) crown thinning and 3) uncut (Control) (Figure 1). Crown thinning consisted of removing co-dominant and some dominant trees. Harvest began in 1985 and was completed in 1986. The grand fir clearcuts were replanted in the

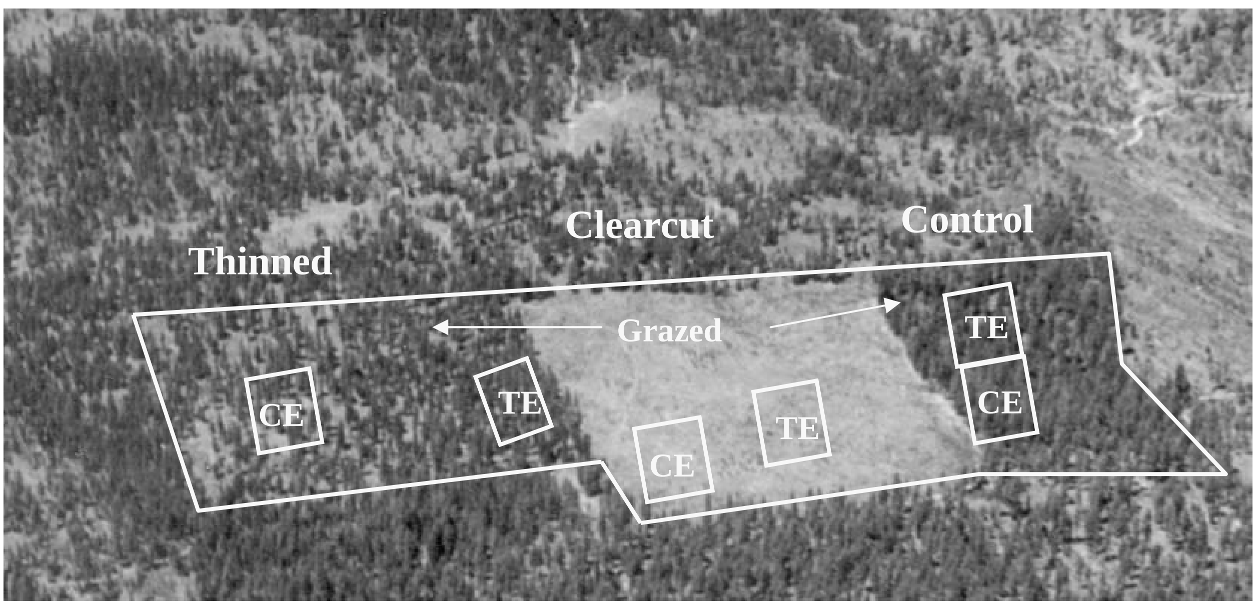

Figure 1. An aerial photo of a grand fir site demonstrating the layout of logging and grazing treatments. (Grazed - both cattle and big game grazing, CE - cattle grazing excluded; TE - cattle and big game grazing excluded)

spring of 1988 with ponderosa pine, Douglas fir (*Pseudotsuga menziesii*) and western larch (*Larix occidentalis*). Whereas, the ponderosa pine sites had two timber harvest treatments applied: 1) commercial thinning and 2) uncut (Control) (Figure 2). Ponderosa pine sites were thinned to achieve a basal area of 24 m^2/ha (tree spacing of approx. 8 m). Logging began and was completed in 1985. In order to protect herbaceous vegetation and soils and minimize the impact of skidding, spacing between skid trails was at least 120 feet if soils were not frozen and had adequate snow cover.

The following grazing treatments were applied to each grand fir and ponderosa pine timber harvest treatment: 1) grazing by cattle and big game (to achieve 60 percent utilization), 2) big game grazing with cattle excluded (cattle exclosure), and 3) exclusion of cattle and big game grazing (see Figure 2). Sixty percent utilization is considered heavy relative to current recommendations (Holechek 1995), but was used because it was the utilization rate employed by many industrial forests within the area at initiation of the study in 1985.

