FINAL REPORT
Western Juniper Harvest Systems Trial

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Executive Summary

The purpose of this project was to evaluate two harvest systems designed or modified specifically for western juniper (*Juniperus occidentalis*) in terms of production costs, worker exposure to use of chainsaws, and on-site dispersion of slash, and compare results with those from juniper harvest trials conducted in 1996.

Over the last 100 years, the area dominated by western juniper has greatly increased throughout its main range in Eastern Oregon, Northeastern California, and Southwestern Idaho. There are now over 3.8 million acres with 10% or more canopy cover, of which at least 1.0 million acres have 20% or more canopy cover. Twenty percent or more canopy cover is a key early indicator of loss of vegetative diversity, groundcover, watershed function, and wildlife habitat. On the other hand, juniper is the least–utilized wood fiber resource in its range. Efforts to commercialize western juniper have occurred off and on for at least 50 years. Beginning in the early 1990s, the most sustained and integrated effort yet attempted was begun under the leadership of several private companies, U.S. Forest Service, and Oregon Economic and Community Development Department. One of the key barriers to successful commercialization identified early in the process was harvest costs and quality of supply for value-added products.

A Northwest Economic Adjustment Initiative grant was obtained by REACH, Inc. (Klamath Falls, OR) from the U.S. Forest Service to follow-up a key recommendation of the 1996 juniper harvest trials: Cooperate with the forest products industry to modify or design harvest equipment better suited to juniper and restoration objectives. REACH, Inc. issued a state-wide “Request for Proposals” (RFP) for two harvest systems designed or modified specifically for juniper. The RFP was awarded to TIM Equipment (Dairy, OR). TIM Equipment proposed to design and fabricate two new pieces of equipment to be integrated with existing logging equipment in two different systems.

The Yankee Group, Inc. (Philomoth, OR) was hired to assess site conditions pre- and post-harvest, record time and motion study results, evaluate economics, and prepare the final report. Harvest trials occurred in winter of 2000 and summer of 2001 on private land about 15 air miles northeast of Klamath Falls. The harvest site was representative of the ecotone between the sagebrush/grassland vegetative community transitioning into an open ponderosa pine and juniper overstory. The contractor chose the site to maximize potential sawlog recovery. The site had been heavily grazed and previously logged over the years.

Two different harvest systems were evaluated. The first system consisted of a shear, rubber-tired skidder equipped with a grapple, and a *Mobile Delimber*. The original intent was to use the shear to fell the juniper and the *Mobile Delimber* to delimb and put the logs on an attached trailer. Due to operation constraints of the *Mobile Delimber*, the delimber had to be operated at a central landing. The skidder was used to whole-tree skid trees cut by the shear. The second system consisted of a custom-built *Delimber/Shear Combination* and a rubber-tired skidder equipped with a grapple. The *Delimber/Shear Combination* was designed to delimb standing juniper, and then shear and lay-down the resulting log.

Over 1300 pieces (log lengths of eight feet plus trim) were processed by the two systems during the harvest trials (almost 300 tons or a little over six log truck loads). About 240

time/motion observations were obtained for the equipment used in the trials, including at least 50 each for the two pieces of customized equipment. Estimated cost of delimbed logs delivered to a central landing was $32.76 per green ton for the system that included the *Mobile Delimber* and $26.47 per green ton for the system that included the *Delimber/Shear Combination*. Although not specifically quantified, worker use of chainsaws was greatly reduced, but not completely eliminated due to the need to top logs for the system that included the *Delimber/Shear Combination*, cut whips and small juniper, and sever live limbs left on stumps.

Slash dispersal was difficult to evaluate due to landowner concerns and requirement to clean-up slash immediately, and the operation of the *Mobile Delimber* on a central landing instead of in the stand. If the *Mobile Delimber* had been able to operate in the stand as intended, it is estimated that slash dispersion would have met project objectives. The *Delimber/Shear Combination* clearly met project objectives of leaving slash dispersed sufficient to allow sunlight penetration. Pre- and post-harvest bulk soil density measurements indicated no additional compaction due to juniper harvest activities (mirroring results from the 1996 juniper harvest trials).

Costs of production for the *Mobile Delimber* system appear to be higher than those reported for the juniper harvest trials conducted in 1996. In the 1996 harvest trials, costs ranged from a low of $27.27 per green ton for a conventional system, consisting of chainsaws and rubber-tired skidder equipped with a grapple, to a high of $29.14 per green ton for a system consisting of chainsaws, skidder, and pull-through pedestal-mounted delimber. Some of the difference can be explained by much higher juniper densities and removal in the 1996 trials (average 55 vs. four to nine trees removed per acre in these harvest trials) and larger logs (average 12.9-inches vs. 10.9-inches DBH in these harvest trials). Delays due to equipment down time were also a significant factor.

Costs of production are expected to drop based on previous experience with new equipment introduced for juniper harvest. Estimates range between $25.67 and $32.76 per green ton delivered to a central landing for the system with the *Mobile Delimber*, and $18.66 and $26.47 for the system with the *Delimber/Shear Combination*. It is likely different carriers will also make a significant difference in production. Both of the custom-built pieces of equipment relied on older-make and model carriers which caused more downtime for repairs, more time for travel between trees, and in the case of the *Mobile Delimber*, prevented use as designed due to operation constraints (too top heavy for conditions).

An unexpected result of the study was compilation of data about juniper log weights and size harvested from pine/juniper stands on lower-productivity sites, similar to where the trials were conducted (see Appendix B). Another unexpected result was the design and results obtained from the delimbing knife system used in the *Mobile Delimber*. The design clearly resulted in less fiber pull-out than other knife designs and may be patentable.

Limited edition, custom- or shop-built equipment designed and fabricated for specific species or tasks has drawbacks. The most significant one is that even if the machine works well, limited production means that parts and manuals may not be readily available, and mechanics may not be familiar with the unique configuration of parts. Savings during fabrication may well be cancelled out by costs incurred in trying to maintain and operate the equipment long-term.

The Yankee Group recommends that additional existing logging equipment be systematically tested and evaluated in differing juniper stands. It is expected that some combination of excavator-mounted “dangle-head processors”, feller-bunchers, harvester/forwarder combinations, and stroke-boom delimbers will yield significant production benefits in conditions similar to where these trials were conducted. The Yankee Group also believes that it is also worth pursuing systematic trials of more modern logging equipment in situations that are “restoration”-focused, i.e. where trees have more limbs and taper, and slash is an integral aspect of site restoration requirements. It is acknowledged that production efficiency increases will come with substantially higher costs for equipment purchase and operation, however, production increases may justify the additional expense and lower overall restoration cost per acre. Machines will probably have to be a manufacturer’s larger models because of juniper’s large and flexible limbs.

Western Juniper Harvest Systems Trial

December, 2001

By The Yankee Group, Philomoth, OR

Project Purpose

The purpose of this project was to evaluate two harvest systems designed or modified specifically for western juniper (*Juniperus occidentalis*) in terms of production costs, worker exposure to use of chainsaws, and on-site dispersion of slash, and compare results with those from juniper harvest trials conducted in 1996.

Project Background

REACH, Inc. (Klamath Falls, OR) submitted a grant request in 1998 to the USDA Forest Service to follow-up recommendations made in the first formal juniper harvest systems trials conducted in 1996 (Swan 1997). The grant was authorized and a Request for Proposals (RFP) was distributed and advertised throughout Oregon, with special emphasis on Eastern Oregon. TIM Equipment (Diary, OR) was awarded the contract.

TIM Equipment's contract with REACH, Inc. required the company to produce and test two different systems designed or modified specifically for juniper. Existing systems could be modified, but TIM Equipment chose to design and fabricate two "purpose-built" pieces of equipment for use in two different juniper harvest systems. Once completed, the two juniper harvest systems had to be evaluated on the basis of three critical criteria identified during harvest trials performed in 1996 (Swan 1997):

1) Juniper Harvest Costs - Average juniper harvest costs in 1996 were estimated between $30 to $35 per green ton of logs delimbed and decked at a landing accessible to a standard log truck hauling a short-reach logging trailer. Average harvest costs of less than $25 per green ton would be considered a significant decrease.

2) Risk Factors Associated With Chainsaw Use - Average time to fall and limb juniper using a chainsaw by competent, but not professional fallers, was estimated to be about nine minutes per tree. Risk associated with chainsaw use would be considered reduced if workers were exposed for 20% less time, on average, to hazards associated with an entirely manual (chainsaw) falling and limbing operation.

3) Slash Dispersion –Juniper slash was difficult to mechanically disperse for restoration objectives once it was piled or bundled. Slash would be considered effectively scattered if there was between 40% and 60% slash cover on-site after harvest (dense mats of slash with no sunlight penetration are not considered "scattered). Slash dispersion would be considered economic if, when combined with other costs, it resulted in average total harvest costs of less than $25 per green ton for logs decked at a landing.

