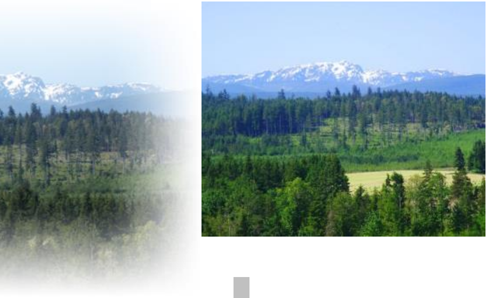

Project Report for the Savannah-Grasslands Pre-Investment Pilot Project

Prepared For: Arizona State Forestry Office
Phoenix, Arizona

Date: June 30, 2016

Prepared by: Southwest Forestry Inc. and
D.R. Systems NW Inc.

Part 1. Pre-Investment Savannah-Grasslands Watershed Analysis Project

This project report is in two major parts. The first part is a description of the work done on the watershed analyses and the second part is a technical report on the actual biomass removal harvests.

Bottom Line Up Front (BLUF) Statement

Assuming it is desired to treat affected watersheds in a timely manner that supports state objectives in reducing fire hazards while improving watershed health and supports facility investments, scenarios where developed which treated the pinyon-juniper areas within the project area within a 25-year time horizon. The pilot project area in the Upper Verde River Watershed encompassed 492,800 acres, of which approximately 100,000 acres were in grasslands and 340,000 acres were in pinyon-juniper savannah vegetation types (200,000 acres in juniper-dominated stands and 140,000 acres in pinyon-dominated stands). A biomass harvest level of 1.8 million ft^3/year, equivalent to an estimated 97,100 green tons/year, would be required. Following that initial harvest, the project area could support an on-going harvest level of 400,000 ft^3/year (21,600 GT/year) for at least an additional 75 years. While these estimates are considered conservative but reasonable, considering the limited inventory data available, the lack of validated yield tables, and the limited actual biomass harvest data available, these estimates must be considered as pre-investment only.

Approximately 100 acres were harvested for biomass using Ponsse equipment provided by Ponsse North America. Based on these results, it is feasible to expect to harvest biomass and place it at roadside at a rate of treating ½ acre to 1 acre per hour at a baseline cost which covers all operating costs, but no allowance for profit and risk, of $200 – $400/acre, assuming the test harvest blocks are representative of the general range of conditions across the pilot project area. The Ponsse equipment was outstanding in flexibility and capability with respect to harvesting the juniper and pinyon vegetation types efficiently and with minimal ground disturbance.

Based on this pilot analysis, subject to the limits of applicability of the pilot area to the rest of Arizona's pinyon-juniper savannahs, it appears that it is feasible to harvest biomass and restore pinyon-juniper watersheds within current accepted guidelines of stand treatments and within normal funding levels associated with landscape recovery using equipment with capabilities and costs similar to that of the Ponsee equipment used in this project.