Herbaceous production was collected by clipping 1.0 x 0.5 m rectangular plots randomly placed within each treatment. Plots were clipped to a two-centimeter stubble height. Production was measured in 2003 for both ponderosa pine and grand fir habitats. Production clips were separated

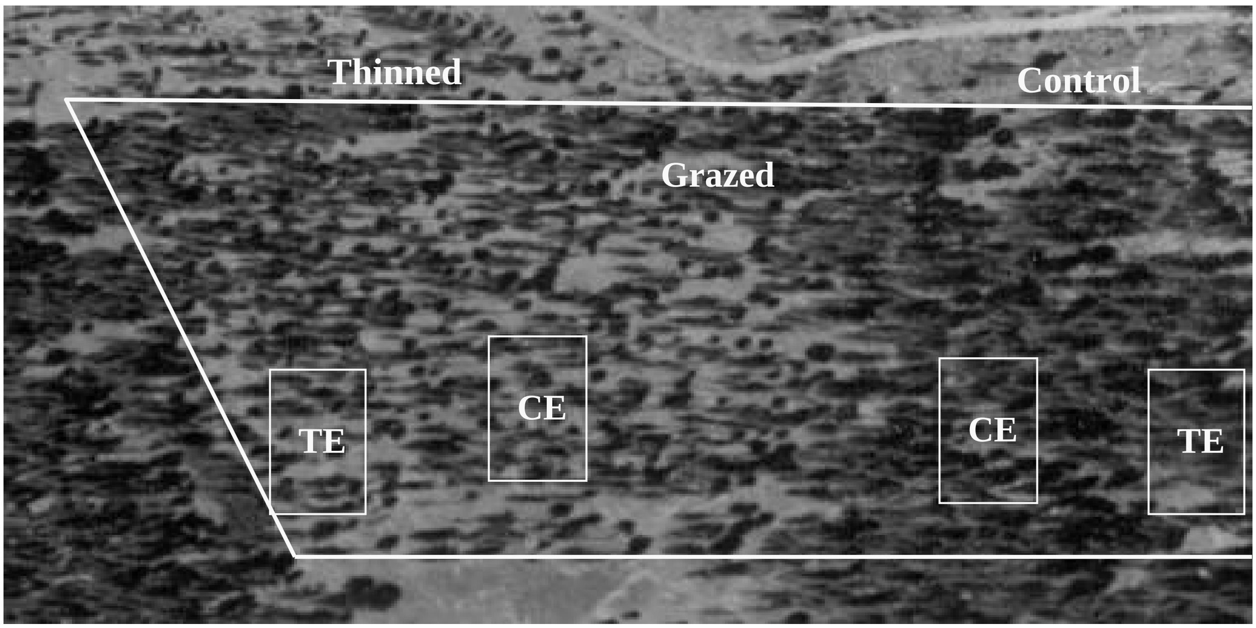

Figure 2. An aerial photo of a ponderosa pine site demonstrating the layout of logging and grazing treatments. (Grazed - both cattle and big game grazing, CE - cattle grazing excluded; TE - cattle and big game grazing excluded)

into the following forage classes for evaluation: elk sedge (*Carex geyeri)*, pinegrass (*Calamagrostis rubescens*), Kentucky bluegrass (*Poa pratensis*), other perennial grasses, perennial forbs, annuals and biennials, and shrubs.

Results

Production, within grand fir and ponderosa pine sites, were affected by both logging and herbivory (Table 1, 2) in 2003. Within the grand fir sites, production in the clearcuts was greater than either the thinned or controls. This is not unexpected, because within the clearcuts, understory vegetation production does not have to compete with the overstory for limited resources, mainly water and nitrogen. However, production in future years will decline and equilibrate with the controls and thinned treatments, in terms of total understory production, as juvenile trees continue to grow and begin out competing for limited resources. For most forage classes, production was greatest within the clearcuts. However, pinegrass production was greatest in the thinned treatments. Reduced production of pinegrass, within clearcuts, could be

Table 1. The effects of herbivory and timber harvest on production (kg/ha) in a grand fir habitat type.

	Timber Harvest Treatment			Herbivory Treatment*		
	Clearcut	Thinned	Control	Grazed	Cattle Exc	Total Exc
Total Production	1431[a]	1070[b]	831[b]	1107	1157	1068
Elk sedge	312[a]	172[b]	211	218	216	260
Pinegrass	212[ab]	302[a]	127[b]	293[a]	167[b]	181[b]
Kentucky bluegrass	243[a]	14[b]	53[b]	71[a]	120[b]	118[b]
Perennial grass	142[a]	197[a]	53[b]	142	166	84
Perennial forbs	220	170	175	194	218	153
Annuals/biennials	61	13	3	24	23	30
Shrubs	242	204	224	213	224	235

* Grazed refers to cattle and big game grazing; Cattle Exc refers to lack of cattle use but plots were grazed by large ungulates; Total Exc refers to lack of use by both cattle and big game.