The contractor was also responsible for identifying an appropriate harvest site with sufficient acres to properly test and evaluate the systems proposed, and if not already done, complete Federally-required environmental review documentation.

TIM Equipment began work on equipment fabrication during the winter, 1999 Field trials occurred between winter, 2000 and summer, 2001. The Yankee Group, Inc. (Philomoth, OR) was hired by REACH, Inc. to gather data and report results of the harvest trials, using standard time/motion and cost data, and pre- and post-harvest site conditions (e.g. vegetation, soils, and other pertinent information).

Juniper Resource and Commercialization Status and Trends

There are over 2.2 million acres of western juniper woodlands in Eastern Oregon with 10% crown cover or more. There are another 2.8 million acres with scattered juniper. Other states with significant juniper acreage of 10% crown cover or more are California (1.3 million acres) and Idaho (275,000 acres). Over 50% of lands classified with 10% crown juniper cover or more is in private ownership, with the majority of the remainder under Federal management (mostly Bureau of Land Management) (Swan et al. 2000).

The number of Eastern Oregon acres with 10% juniper crown cover or more has increased about 500% since the first inventory was completed in the mid-1930s. It is projected that hundreds of thousands more acres will convert to woodlands over the next 20 to 40 years. Forest Service inventory scientists estimate that total juniper woodland area (all densities) could increase to 6.0 million acres within the next 50 years. This would represent about 10% of Oregon's total land area and make juniper woodlands the most extensive forest cover type in Eastern Oregon, instead of ponderosa pine (Gedney et al. 1999).

Western juniper is the least-utilized wood fiber resource in its range. Total volume in woodlands with crown cover over 10% and in mixed conifer forests is estimated to be 467 million cubic feet. Average volume per acre is 198 cu. ft. (ranges between 15 cu. ft. and 700 cu. ft.). About 53% of the total juniper volume and 90% of the volume in mixed conifer forests, which is often considered higher quality by commercial interests, is on private or Indian reservation lands (Gedney et al. 1999).

An estimated 1.0 million acres of the at least 4.4 million acres of juniper woodlands inventoried can probably be classified as severely degraded rangeland habitat due to a key indicator of 20% or more canopy cover. Canopy cover of over 20% is often an early indicator of loss of vegetative diversity, groundcover, watershed function, and wildlife habitat (Swan et al. 2000).

Prescribed fire is not a restoration option for much of the severely degraded rangeland habitat because the juniper overstory has already out-competed the ground vegetation necessary to carry fire. Remaining restoration options are costly ($50 to over $200 per acre), and normally involve manipulating juniper overstory through a combination of manual (chainsaws) and mechanical (dozers, shears, and chainsaws) means.

One way to partially defray costs is to find viable markets for juniper logs and other material not needed to assist restoration efforts. Efforts to create a commercial juniper industry have been underway since 1992. There have been successes, but high costs associated with juniper harvest are a critical limiting factor, even on better sites with more trees per acre and more volume per tree. Harvest costs are higher than traditional commercial species because of: 1) numerous, large and flexible limbs; 2) low volume per acre; 3) poor road access; and 4) rocky terrain (Swan 1997).

Current Western Juniper Harvest Systems and Equipment

The most common juniper harvest system consists of a chainsaw to fall and limb juniper, coupled with some method of yarding logs to a central landing (e.g. crawler tractor, rubber tired skidder, or farm tractor). Although not "state-of-the-art", a harvest system involving this type of equipment is relatively easy to put together, low cost, and widely available. Production is estimated at about 50 green tons per day with a three-person crew.

A minor modification of the juniper chainsaw/yarder harvest system involves use of a shear or a feller-buncher to fall trees instead of fallers using chainsaws. A shear is a rigidly mounted device on the front-end of a wheeled or tracked carrier. Hydraulic pressure closes two opposing knives that sever a tree at its base. A feller buncher uses either a retractable saw (like a standard chainsaw bar and chain, only larger) or a rotating disk with cutting teeth on the outside edge (also called a "hot saw"). Many different carriers are used with these technologies.

A pedestal-mounted delimber has also been used with juniper. Trees are cut either with chainsaws, shears, or a feller-buncher, and whole-tree skidded to a central landing where the pedestal-mounted delimber is located. A loader then picks the tree up and pulls it through the delimbing knives. No matter what system is used to fall and skid juniper, a certain amount of chainsaw work is usually needed to remove limbs from the butt of the log to permit proper placement of the tree on the pedestal where the delimbing knives are located.

The most extensive commercial juniper harvest within the last 10 years has occurred recently in Northeast California for biomass used for power generation (at least 2,000 acres). The entire tree is chipped in this operation, not just the bole, which makes production figures appear more attractive. According to the biomass power facility fuel buyer, when operations are within a quarter-mile of a landing trees are sheared or cut with a "hot saw" and then whole-tree skidded to a landing where a chipper is located. Juniper harvest beyond about a quarter-mile from a landing is accomplished with a shear or "hot saw", mobile chipper (Morbark Mountain Goat), and forwarder with a customized self-tipping dump for transport of chips back to the landing. Production averages about 10 to 12 chip van loads per day (about 24 to 26 tons per load), which translates to about 15 acres per day (0.5 to 1.25 loads/acre) (Thayer, Personal Communication 2000).

Discussion Related to Current Juniper Harvest Systems and Equipment

Conventional harvest systems that use chainsaws to fell and/or delimb juniper have to deal with idiosyncrasies particular to western juniper. One is that the limbs on these trees are large and flexible, and often grow close to the ground. This heightens the risk a lightly-protected hand faller will be injured by limbs during the falling, limbing, and bucking processes. Additional time is also frequently required to fall juniper because limbs must be removed in order to approach the tree, place an undercut and backcut for felling, and provide an escape route. Once the tree is felled, remaining limbs are stout enough to keep the stem a couple of feet off the ground, increasing the risk of roll-over as the tree is limbed.

In regards to the pedestal-mounted delimber tried by at least one juniper harvest business, hand cutters must still limb the bottom four feet of the tree so the loader that pulls the tree through the delimbing knives can grasp the tree and achieve proper placement in the delimber cradle. Problems arise when the delimbing knives cannot conform to the stem of the tree (due to large knot swell, staubs from large limbs, and high taper) and if loaders have insufficient power. Limbs also accumulate quickly and must be removed to allow proper placement of the tree in the delimber cradle. The delimber itself also must be fairly heavy to withstand the "pull" by the loader.

Use of shears to fall juniper is becoming more common. Shears are relatively affordable, but slow and cumbersome. Live limbs often remain after a tree is sheared (or cut with a "hot saw"), which must be removed with a chainsaw. Shears can also cause a phenomenon known as "butt shatter" (see Figure 1). This means that if the log is to be sawn into lumber, the first foot or so of the butt log may have to be bucked to where the remaining wood fiber is not damaged. This results in loss of volume and the added expense of a hand cutter. Loss of volume many not be such an issue if there is significant butt swell or other common juniper log defect, such as old live limbs (a phenomenon often encountered with juniper, where a tree continues to grow around a limb, but the limb remains live and is never tightly encased; as compared to other species where lower limbs tend to drop-off and the tree grows around and tightly encases the old limb location). Many shears also do not open sufficiently for the butt swell often encountered with juniper.

Previous Formal and Informal Juniper Harvest Trials

Several informal and formal juniper harvest trials occurred in the 1990s. In 1993, an informal trial was conducted with a system consisting of chainsaws to fell the trees, rubber-tired skidder to transport the logs to a central landing, and a stroke delimber to delimb the tress at the landing. About 100 boles were delimbed. Average delimbing time was about one minute per log. The majority of the trees delimbed were considered "sawlog" quality. This meant they had less taper, fewer limbs, and more spacing between limbs, on average, than most juniper. Some difficulty was observed in the stroke delimber's capability to clamp juniper sufficiently so that the butt would not move. Re-clamping and situating the log increased the time necessary to delimb the log. Fiber pull-out caused by the shearing action of the delimbing knives was also a concern, but not considered unsolvable so long as knives were well-sharpened and maintained (fiber pull-out causes degrade in "jacket boards") (Swan 1993).

The first formal juniper harvest trials were conducted in 1996. The purpose of the trials was to obtain baseline economic data, evaluate impacts, and test several different types of delimbers. Soil compaction was also measured pre- and post-harvest. Results indicated no significant cost differences between harvest systems that relied on chainsaws to fall and delimb juniper, and a pedestal-mounted, pull-through delimber (ranged between $27 to $29 per green ton). Using data provided by industry, it was projected that some savings could be obtained by combining a forwarder and other equipment. Actual trials with this equipment were not conducted (Swan 1997).

A serious challenge encountered during the first juniper harvest trials involved use of slash for site restoration purposes. Juniper slash tends to ball-up and interweave whenever attempts are made to move, separate, or distribute it. Attempts to increase slash dispersion were minimally effective and costly. Another serious challenge related to use of chainsaws to fall and delimb juniper. Costs and exposure to hazards are higher with juniper because of numerous, large and flexible limbs. For example, because juniper limbs often are not shed as the tree grows, they must be removed to safely approach the tree and provide an escape route when it is felled. Once the tree is felled the remaining limbs keep the butt off the ground. The tree then tends to roll as it is limbed due to the weight of the limbs and being elevated.