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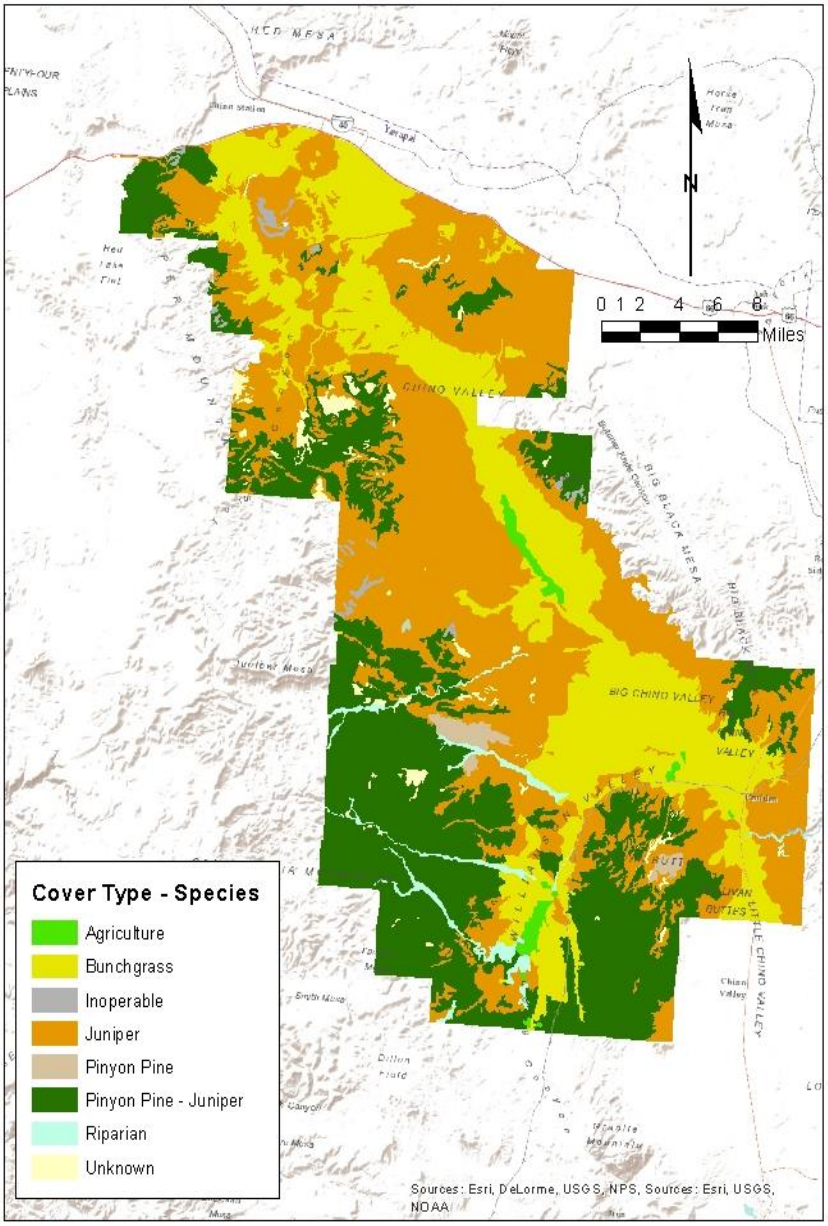
Background Overview

Much of the forest and woodland lands in Arizona can be characterized as supporting excess woody biomass. This general overstocking is in the magnitude of four to five times the natural capacity of the land and gives rise to significant environmental, social, and financial risks and negative effects. This condition is especially true for the grassland savannahs which have been colonized by Pinyon-juniper woodlands with attendant significant increases in woody biomass across the affected landscapes.

The purpose of the project was to identify and define strategies and activities which will lead to improved management of Arizona's watersheds with significant proportions in grasslands and Pinyon-juniper savannahs. The project was designed to provide information on the potential for recovering economically feasible supplies of fiber/biomass from these woodlands as a key activity for restoring these landscapes and watersheds.

The analysis area included in this project encompassed approximately 500,000 acres of the upper Verde River watershed of which approximately 100,000 acres were in grasslands and 340,000 acres in savannah vegetation types (200,000 acres in juniper-dominated stands and 140,000 acres in pinyon-dominated stands). The juniper occurs primarily on low site land while the pinyon is primarily distributed on medium site lands. The project area was chosen to be representative of watershed management opportunities in treating grasslands and savannah vegetation types to replicate their historical reference conditions. The analysis focused on the uplands portions of the watershed (non-riparian areas) as another group is working on management strategies in riparian zones, although some small riparian areas were encountered as part of the pilot harvest portion of the project.

Figure 1. Overview map of project area.



As can be seen from the map the project area is dominated by juniper and pinyon-juniper woodlands with a large grassland area oriented NW-SE roughly through the middle of the project area.