[a,b] values with differing superscripts are different at $P<0.05$

Table 2. The effects of herbivory and timber harvest on production (kg/ha) in a ponderosa pine habitat type.

	Logging Treatment		Grazing Treatment*		
	Thinned	Control	Grazed	Cattle Exc	Total Exc
Total Production	1111[a]	873[b]	974	1016	986
Elk sedge	324	284	233	348	331
Pinegrass	81	82	37	110	98
Kentucky bluegrass	105[a]	48[b]	86	83	60
Perennial grass	116	121	207	103	44
Perennial forbs	260[a]	130[b]	205	186	194
Annuals/biennials	32	3	18	9	25
Shrubs	82	53	43[a]	55[a]	105[b]

* Grazed refers to cattle and big game grazing; Cattle Exc refers to lack of cattle use but plots were grazed by large ungulates; Total Exc refers to lack of use by both cattle and big game.

[a,b] values, within the same treatment, with differing superscripts are different at $P<0.05$

due to the abundance of Kentucky bluegrass. Kentucky bluegrass was able to rapidly increase in production following logging, within clearcuts, thereby filling open sites. However, Kentucky bluegrass production has subsequently declined from 1995 to 2003. It is interesting to note that 18 years following timber harvest, production of perennial forbs, annuals/biennials and shrubs were not different due to either timber harvest or herbivory.

Within the ponderosa pine sites in 2003, thinned treatments had approximately 240 kg/ha greater production than the controls. Again, with the removal of overstory, understory production can increase due to increased available resources. Production of Kentucky bluegrass and perennial forbs also increased with reduction of canopy cover by 2003. Limited production increases within thinned treatments may be due to shallower soils, as compared to the grand fir sites, and/or increased production of Kentucky bluegrass and forbs immediately following logging in 1985.

Even at 60 percent utilization, total production in 2003 was not affected on either the grand fir or ponderosa pine sites. However, within the grand fir sites, pinegrass and Kentucky bluegrass were affected by herbivory. Pinegrass production increased over 100 kg/ha in the grazed treatments as compared to the cattle and total exclosures. Whereas, Kentucky bluegrass production was reduced by 50 kg/ha in the grazed treatments as compared to the cattle and total exclosures. The only group that was affected by herbivory within the ponderosa pine sites was shrub production. In 2003, shrub production was reduced by 50 kg/ha in cattle and/or big game grazing treatments as compared to the total exclosures.

Study 2. The Sled Springs Biomass/Forage Quality Project

The Sled Springs Biomass/Forage Quality Project is currently in the third season of sampling biomass production and the second season of sampling forage quality. Caged biomass plots (1.5 m diameter) were established throughout the Sled Springs Wildlife management unit and were used to determine the effects of overstory successional stage and habitat types on understory production. These plots represented differing successional stages of dry grand fir sites, wet grand fir sites, ponderosa pine sites, dry Douglas Fir sites, wet Douglas Fir sites, and recently logged sites. Also, forage quality sampling began in early-May with subsequent samples taken in mid-June, early August, and final samples to be taken in mid-September.

Preliminary results suggest that overstory manipulation has a dramatic effect on understory production and diversity. Understory production ranged form 600 to 800 kg/ha for all habitat types during the 2003 sampling season (Figure 3A). However, production data irrespective of canopy age and structure does little to characterize species diversity and production in transitional forested rangelands.