One recommendation from the 1997 juniper harvest systems report was that specially-designed equipment was needed for juniper that would improve economics, safety, and slash dispersal. Suggested price range of such equipment was $75,000 to $80,000. This would make the equipment cost competitive with the most effective and economic delimbing system measured to-date, which consisted of a used loader and pedestal-mounted delimber.

Trial Site

Figure 1: Trial Site Photo

The trial site for this study was located on a privately held ranch about 15 miles northeast of Klamath Falls. Cattle and sheep have grazed the site heavily for at least 100 years (see Figure 3). Ground cover was sparse, consisting primarily of cheat grass and some sagebrush. Overstory consisted of scattered ponderosa pine, and western juniper.   Juniper averaged 8 inches in diameter and 41 feet in height while ponderosa pine averaged 12 inches in diameter and 54 feet in height. On average, 17 juniper stems per acre were present as opposed to 10 stems per acre of ponderosa pine. Aspect ranged from eastern around to northern with about a third of the unit located along a ridge top. The portions of the unit that were on the eastern aspect were comprised mainly of juniper and transitioned to ponderosa pine on the northern aspect and along the ridge. Slope ranged from zero percent to 25 percent. A road system was already in place that consisted of dirt roads such that no area of the unit was more than 300 feet from a road. Fire appears to have been excluded for multiple generations as evidenced by a lack of fire scars or burnt stumps.

Figure 2: Trial Site Location

Equipment Description

<u>Mobile Delimber</u>

Figure 3: Mobile Delimber

The *Mobile Delimber* consists of a self-propelled carrier/prime mover of other manufacture (in this case, a retired lumber stacker chassis) with a mounted log loader, and delimbing and bucking apparatus. The delimbing system features a chain in-feed mechanism that draws the juniper bole through a set of knives. This purpose of this design is to reduce the amount of fiber pull-out from around the limb where it attaches to the bole (often occurs to at least some extent with mechanical delimbing). Many delimbing systems have knife systems that are not designed for large, flexible limbs, and can cause degrade in some of the best lumber by ripping out chunks of fiber from the "jacket" boards during delimbing. The Contractor estimates a second-generation machine would cost $125,000 to $150,000 to build, and approximately $45 per hour to own and operate if built on a similar used carrier.

Delimber/Shear Combination

Figure 4: Delimber/Shear Combination

The *Delimber/Shear Combination* system consists of a prime mover of other manufacture (in this case a Drott tracked carrier) and a delimber that travels on a vertical boom. The second machine differs from the first in that the juniper tree is limbed before the stem is severed from the sump. After limbing, the shear cuts the tree off the stump. This machine is very similar to a Beloit Tree Harvester, which was built in 1966 and is on display at the Collier State Park Logging Museum (Hwy. 97, between Chiloquin and Chemult, OR). The Contractor estimates a second-generation attachment (vertical boom, limbing knives, and shear) would cost $50,000 to $60,000 to build and approximately $45 per hour to own and operate (when mounted on a used carrier, such as the Drott).

Shear

Figure 5: Shear

The shear used for this trial has a 20-inch capacity shear and is mounted on a rubber-tired International Harvester articulated payloader. The Contractor estimates the shear costs approximately $55 per hour to own and operate.

<u>Skidder</u>

Figure 6: Skidder

The skidder used for this trial is a Caterpillar 518 rubber tired skidder with grapple. The Contractor estimates this machine costs approximately $45 per hour to own and operate.

Methodology

A total of 50 ¼-acre plots were established prior to the harvest trials. Plots were evenly-distributed across the study area of approximately 50 acres. Pre- and post-harvest trials data recorded included overstory and understory composition, trees per acre, canopy cover, and percent ground covered by woody debris. Soil samples for bulk density comparisons were taken from the center of each plot. To accentuate pre- and post-harvest differences, post-harvest soil samples were taken in areas that, based on visual evidence, experienced the most disturbance and potential compaction. Soil bulk density samples were evaluated at an off-site, independent lab. Post-harvest data also included any damage observed to the residual stand.

Time and motion studies were performed for the two systems used in the harvest trials. For each piece of equipment used in the two systems, the time/motion cycle was broken-down into distinct segments, such as travel, positioning, falling, delimbing, and bucking. Time was measured for each segment. Parameters such as diameter of large-end of log, distance traveled, types and length of delays, operator, and number of logs produced per stem processed, were also recorded.

Results were summarized and analyzed using standard statistical measures, such as mean, standard error, median, mode, standard deviation, sample variance, range, minimum, maximum, and confidence level. Certain data relationships were developed and graphed using regression analysis, such as cycle time versus parameter such as diameter and distance traveled.

Production data consisted of tons per truckload (commercial weight scale ticket) and number of logs per truck (recorded by the contractor). Income was estimated based on average price per ton paid by the receiving mill (REACH, Inc., Klamath Falls).

Results

Two harvest systems were evaluated. The first system consisted of three separate pieces of equipment: 1) A 20-inch shear mounted on an International Harvester articulated payloader; 2) Caterpillar 518 rubber-tired, grapple skidder; and 3) *Mobile Delimber*. The original configuration proposed by the contractor consisted of a shear, and shop-built mobile delimber with attached trailer to carry the stems after they were processed. Due to operational constraints such as the top-heavy design combined with a short, narrow wheelbase, the delimber was operated on a central landing and a skidder used to whole-tree skid trees cut by the shear.

The second system consisted of two pieces of equipment: 1) *Delimber/Shear Combination* and 2) Caterpillar 518 rubber-tired skidder with grapple previously described. The first system operated over about 20 acres and the second about nine acres. System No. 1 trials were conducted during the winter of 2000. Ground was frozen with zero to six inches of snow. System No. 2 trials were conducted during the summer of 2001. Only merchantable (greater than six inches in diameter) juniper was removed by either system.

The area where System No. 1 operated averaged about 20 trees per acre (TPA) pre-harvest, of which approximately 70% (14 TPA) were western juniper and the remainder ponderosa pine. The juniper averaged about eight-inches "diameter-at-breast height" (DBH) and 42-feet in height. Pine averaged about 13-inches DBH and 56-feet in height. About 64% of the area where System No. 1 operated had some type of ground vegetation pre-harvest (mainly cheat grass and sagebrush) and 8% was classified as having some type of woody down debris. There were many open spaces without any trees in this area of the project.

The area where System No. 2 operated averaged about 33 TPA pre-harvest, of which approximately 60% (20 TPA) were juniper and the remainder ponderosa pine. The juniper averaged about eight-inches DBH and 40-feet in height. Pine averaged about 11-inches DBH and 52-feet in height. About 53% of the area where System No. 2 operated had some type of ground vegetation pre-harvest (mainly cheat grass and sagebrush) and 7% was classified as having some type of woody down debris. Trees were more evenly spaced in this area than where System No. 1 operated.

About 747 pieces (187 tons of logs) were produced by System No. 1 (average length 8 feet plus trim). The post-harvest stand where System No. 1 operated averaged 15 TPA, of which approximately 67% (10) were juniper and the remainder ponderosa pine. The DBH of juniper removed averaged about 11.9-inches and the average log weighed 507 pounds. Post-harvest woody debris was not measured since all delimbing was done at a central landing and slash piled per landowner's direction. It is estimated post-harvest down woody debris cover would have increased from about 6% pre-harvest to 25+% if the landowner had not required immediate slash clean-up. Post-harvest vegetation cover data were also not obtained, but did not decrease significantly based on observations made during time and motion studies. No residual stand damage was observed.

About 600 pieces (101 tons of logs) were produced by System No. 2 (average length 8 feet plus trim). The post-harvest stand averaged 17 TPA, approximately 47% (8) of which were juniper and the remainder ponderosa pine. The DBH of juniper removed averaged about 9.9-inches and the average log weighed 337 pounds. It is estimated post-harvest down woody debris cover would have increased from about 7% pre-harvest to 50+% if the landowner had not required immediate slash clean-up. Post-harvest vegetation cover data were not obtained, but did not decrease significantly based on observations made during time and motion studies. No residual stand damage was observed.

A total of 44 soil bulk density samples were taken pre-harvest and 19 post-harvest. There were no statistical differences between pre- and post-harvest soil bulk density measurements for either system.

Time and Motion Study Results

A total of 87 observations were taken of the shear (103 minutes total) for time and motion study purposes. Average cycle time for the shear, including travel, positioning, clearing limbs from the lower portion of the tree, shearing the stem, and delays, was about one minute. Figure 7 portrays graphically percent of time for each cycle segment. The most time (40%) was spent traveling from tree to tree and positioning the shear. Very few delays were observed.