The project was conducted in two main phases, done roughly in parallel. A pilot harvest of a range of vegetation density classes and conditions was conducted on approximately 100 acres of pinyon-juniper woodlands. Seventy-five acres in 7 different cut blocks were analyzed in detail. As part of that work, a time and motion analysis was conducted on the harvest operations and a monitoring program documenting pre-treatment and post-treatment conditions was done. At roughly the same time, GIS data for the overall project area was collected and prepared, trial growth and yield models were constructed and the entire project area was mapped into vegetation types based upon species, stocking density and site productivity classes. The vegetation type maps were digitized and compiled into a GIS file which included roads and infrastructure, riparian features, topography, sensitive habitats and ownership. The resultant file was uploaded into OPTIONS, DRSNW's spatial, computer-based strategic planning analysis model. Modeling scenario(s) were developed for vegetation treatment regimes based on the results of the pilot harvest project, the trial yield tables and silvicultural treatment strategies for harvest and management. A general restriction on harvesting for 10% of the area of each individual polygon for sensitive cultural and historic sites was applied based on input from the local Prescott National Forest Archaeologist. An additional allowance of 2% for unoperable areas including steeper slopes and small, unmapped riparian areas and erosion cuts was also applied. The 2% reduction was based on analysis of the project GIS files.

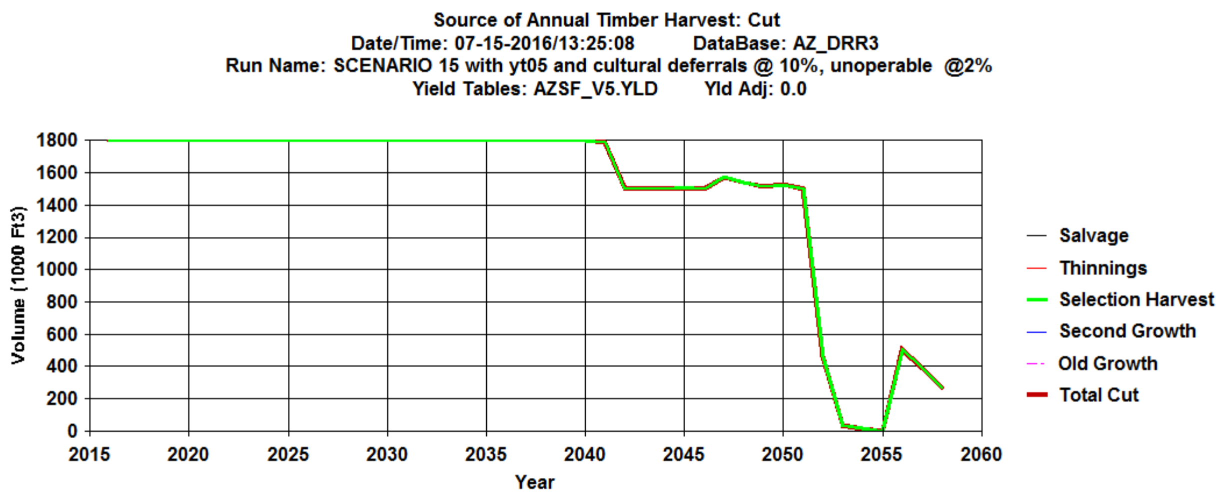
Since there were no inventory data available for the savannah woodlands vegetation types in the study area, the necessary vegetation descriptive data for each vegetation polygon was filled in based on the assignment of species, stand density class and site class from the vegetation typing work, growth and yield model predictions based on the typing and the results of vegetation inventory field sampling conducted as part of locating and monitoring the harvest trials. The yield tables forecast solid wood volumes in ft3/acre.

It should be noted that a more precise vegetation inventory should be conducted as well as further studies on the relationship between solid wood estimates and recoverable biomass volumes before any significant level of investment is made based on utilization of fiber/biomass in Arizona's pinyon-juniper woodlands.