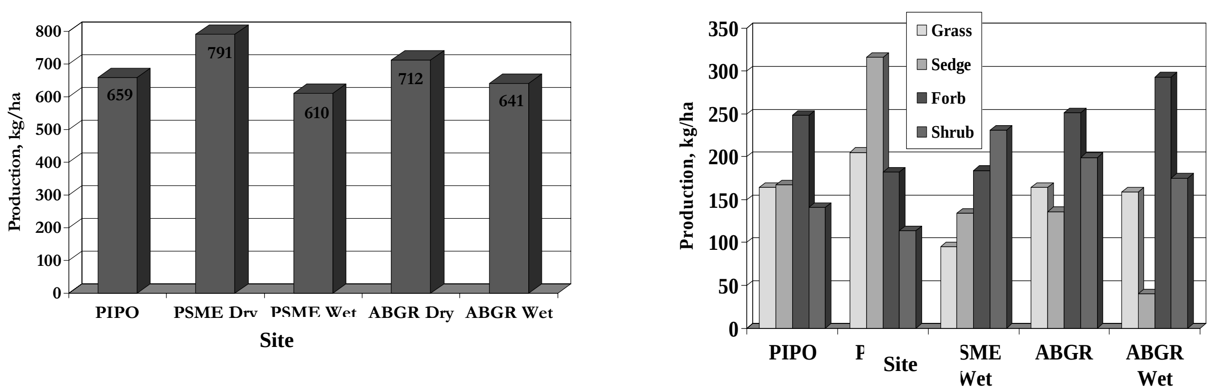

Figure 3. Understory production (A) and production by forage groups (B) in ponderosa pine (PIPO), Douglas fir (PSME), and grand gir (ABGR) forest types on the Sled Springs Wildlife Management Unit (2003 preliminary data). These results do not include production estimates for the grass/forb/shrub stage.

Production by forage groups (grass, grasslikes, forbs, and shrubs; Figure 3B) shows dramatic differences among habitat types.

Our preliminary results also suggest that understory production is strongly influenced by successional stage (stand age) and forest type (Figure 4). Forage production in ponderosa pine habitats is relatively high up through the small log stage of succession. In contrast, Douglas fir habitats show declining understory production after the sapling stage with the substantial declines early in the wetter habitats. Production in wet Douglas was highest in sapling stand ages and declines rapidly to remain relatively stable for pole, small saw log and saw log stand ages. Wet Grand Fir ecotypes appear to show a quadratic response with mid age stands (pole and small saw log) having greater production than early or late stand ages.

Study 3. Fuels Reduction at Starkey Experimental Forest and Range

In recent years, the financial and ecological impacts of catastrophic wildfires in the Western United States have become a major issue in forest land management. Forest fire suppression has led to the buildup of understory and ladder fuels in forest stands which has greatly increased the