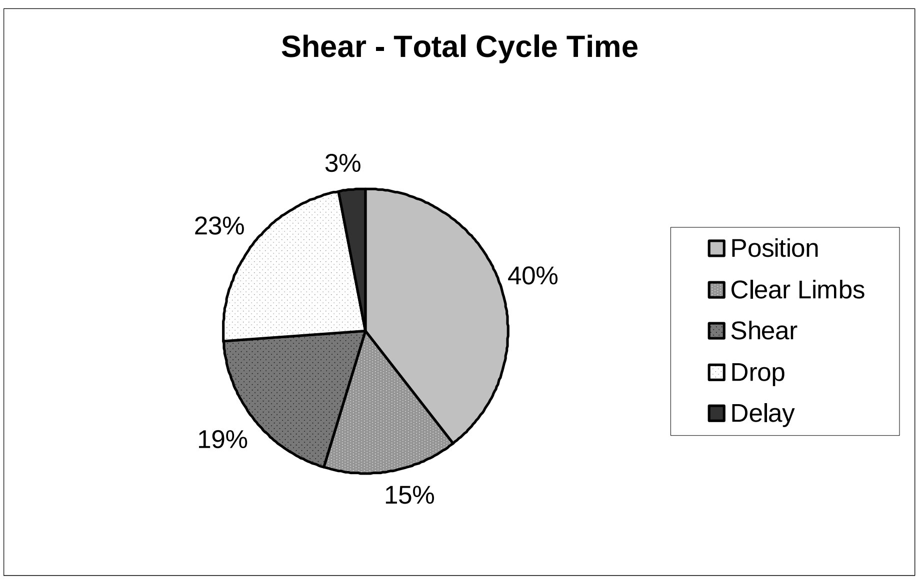

Figure 7: Breakdown of Shear Total Cycle Time

A total of 64 observations were taken of the delimber used in System No. 1 (260 minutes total). Average cycle time for the *Mobile Delimber*, including loading and positioning the stem, delimbing, bucking, unloading the top of the stem, clearing limbs away from the delimber, and delays, was about four minutes. Figure 8 portrays graphically percent of time for each cycle segment. The most time (32%) was spent delimbing the stem while nearly as much time, 29%, was spent loading and positioning the stem in the delimbing knives. Very little pull-out was observed.

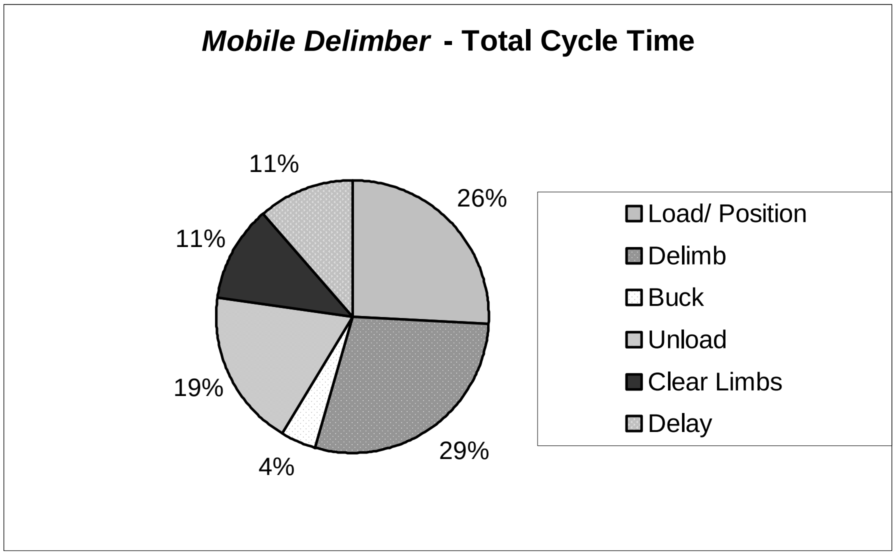

Figure 8: Breakdown of *Mobile Delimber* Total Cycle Time

A total of 33 observations were taken of the rubber-tired skidder with grapple used in both systems (113 minutes total). Average cycle time for the skidder, including operator, travel, positioning, assembling trees, skidding, decking, and delays was about eight minutes. Figure 9 portrays graphically percent of time for each cycle segment. Due to mechanical difficulties, all skidder time and motion study data were taken during Harvest System No. 1 trials. Significant differences of about 2 minutes per cycle for the same travel distance were found between the two skidder operators observed. Both operators averaged about 1.7 pieces per cycle (also called a "turn") (these were whole trees, not delimbed).

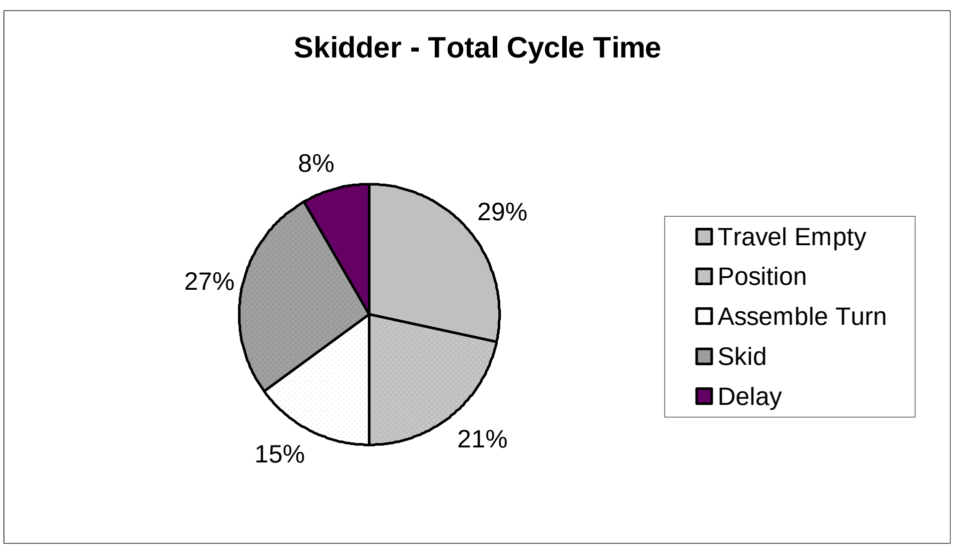

Figure 9: Breakdown of Skidder Total Cycle Time

A total of 54 observations were taken of the *Delimber/Shear Combination* used in System No. 2 (176 minutes total). Average cycle time for the *Delimber/Shear Combination*, including travel, positioning, limbing, shear, log laydown, and delays, was about three-minutes. Figure 10 portrays graphically percent of time for each cycle segment. The largest portion of productive cycle time was spent delimbing (35%). Mechanical difficulties added about the same amount to total cycle time as the main activity of delimbing. This particular delimber did not leave as clean a log as the *Mobile Delimber* used in System No. 1 (leaving what sawmills call "pigs ears", or remnants of limbs still attached to the log).

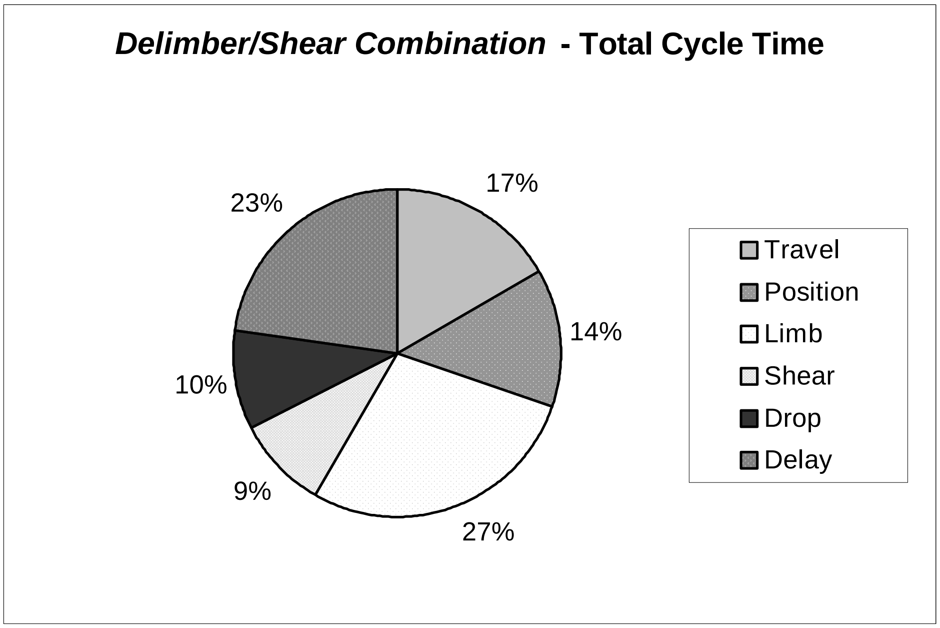

Figure 10: Breakdown of *Delimber/Shear Combination* Total Cycle Time

Stand conditions varied for the two systems. The area where System No. 1 operated contained spaces with few if any trees whereas trees more evenly occupied the area harvested by System No. 2. The area in which System No. 1 operated also was dominated by juniper, with scattered pine, whereas System No. 2 operated in a stand dominated by ponderosa pine with scattered juniper. This meant that a larger proportion of the juniper where System No. 2 operated was harvested (45% of standing juniper) compared to System No. 1 (30% of standing juniper).