Project Results

If it is desired to completely treat the pilot area within a period of 25 years, the estimated harvest level required to do that is 1.8 million ft3/year or about 38,900 BDT/year in yield table terms. Expanding this using the ratio of 2.8 for juniper (juniper-dominated stand contribute 75% of harvest volumes) and 1.3 for pinyon pine (pinyon-dominated stands contribute 25% of harvest volumes) indicates an average annual harvest rate of 97,100 green tons/year of biomass would be required to treat all pinyon-juniper vegetation types within the project area within a 25-year time span. Figure 2 depicts the harvest profile for this scenario.

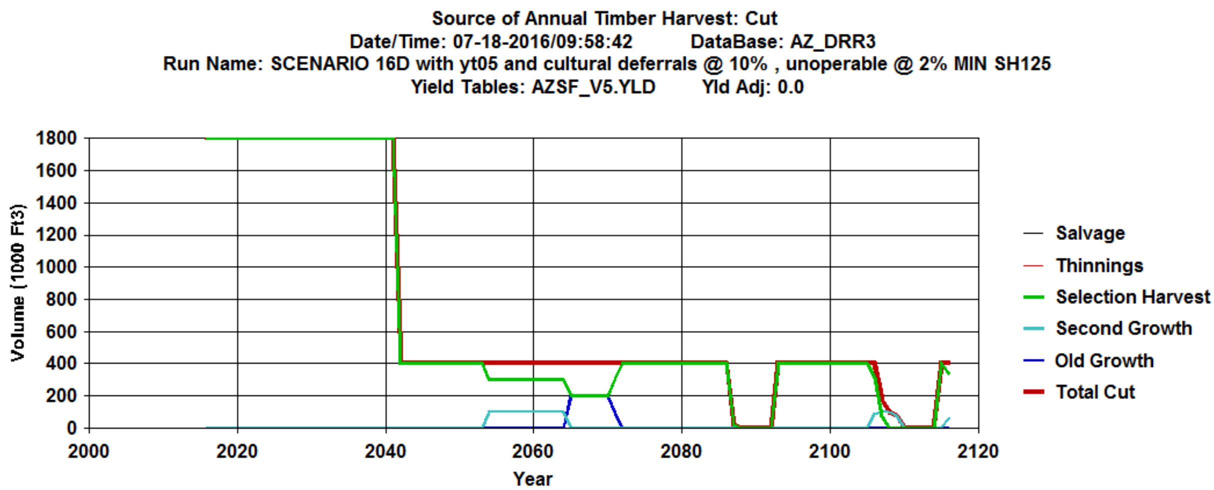
Figure 2. Harvest Profile for Scenario 15 – treat entire landscape within 25 years (by 2041) assuming no re-colonization of treated areas.



The above estimates are based on the implementation of a post-harvest fire regime which is assumed to successfully prevent the re-colonization of the treated acres. Since most such treatment programs are not 100% successful, there will be requirements for re-treatment of a percentage of the landbase over time. Note that there is a significant level of harvesting being carried on for the next 10+ years to complete the treatment across all feasible sites. However, increasing the harvest level to ensure those volumes are captured within the first 25 years is somewhat difficult due to the uneven distribution of ages, site classes and species mixes across the project area. Considering that the inventory is largely based on office typing and yield table estimates, in the absence of actual field data, it was not deemed useful to try to get an exact fit of harvest levels within 25 years. In this scenario the target harvest levels were left at the 1,800,000 ft3/year level for the duration of the run. The drop in harvest level following 2041 reflects the fact that the landbase can no longer support that level of harvest/treatment.