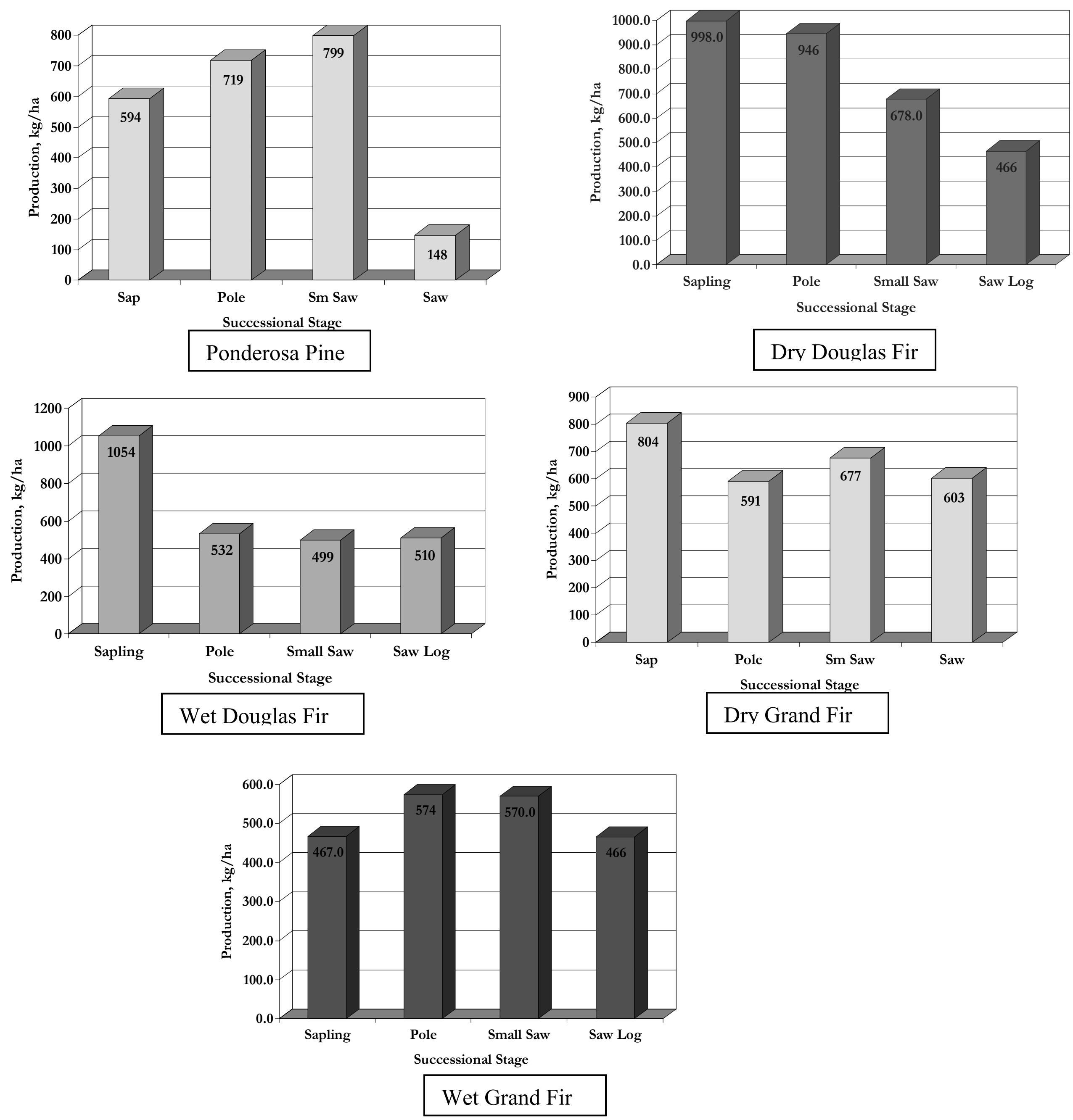

Figure 4. The influence of sucessional stage (stand age) on understory production in ponderosa pine, dry Douglas fir, wet Douglas fir, dry grand fir, and wet grand fir forest types (2003 preliminary data). These results do not contain production estimates for the grass/forb/shrub stage (seedling establishment).

risk of large stand-replacement wildfires. The importance of fire as a natural component of ecological systems is now recognized by scientists and managers who have developed methods, using prescribed fire and the mechanical removal of trees, as a means of preventing catastrophic wildfires. Since ungulates feed selectively and can alter the plant species composition of a community (Augustine et al. 1998, Riggs et al. 2000), the subsequent effect of herbivory following prescribed fires may result in species replacement and possibly a change in the successional pathway. Therefore, it is important to understand how herbivory can affect vegetation following fuels reduction treatments. The nature and extent of these herbivory effects are currently unknown. Because there are dietary differences between species, large scale experiments that observe different species of herbivores at different densities are needed in order to document these changes in successional pathways (Riggs et al. 2000). As part of this documentation, the changes in herbivore diet selection and diet quality after fuel reduction treatments need to be recognized. These dietary changes should be measured seasonally, at different levels of utilization, within treatment, between treatment and control, as well as over time. In order to better understand how herbivory can affect vegetation following fuels reduction treatments and to see what effects fuel reduction treatments have on diets of cattle, we will pursue the following objective.

The objectives of this phase of the study are to first determine the initial effects of fuels reduction on the botanical composition of cattle diets at different levels of forage utilization and, secondly, to determine the initial effects of fuels reduction on the diet quality of cattle at different levels of forage utilization.

This study, which will be conducted in 2005 and 2006, will yield critically needed information about how vegetation responds after fuel reduction treatments. The success of future fuel treatments, and even the ability to complete such treatments, will be greatly enhanced if we understand how herbivory affects the vegetation of sites treated with fuels reduction. Without this understanding, we may unknowingly alter the vegetation of treated sites with the mismanagement of cattle grazing. This mismanagement could ultimately lead to an increase in weedy plant species, reduced cattle grazing efficiency, and lower quality wildlife habitat. Proper timing of grazing and grazing at optimum utilization is essential for sustainable livestock grazing. The results of this study will be used as part of a larger long term study that will provide information and models on the effects of ungulate herbivory to inform and guide the management of multi-use forests.

Conclusions

Low impact logging, as represented with the Hall Ranch study, may not have a profound effect on changing plant communities. The results from this study indicate that following timber harvest, forage production increased. This increase on production was mainly due to the increase in perennial grass and perennial forbs species. Timber harvest had a greater effect on understory production than did herbivory even though cattle grazing would be considered heavy on these sites. Elk and deer also influenced shrub production within ponderosa pine sites.

Our combined data sets will quantify species responses to habitat, successional stage, and tree density. We believe, that these data sets will provide the most thorough characterizing of Blue Mountain forested region and how overstory manipulation changes the understory vegetation, biological diversity of vegetation, and nutritional opportunities for grazing herbivores. In fact, these data will provide a solid basis that demonstrates overstory manipulation and, in turn, the creation of early and mid-seral vegetation is critical for developing ideal habitat for grazing herbivores.

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