Discussion and Interpretation

Site Selection and Conditions

Sites with a western juniper vegetative component vary greatly. The particular site chosen by the contractor reflected his desire to obtain better form juniper for sawing and minimize adverse harvest factors, such as slope and large surface rock. This type of juniper often comes from sites similar to that chosen - located at the ecotone of a sagebrush/grass community transitioning to what was probably an open ponderosa pine stand prior to overstory removal (Swan, Personal Communication). According to the contractor, the juniper component of the remaining mixed juniper/ponderosa pine stand was below average for this type of site in the Klamath Basin in terms of DBH and trees per acre (average DBH of eight- to nine-inches and 14 to 20 trees per acre), and about average in terms of height (40- to 42-feet). Spacing between branches was better than normally seen with more open-growing juniper.

It is important to note that the harvest site chosen did not simulate the conditions commonly encountered when juniper is removed for rangeland habitat restoration rather than higher quality log recovery (high taper, average DBH less than 12-inches, less than 50 trees per acre, average height of 20- to 30-feet, and with numerous large limbs going all the way to the ground).

Results

The contract for this project specified that results would be evaluated in terms of three criteria:

1. Cost of Logs Delivered to Central Landing - The estimated cost of delimbed logs delivered to a central landing was $32.76 per green ton for the *Mobile Delimber* and $26.47 per green ton for the *Delimber/Shear Combination*. This is higher than results reported for the first documented juniper harvest trials in 1996, which ranged from a low of $27.27 per green ton for a conventional system, consisting of "manual falling and delimbing/rubber-tired skidder (RTS) with grapple", to a high of $29.14 per green ton for a system consisting of "manual falling and partial delimbing/RTS with grapple/pull-through delimber" (Swan 1997). The difference in results between the two trials can be partially attributed to stand characteristics. Many more juniper were removed per acre in 1996 (55 vs. four to nine in this trial) and the logs were larger (average 12.6-inches DBH vs. 10.9-inch DBH in this trial).

   Productivity gains of 10%, 25%, and 50% were calculated based on contractor reports of productivity gains for the "pull-through delimber" because of operator experience and machine break-in time. Actual results are projected somewhere between the 25% and 50% productivity gain shown below in Figure 11:

Figure 11: Productivity Gains

Trial

Equipment	*Mobile Delimber*	Skidder	Shear	Total		*Delimber/Shear Combination*	Skidder	Bucker	Total
Hours	59	48	24			35	21	10	
Days	7.38	6.00	3.00			4.38	2.63	1.25	
# Loads	8	8	8			4.5	4.5	4.5	
Loads/Day	1.08	1.33	2.67			1.03	1.71	3.60	
Loads/Hour	0.14	0.17	0.33			0.13	0.21	0.45	
Tons	187.26	187.26	187.26			100.88	100.88	100.88	
Tons/Day	25.39	31.21	62.42			23.06	38.43	80.70	
Tons/Hour	3.17	3.90	7.80			2.88	4.80	10.09	
Pieces	747	747	747			600	600	600	
Pieces/Day	101.29	124.50	249.00			137.14	228.57	480.00	
Pieces/Hour	12.66	15.56	31.13			17.14	28.57	60.00	
Machine Cost	$ 45	$ 45	$ 55			$ 45	$ 45	$ 15	
Total $/Hour	$ 45	$ 45	$ 55			$ 45	$ 45	$ 15	
Total Cost	$ 2,655	$2,160	$ 1,320	$ 6,135		$ 1,575	$ 945	$ 150	$ 2,670
$/Ton Stump to Landing				$ 32.76					$ 26.47

10% Improvement

Equipment	*Mobile Delimber*	Skidder	Shear	Total		*Delimber/Shear Combination*	Skidder	Bucker	Total
Hours	53.1	48	24			31.5	21	10	
Days	6.64	6.00	3.00			3.94	2.63	1.25	
# Loads	8	8	8			4.5	4.5	4.5	
Loads/Day	1.21	1.33	2.67			1.14	1.71	3.60	
Loads/Hour	0.15	0.17	0.33			0.14	0.21	0.45	
Tons	187.26	187.26	187.26			100.88	100.88	100.88	
Tons/Day	28.21	31.21	62.42			25.62	38.43	80.70	
Tons/Hour	3.53	3.90	7.80			3.20	4.80	10.09	
Pieces	747	747	747			600	600	600	
Pieces/Day	112.54	124.50	249.00			152.38	228.57	480.00	
Pieces/Hour	14.07	15.56	31.13			19.05	28.57	60.00	
Machine Cost	$ 45	$ 45	$ 55			$ 45	$ 45	$ 15	
Total $/Hour	$ 45	$ 45	$ 55			$ 45	$ 45	$ 15	
Total Cost	$ 2,390	$2,160	$ 1,320	$ 5,870		$ 1,418	$ 945	$ 150	$ 2,513
$/Ton Stump to Landing				$ 31.34					$ 24.91

25% Improvement

Equipment	*Mobile Delimber*	Skidder	Shear	Total		*Delimber/Shear Combination*	Skidder	Bucker	Total
Hours	44.25	48	24			26.25	21	10	
Days	5.53125	6	3			3.28125	2.625	1.25	
# Loads	8.00	8.00	8.00			4.50	4.50	4.50	
Loads/Day	1.446328	1.3333	2.66667			1.371428571	1.7143	3.6	
Loads/Hour	0.18	0.17	0.33			0.17	0.21	0.45	
Tons	187.26	187.26	187.26			100.88	100.88	100.88	
Tons/Day	33.85492	31.21	62.42			30.74438095	38.43	80.704	
Tons/Hour	4.23	3.90	7.80			3.84	4.80	10.09	
Pieces	747.00	747.00	747.00			600.00	600.00	600.00	
Pieces/Day	135.0508	124.5	249			182.8571429	228.57	480	
Pieces/Hour	16.88	15.56	31.13			22.86	28.57	60.00	
Machine Cost	45.00	45.00	55.00			$ 45	$ 45	$ 15	
Total $/Hour	$ 45	$ 45	$ 55			$ 45	$ 45	$ 15	
Total Cost	$ 1,991	$2,160	$ 1,320	$ 5,471		$ 1,181	$ 945	$ 150	$ 2,276
$/Ton Stump to Landing				$ 29.22					$ 22.56

50% Improvement

Equipment	*Mobile Delimber*	Skidder	Shear	Total		*Delimber/Shear Combination*	Skidder	Bucker	Total
Hours	29.5	48	24			17.5	21	10	
Days	3.69	6.00	3.00			2.19	2.63	1.25	
# Loads	8	8	8			4.5	4.5	4.5	
Loads/Day	2.17	1.33	2.67			2.06	1.71	3.60	
Loads/Hour	0.27	0.17	0.33			0.26	0.21	0.45	
Tons	187.26	187.26	187.26			100.88	100.88	100.88	
Tons/Day	50.78	31.21	62.42			46.12	38.43	80.70	
Tons/Hour	6.35	3.90	7.80			5.76	4.80	10.09	
Pieces	747	747	747			600	600	600	
Pieces/Day	202.58	124.50	249.00			274.29	228.57	480.00	
Pieces/Hour	25.32	15.56	31.13			34.29	28.57	60.00	
Machine Cost	$ 45	$ 45	$ 55			$ 45	$ 45	$ 15	
Total $/Hour	$ 45	$ 45	$ 55			$ 45	$ 45	$ 15	
Total Cost	$ 1,328	$2,160	$ 1,320	$ 4,808		$ 788	$ 945	$ 150	$ 1,883
$/Ton Stump to Landing				$ 25.67					$ 18.66

2. Worker Exposure to Chainsaws – Use of chainsaws was significantly reduced for the two systems in these trials. The *Mobile Delimber* system included a separate wheeled shear for falling and the *Delimber/Shear Combination* has a shear as an integral component. Chainsaws were used to clean-up "pig's ears" (portions of limbs remaining after mechanical delimbing), and top and buck trees yarded for the *Delimber/Shear Combination*. It is assumed that in many cases chainsaws will still be required to cut juniper saplings and whips, and sever remaining live limbs on stumps.

3. On-Site Dispersion of Slash – It is estimated that if the carrier for the *Mobile Delimber* had functioned as intended, slash dispersion might have been 50+%. Slash dispersion for the Delimber/Shear Combination system was estimated to be about 25%. Comparison with the 1996 juniper harvest trials is difficult because of significant differences in juniper per acre and amount of slash able to be distributed. The 1996 trials averaged 55 trees removed per acre compared to these trials, which averaged four to nine trees removed per acre. In qualitative terms, slash dispersion was considered "very good" for the *Delimber/Shear Combination* and probably similar for the *Mobile Delimber* if it had operated as intended (Swan, Personal Communication).