To gain an initial understanding of the possible effects of re-colonization by juniper and pinyon, several scenarios were developed and tested where 30% - 50% of the initial treatment areas were re-colonized by the original treated species and density class over a 10-year to 15-year period and 50% -70% of each treated stand was assumed to stay in grasslands. Each time a stand was retreated we reduced the area available to juniper regen by 50% and reduced the area re-colonized by pinyon by 70% -assuming pinyon would regenerate 30% of the treated area. This strategy assumes that a fire management regime is in place and being implemented and is slowly preventing the unwanted pinyon and juniper regeneration to occur. It appears based on these analyses that a repeat biomass harvest level after the first 25 years of treatment on the order of 400,000 ft3/year on a long-term basis would likely be required under the above scenario assumptions. Figure 3 below depicts the harvest profile for such a likely scenario.

Figure 3. Harvest Profile for Scenario 16D – assumes that 30% - 50% of treated areas will be re-colonized and will need to be re-treated over time.



In this scenario, the harvest levels going forward beyond 2041 were deliberately reduced. The dramatic drop in harvest following 2041 was driven by the desire to spread out the recurring on-going harvest on a more evenflow basis. Scenarios with totally uncontrolled harvest levels beyond 2041 created a very uneven harvest flow with short periods of high harvest levels followed by longer periods of little or no harvest opportunities. It was felt that it would be difficult to maintain the desired watershed conditions and processing facilities under such scenarios.

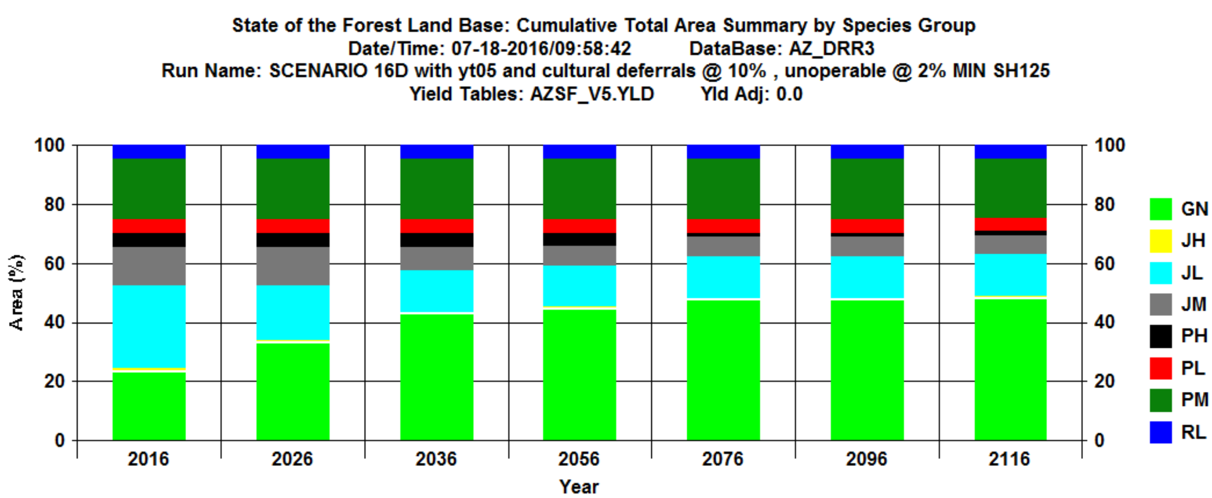
There are 8 main vegetation types within the project area. In the following graphs in this report the following species codes are being used:
GN – Grasslands; RL – Riparian zones (willow, Arizona walnut, sycamore, cottonwood)
JH – Juniper with high stocking levels; JM – Juniper with medium stocking levels;
JL – Juniper with low stocking levels;
PH – Pinyon and PJ with high stocking levels; PM – Pinyon and PJ with medium stocking levels;
PL – Pinyon and PJ with low stocking levels.

Obviously there are a number of assumptions which affect the re-treatment requirements. These include assumptions about the quickness with which juniper and pinyon can re-colonize treated areas, early growth rates of these trees, typical stocking levels which would be achieved within the next 20-30 years and the point at which these stands would be re-treatable from a cost of treatment and a treatment gain point of view as well as considerations for the resulting post-treatment desired vegetation conditions (shade and habitat). Keep in mind that 12% of every polygon is restricted from harvest to account for the presence of cultural artifacts as well as unoperable areas. So in these scenarios there will not be large woodland/savannah areas devoid of trees.