Soil Compaction

Bulk soil density sampling strategy used for these trials was similar to that used in the 1996 juniper trials (Swan 1997). Pre-harvest trial samples were taken throughout the trials site and compared to samples taken post-harvest in heavily-traveled areas. Results were also similar - virtually no soil compaction was observed. This is not surprising given that the area impacted by the *Mobile Delimber* was for the most part frozen during harvest activities (winter 2000) and that very dry soils were observed when the *Delimber/Shear Combination* trial was conducted (summer 2001). It is also speculated that past activities, such as heavy grazing beginning about 100 years ago and previous logging, have already impacted the site to the extent that limited activities, such as those associated with the harvest trials, do not cause quantifiable compaction damage. There is some evidence to support this theory in the form of “platey” soil structure observed in the upper soil horizons. Given data from two juniper harvest trials, it is assumed compaction may not be an issue in sites with similar soils (dry clay loam and clay soils) and history, so long as the soils are frozen or dry.

Regression Analysis

Regression analyses were performed to quantify relationships between times for machine cycle elements and variables such as stem diameter and travel distance that affect those cycle elements. The formulas derived are probably somewhat accurate for projecting time/motion and estimating costs for the shear and rubber tired skidder with grapple, because observations tended to cluster. Operator experience, as observed for the skidder, was more significant than any other measured factors. The formulas derived for the two delimbing apparatus are simply too speculative to comment on because of major potential improvements possible with more stable and faster carriers (see Appendix A for regression calculation details).

Innovations

A significant innovation that was not measured is the unique, flexible knife arrangement on the *Mobile Delimber*. Less fiber “pull-out” was evident when compared to other delimbing mechanisms, such as the *Delimber/Shear Combination*. People who had been present in 1993 when a stroke delimber was used with better form juniper observed that there appeared to be less pull-out with the *Mobile Delimber* knife arrangement (Swan, Personal Communication).

Methodological Weaknesses

Methodology and results were affected by a number of factors:

1. Slash Piling – Data collection about ability of the harvest systems to scatter slash was hampered by landowner concerns about slash accumulation. Only crude estimates could be obtained.

2. Equipment Downtime – There were major equipment downtime and delays for repair and adjustment. This was expected for “proof of concept” prototypes, but it means that the results reported may not be a good indication of potential results. Attempts were made to address this issue by extrapolating effects of potential production gains (see below).

3. Carriers Used in Trials – The carriers used in the trials are probably not indicative of what would be used in the future. The retired "lumber stacker" used for the *Mobile Delimber* had a high center of gravity, which hindered use on slopes over 5%, and the former irrigation ditch excavator used with the *Delimber/Shear Combination* was very slow.

Concerns About Custom- or Shop-Built Equipment

Limited edition, custom- or shop-built equipment designed and fabricated for specific tasks has drawbacks. The most significant one is that even if the machine works well, limited production means that parts and manuals may not be readily available, and mechanics may not be familiar with the unique configuration of parts. Savings during fabrication may well be cancelled-out by costs incurred in trying to maintain and operate the equipment long-term.

Recommendations

It is suggested future studies include systematic evaluation of excavator-mounted "dangle head" processors[1], purpose-built feller-bunchers[2], harvester/forwarder combinations[3], and stroke-boom delimbers[4] made by major forestry equipment manufacturers. These machines are likely to achieve dramatically higher production rates on more productive sites (e.g. when juniper is mixed in with ponderosa pine) compared to the systems described above. Parts and repairs are also more easily obtained and performed than with custom-built or limited-production machines.

An indication of the potential productivity of existing logging systems was provided by eyewitness accounts of feller-buncher performance in a scattered juniper stand (about two-minutes per tree, including travel and felling) (Swan Personal Communication). The authors also viewed 1993 video footage of a stroke-boom delimber processing juniper harvested from what was considered a more productive site (e.g. trees averaged at least 35- to 40-ft. tall). Production rate was about one stem per minute. In addition, the authors had the opportunity to try a small "dangle-head processor" with a limited sample of juniper removed during a pine

[1] Mounted on the end of an excavator's (or converted excavator – log loader) boom, a dangle head processor grabs the butt of a fallen tree, often while sitting at a landing, and pulls the log using roller wheels through a set of delimbing knives. The processor head measures log length and the operator is able to cut logs to length with a saw bar mounted in the processor head.

[2] A feller-buncher is either a tracked or wheeled machine that fells and bunches trees. The felling may be accomplished using a saw bar or a continually turning cutting wheel ("hot saw").

[3] A harvester is similar to a feller-buncher with the exception that the harvester always uses a saw bar-type felling head. In addition to felling the tree, the harvester has capabilities similar to the dangle head processor to delimb and buck stems. The harvester is followed by a forwarder. A forwarder is a tracked or wheeled machine equipped with log bunks and a loading boom used to pick up logs from the forest floor and place them in the forwarder's log bunks. Logs are then "forwarded" out of the woods to a landing where they are offloaded from the forwarder's bunks using the loading boom.

[4] Like a dangle head processor, a stroke-boom delimber grabs the butt of a fallen tree, often while sitting at a landing, delimbs, measures, and bucks the tree into logs. However, instead of using roller wheels to feed the tree through the delimbing knives, a stoke-boom delimber rigidly holds onto one end of the log with a grapple. The log is parallel to a boom on which a second set of grapples rides. This second set of grapples contain delimbing knives and a bucking saw. As this second set of grapples is forced out along the tree, the tree is delimbed, measured, and bucked into log lengths.

thinning demonstration (n = 5). The operator had the same difficulties in removing limbs from the stem observed with the custom-built machines documented for this report, but was still substantially faster (less than one minute per tree; average log lengths of 8 ft.). Fiber pull-out was about what was observed with the *Delimber/Shear Combination*. The operator reported that he thought he could be much more efficient with a larger processor head.

Unfortunately, with the increase in production efficiency comes substantially higher costs to purchase and maintain the equipment. It is unknown whether market demand, prices, and subsidies for rangeland and watershed restoration projects can sustain such operations. Also unknown is how these machines will perform in situations where the primary objective is rangeland or watershed restoration, where juniper have much larger limbs and more taper. Testing protocol will need to include provisions for testing the equipment with and without use of chainsaws to prepare the tree (e.g. remove limbs) so machines can more easily access and grip them.

Summary and Conclusions

The purpose of this project was to evaluate two harvest systems designed or modified specifically for western juniper (*Juniperus occidentalis*) in terms of production costs, worker exposure to use of chainsaws, and on-site dispersion of slash, and compare results with those from juniper harvest trials conducted in 1996.

Over the last 100 years, the area dominated by western juniper has greatly increased throughout its main range in Eastern Oregon, Northeastern California, and Southwestern Idaho. There are now over 3.8 million acres with 10% or canopy cover, of which at least 1.0 million acres have 20% or more canopy cover. Twenty percent or more canopy cover is a key early indicator of loss of vegetative diversity, groundcover, watershed function, and wildlife habitat. On the other hand, juniper is the least–utilized wood fiber resource in its range. Efforts to commercialize western juniper have occurred off and on for at least 50 years. Beginning in the early 1990s, the most sustained and integrated effort yet attempted was begun under the leadership of several private companies, U.S. Forest Service, and Oregon Economic and Community Development Department. One of the key barriers to successful commercialization identified early in the process was harvest costs and quality of supply for value-added products.

A Northwest Economic Adjustment Initiative grant was obtained by REACH, Inc. (Klamath Falls, OR) from the U.S. Forest Service to follow-up a key recommendation of the 1996 juniper harvest trials: Cooperate with the forest products industry to modify or design harvest equipment better suited to juniper and restoration objectives. REACH, Inc. issued a state-wide “Request for Proposals” (RFP) for two harvest systems designed or modified specifically for juniper. The RFP was awarded to TIM Equipment (Dairy, OR). TIM Equipment proposed to design and fabricate two new pieces of equipment to be integrated with existing logging equipment in two different systems.

The Yankee Group, Inc. (Philomoth, OR) was hired to assess site conditions pre- and post-harvest, record time and motion study results, evaluate economics, and prepare the final report. Harvest trials occurred in winter of 2000 and summer of 2001 on private land about 15 air miles northeast of Klamath Falls. The harvest site was representative of the ecotone between the sagebrush/grassland vegetative community transitioning into an open ponderosa pine and juniper overstory. The contractor chose the site to maximize potential sawlog recovery. The site had been heavily grazed and previously logged over the years.

Two different harvest systems were evaluated. The first system consisted of a shear, rubber-tired skidder equipped with a grapple, and a custom-built *Mobile Delimber*. The original intent was to use the shear to fell the juniper and the *Mobile Delimber* to delimb and put the logs on an attached trailer. Due to operation constraints of the prime mover, the delimber had to be operated on a central landing. The skidder was used to whole-tree skid trees cut by the shear. The second system consisted of a custom-built *Delimber/Shear Combination* and a rubber-tired skidder equipped with a grapple. The *Delimber/Shear Combination* was designed to delimb standing juniper, and then shear and lay-down the resulting log.

Over 1300 pieces (logs 8 feet in length plus trim) were processed by the two systems during the harvest trials (almost 300 tons or a little over six log truck loads). About 240 time/motion observations were obtained for the equipment used in the trials, including at least 50 each for the two pieces of customized equipment. Estimated cost of delimbed logs delivered to a central landing was $32.76 per green ton for the system that included the *Mobile Delimber* and $26.47 per green ton for the system that included the *Delimber/Shear Combination*. Although not specifically quantified, worker use of chainsaws was greatly reduced, but not completely eliminated due to the need to clear the first two feet of limbs at the base of each tree for both systems, top logs for the system that included the *Delimber/Shear Combination*, cut whips and small juniper, and sever live limbs left on stumps.

Slash dispersal was difficult to evaluate due to landowner concerns and requirement to clean-up slash immediately, and the operation of the *Mobile Delimber* on a central landing instead of in the stand. If the *Mobile Delimber* had been able to operate in the stand as intended, it is estimated that slash dispersion would have met project objectives. The *Delimber/Shear Combination* clearly met project objectives of leaving slash dispersed sufficient to allow sunlight penetration. Pre- and post-harvest bulk soil density measurements indicated no additional compaction due to juniper harvest activities (mirroring results from the 1996 juniper harvest trials).

Costs of production for both of the systems evaluated appear to be higher than those reported for the juniper harvest trials conducted in 1996. In the 1996 harvest trials, costs ranged from a low of $27.27 per green ton for a conventional system, consisting of chainsaws and rubber-tired skidder equipped with a grapple, to a high of $29.14 per green ton for a system consisting of chainsaws, skidder, and pull-through pedestal-mounted delimber. Some of the difference can be explained by much higher juniper densities and removal in the 1996 trials (average 55 vs. four to nine trees removed per acre in these harvest trials) and larger logs (average 12.9-inches vs. 10.9-inches DBH in these harvest trials). Delays due to equipment down time were also a significant factor.

Costs of production are expected to drop based on previous experience with new equipment introduced for juniper harvest. Estimates range between $32.76 and $25.67 per green ton delivered to a central landing for the system with the *Mobile Delimber*, and $26.47 and $18.66 for the system with the *Delimber/Shear Combination*. It is likely different carriers/prime movers will also make a significant difference in production. Both of the custom-built pieces of equipment relied on older-make and model prime movers which caused more downtime for repairs, more time for travel between trees, and in the case of the *Mobile Delimber*, prevented use as designed due to operation constraints (too top heavy for conditions).

An unexpected result of the study was compilation of data about juniper log weights and size harvested from pine/juniper stands on lower-productivity sites, similar to where the trials were conducted (see Appendix B). Another unexpected result was the design and results obtained from the delimbing knife system used in the *Mobile Delimber*. The design clearly resulted in less fiber pull-out than other knife designs and may be patentable.

Limited edition, custom- or shop-built equipment designed and fabricated for specific species or tasks has drawbacks. The most significant one is that even if the machine works well, limited production means that parts and manuals may not be readily available, and mechanics may not be familiar with the unique configuration of parts. Savings during fabrication may well be cancelled-out by costs incurred in trying to maintain and operate the equipment long-term.

The Yankee Group recommends that additional existing logging equipment be systematically tested and evaluated in differing juniper stands. It is expected that some combination of excavator-mounted "dangle-head processors", feller-bunchers, harvester/forwarder combinations, and stroke-boom delimbers will yield significant production benefits in conditions similar to where these trials were conducted. The Yankee Group also believes that it is also worth pursuing systematic trials of more modern logging equipment in situations that are "restoration"-focused, i.e. where trees have more limbs and taper, and slash is an integral aspect of site restoration requirements. It is acknowledged that production efficiency increases will come with substantially higher costs for equipment purchase and operation, however, production increases may justify the additional expense and lower overall restoration cost per acre. Machines will probably have to be a manufacturer's larger models because of juniper's large and flexible limbs.

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Appendix A – Regression Analysis

Mobile Delimber

Timed elements for the *Mobile Delimber* were: Load and position stem, delimb stem, buck log, unload the top of the stem, clear limbs away from the machine, and delays. Additionally, the large-end diameter was estimated and recorded, as was the number of logs produced per stem and delay types.

The following table (Figure A1) gives the average time for each element from the 64 observations made, totaling 260 minutes (4.3 hours, 7.3% of the total time).

Figure A1: *Mobile Delimber* Cycle Time Elements

	Load/ Position	De-limb	Buck	Unload	Clear Limbs	Total Productive Time	Delay	Total Time
Average Time (min.)	1.05	1.16	0.17	0.76	0.47	3.60	0.46	4.06
% of Productive Cycle	29.16%	32.08%	4.80%	21.01%	12.95%			
% of Total Cycle	25.87%	28.46%	4.26%	18.64%	11.49%	88.73%	11.27%	

As shown in Figure A1, the largest amount of time, 32%, is spent delimbing while nearly as much time, 29%, is spent loading and positioning the stem in the delimbing knives. Little stem pull caused by delimbing was observed (Figure 29).

Using time and motion study data, a model was created to estimate productive cycle time for Delimber 1:

$$t_{d1} = 0.1131 * d + 1.8067 * n_l$$

Where:

t_{d1} = productive cycle time for *Mobile Delimber*

d = large-end diameter of stem

n_l = number of logs produced from given stem

Figures A2 and A3 give statistics for this regression model.

Figure A2: *Mobile Delimber* Regression Statistics

R^2	0.3883
Adjusted R^2	0.3624
Standard Error	1.2767
Observations	64

Figure A3: *Mobile Delimber* Coefficient Statistics

Variable	Coefficient	Standard Error	t Statistic	P-Value
d	0.1131	0.0375	3.0192	0.0037
n_l	1.8067	0.4688	3.8539	0.0003

This tells us that, on average, each increase in large-end diameter of 1 inch will result in a 0.1131 minute increase in productive cycle time. Also, a two-log stem will take an average of 1.8067 minutes longer to process than a one-log stem.

Shear

Timed elements for the shear were: Position machine (including travel time), clear limbs from the lower portion of the tree, shear, drop the stem, and delays. Additionally, the diameter at the base of the stem was estimated and recorded, as was the distance moved between trees and delay types.

The following table (Figure A4) gives the average time for each element from the 87 observations made, totaling 103 minutes (1.7 hours, 7.1% of the total time).

Figure A4: Shear Cycle Elements

	Position	Clear Limbs	Shear	Drop	Productive Time	Delay	Total Time
Average Time (min.)	0.47	0.18	0.23	0.27	1.15		1.19
% of Productive Cycle	41.15%	15.99%	20.33%	23.93%			
% of Total Cycle	39.71%	15.43%	19.62%	23.09%	96.79%	3.15%	

The largest amount of time (40%) was spent positioning the shear. This time included the time required to move from tree to tree as well as to position the stem within the shear. Very little (3%) delay was observed.

Using time and motion data, a model was created to estimate productive cycle time for the shear:

$$T_{sh} = 0.0810 * d + 0.0066 * tr$$

Where:

T_{sh} = productive cycle time for the shear

d = base diameter of stem

tr = travel distance in feet

Figures A5 and A6 give statistics for this regression model.

Figure A5: Shear Regression Statistics

R^2	0.2755
Adjusted R^2	0.2553
Standard Error	0.4119
Observations	87

Figure A6: Shear Coefficient Statistics

Variable	Coefficient	Standard Error	t Statistic	P-Value
d	0.0810	0.0034	23.5188	<0.0001
tr	0.0066	0.0014	4.7770	<0.0001

This tells us that, on average, each increase in base diameter of 1 inch will result in a 0.0810 minute increase in productive cycle time and for each food of distance traveled, productive time will increase 0.0066 minutes. It is interesting to note that even through the limbs at the base of the stem were cleared 64% of the time and on average, account for 16% of the productive cycle time, this variable (activity) was not statistically significant.

Skidder

Timed elements for the skidder were: Travel empty, position, assemble a turn, skid, deck, and delays. Additionally, the operator (our data included two operators), skidding distance, number of stems in a turn, and delay types were recorded.

The following table (Figure A7) gives the average time for each element from the 33 observations made, totaling 113 minutes (1.9 hours, 2.8% of the total time). Due to mechanical difficulties, all skidder time and motion study data was taken while the skidder was operating with the *Mobile Delimber* and represents 4.0% of the total skidder time with this system.

Figure A7: Skidder Cycle Elements

	Travel Empty	Position	Grab	Skid	Productive Time	Delay	Total Time
Average Time (min.)	0.95	0.72	0.56	0.90	3.71	3.98	7.70
% of Productive Cycle	25.51%	19.51%	15.01%	24.16%			
% of Total Cycle	12.31%	9.41%	7.24%	11.65%	48.24%	51.76%	

However, large differences were seen between the two operators. Average skidding distance was 210 feet for Operator A and 220 feet for Operator B. Average number of pieces per turn was 1.7 for both operators. This difference is represented in the model below.

Using time and motion data, a model was created to estimate productive cycle time for the skidder:

$$T_{sk} = 2.0016 * op + 0.0048 * tr + 0.5725 * n_s$$

Where:

T_{sk} = productive cycle time for the skidder

op = operator

tr = travel distance in feet

n_s = number of stems per turn

Figures A8 and A9 give statistics for this regression model.

Figure A8: Shear Regression Statistics

R^2	0.7193
Adjusted R^2	0.6672
Standard Error	0.8766
Observations	33

Figure A9: Shear Coefficient Statistics

Variable	Coefficient	Standard Error	t Statistic	P-Value
op	2.0016	0.2887	6.9316	<0.0001
tr	0.0048	0.0011	4.4085	0.0001
n_s	0.5725	0.1734	3.3021	0.0025

This tells us that, on average, Operator B will take 2 minutes per turn longer than Operator A for the same skidding distance and number of stems per turn. Each additional stem in the turn will increase productive cycle time by an average of 0.58 minutes.

Delimber/Shear Combination

Timed elements for the *Delimber/Shear Combination* were: Travel, position, limb, shear, drop, and delays. Additionally, travel distance, diameter at breast height, and delay types were recorded.

The following table (Figure A10) gives the average time for each element from the 54 observations made, totaling 176 minutes (2.9 hours, 8.3% of the total time

Figure A10: *Delimber/Shear Combination* Cycle Elements

	Travel	Position	Limb	Shear	Drop	Productive Time	Delay	Total Time
Average Time (min.)	0.49	0.40	0.82	0.27	0.28	2.26	0.66	2.93
% of Productive Cycle	21.68%	17.61%	36.15%	12.03%	12.54%			
% of Total Cycle	16.76%	13.61%	27.94%	9.30%	9.69%	77.30%	22.70%	

As expected, the largest portion of the productive cycle time is spent delimbing (35%). However, mechanical difficulties added up approximately the same amount of the total cycle time (23%) as did the main activity of delimbing (27%). More cases of "pigs ears" occurred with the *Delimber/Shear Combination*, where the deliming knife was unable to sever the entire limb from the stem leaving a flap of the limb remaining.

Using time and motion data, a model was created to estimate productive cycle time for *Delimber/Shear Combination*:

$$t_{d2} = 0.2304 * d + 0.0203 * tr$$

Where:

t_{d2} = productive cycle time for *Delimber/Shear Combination*

d = diameter at breast height

tr = travel distance in feet

Figures A11 and A12 give statistics for this regression model.

Figure A11: Shear Regression Statistics

R^2	0.2380
Adjusted R^2	0.2125
Standard Error	0.8006
Observations	71

Figure A12: Shear Coefficient Statistics

Variable	Coefficient	Standard Error	t Statistic	P-Value
d	0.2304	0.0113	20.3231	<0.0001
tr	0.0203	0.0079	2.5493	0.0130

This tells us that, on average, each inch of increased diameter will mean a corresponding increase in productive cycle time of 0.2304 minutes. Although travel distance was only minimally significant, it was decided that it was significant enough to warrant inclusion in the mode. Like the shear, the *Delimber/Shear Combination* is more sensitive to changes in diameter than to changes in travel distance.

Appendix B – Log Weight Information

The following data shown in Figure B1 was gathered from trip tickets, weight information provided by REACH, Inc. (the mill), and piece counts as provided by the Contractor. The price of $50/green ton shown below reflects subsidies obtained by REACH, Inc. for watershed restoration.

Figure B1: Ticket Information

System	Month	Ticket Number	Weight (lbs)	Weight (tons)	Number of Pieces	Ton/Piece	$/Load	$/Piece
1	November	1109	41800	20.9	85	0.2459	$1,045	$12.29
1	November	1110	47240	23.62	93	0.2540	$1,181	$12.70
1	November	1111	47540	23.77	103	0.2308	$1,189	$11.54
1	November	1112	42680	21.34	93	0.2295	$1,067	$11.47
1	November	1113	49660	24.83	76	0.3267	$1,242	$16.34
1	November	1114	49080	24.54	88	0.2789	$1,227	$13.94
1	November	1115	48120	24.06	106	0.2270	$1,203	$11.35
1	November	1116	48400	24.2	103	0.2350	$1,210	$11.75
TOTAL *Mobile Delimber*			**374520**	**187.26**	**747**	**0.2535**	**$9,363**	**$12.67**
2	July	1158	21000	10.5	65	0.1615	$ 525	$ 8.08
2	July	1159	47560	23.78	125	0.1902	$1,189	$ 9.51
2	July	1160	39620	19.81	129	0.1536	$ 991	$ 7.68
2	July	1161	47400	23.7	136	0.1743	$1,185	$ 8.71
2	July	1162	46180	23.09	145	0.1592	$1,155	$ 7.96
TOTAL *Delimber/Shear Combination*			**201760**	**100.88**	**600**	**0.1678**	**$5,044**	**$ 8.39**

It is interesting to note the difference in weight per piece between the two harvest systems. All pieces were eight feet in length plus trim. This difference in weight can reasonably be attributed to two factors. The first trial with the *Mobile Delimber* occurred in November and the juniper harvested originated in a stand comprised primarily of juniper, averaged 11.9 inches in breast height diameter with the average log weighing 507 pounds. The second trial with the *Delimber/Shear Combination* occurred in July in a stand dominated by ponderosa pine, and the juniper harvested was, on average, 2 inches smaller in breast height diameter at 9.9 inches and the average log weighing 170 pounds less at 337 pounds. It would be interesting to determine the effect of these two factors of piece size (diameter) and time of year on total piece weight.

Appendix C – Soil Conditions

Soil bulk density was measured before harvest at the center of each 1/5-acre plot used to collect stand data, and again after harvest in the most heavily impacted areas, such as skid trails and landings. Results are shown in tabular form in Figure C1 and graphically in Figure C2 where bulk density figures are shown in grams per cubic centimeters (g/cm^3).

Figure C1: Soil Bulk Density Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Mobile Delimber – Pre-Harvest	30	.88	1.99	1.2702	.2739
Mobile Delimber – Post-Harvest	13	.44	1.65	1.0177	.3554
Delimber/Shear Combination – Pre-Harvest	14	.70	1.97	1.1803	.4038
Delimber/Shear Combination – Post-Harvest	6	.79	1.23	1.0042	.1475

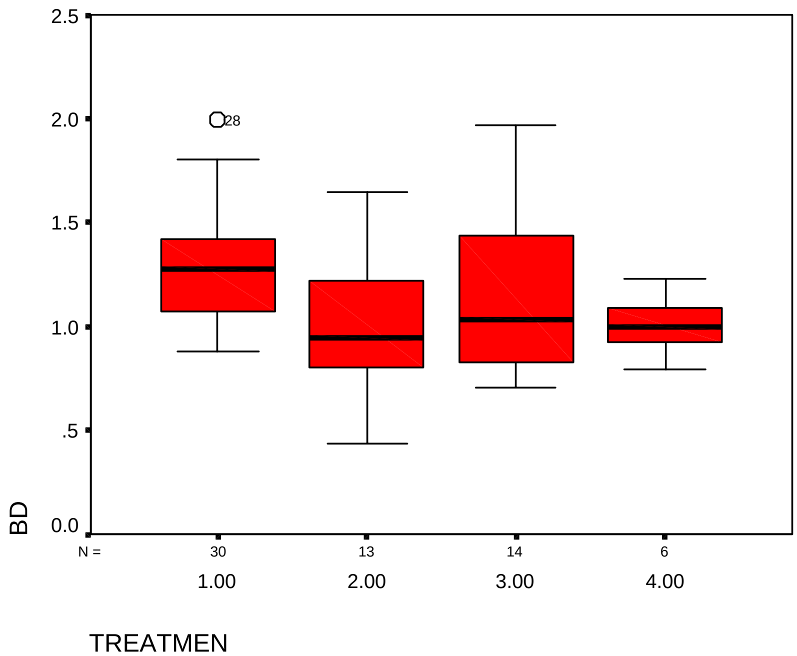

Figure C2: Graph of Bulk Density

In Figure C2, "BD" on the y-axis refers to bulk density in g/cm^3, and the x-axis "TREATMENT" values are:

- 1 = *Mobile Delimber*, Pre-Harvest
- 2 = *Mobile Delimber*, Post-Harvest
- 3 = *Delimber/Shear Combination*, Pre-Harvest
- 4 = *Delimber/Shear Combination*, Post-Harvest

Figure C3 confirms what Figure C2 clearly shows; there is no statistically significant difference between pre- and post-harvest soil bulk density measurements.

Figure C3: Bulk Density ANOVA

	t	p (2 tailed)
Mobile Delimber	2.285	0.034
Delimber/Shear Combination	1.425	0.171