The regeneration assumptions for the above scenarios are that over 10 years following treatment, 50% of the juniper-dominated treated areas will become re-colonized with juniper and over a period of 15 years up to 30% of pinyon-dominated stands will be re-colonized by pinyon and juniper. These areas will eventually need re-treatment. The retreatment of a previously thinned stand is controlled by the allowable sequencing time between repeat selection harvests. In these scenarios the repeat selection harvest interval was set at a minimum of 30 years; 10 years for regeneration to occur and another 20 years of growth required before the stand could re-enter the harvest queue. Selection harvest rules require the stand to obtain a minimum threshold merchantable solid wood volume of 125 ft3/acre, equivalent to 350 ft3 of biomass recovery based on pilot harvesting results. For low site juniper stands, this threshold can be achieved by stand age 60; for medium site juniper stands, the threshold can be reached by stand age 40 and for good site juniper stands, the threshold is achievable by stand age 35.

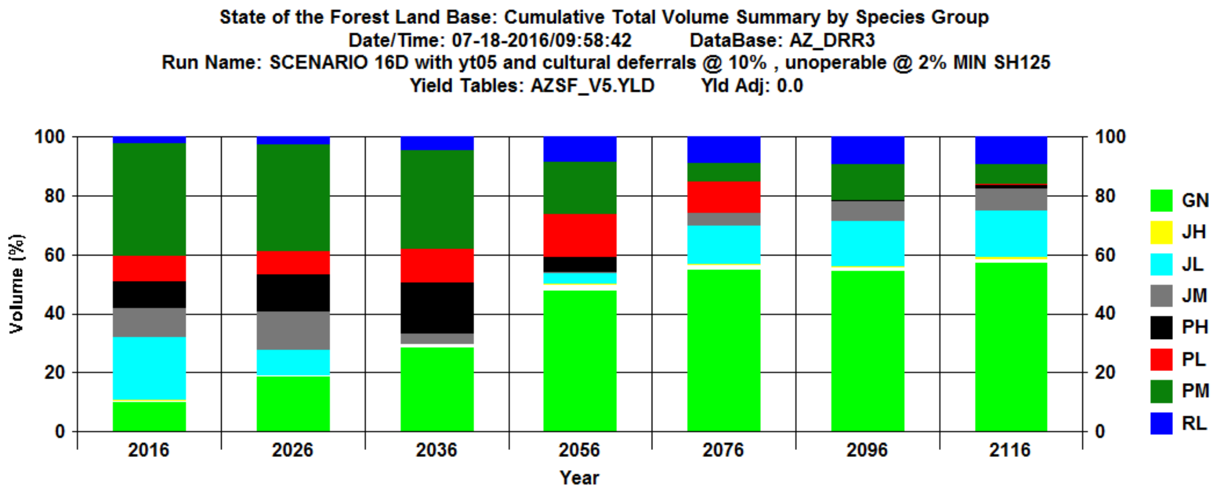
When the stands are re-treated (in 35-60 years depending on site and stocking), again 30% - 50% of the treated areas will be re-colonized over time. Thus over time the pinyon-juniper woodlands will return to a grassland savannah with over half of the landscape in grass at the end of 100 years, and with the remainder in scattered and clumped juniper and pinyon-juniper similar to historic conditions. Figure 4 illustrates the distribution of the vegetation types over time across the project area.

Figure 4. Distribution of Primary Woodland Species by Area over time using Scenario 16D.



The above chart illustrates the changes in distribution of area by species. The following chart depicts the change in distribution of volumes over time by species. What is important to note is the reduction in juniper and pinyon-juniper volumes over time.

Figure 5. Distribution of Woodland Species by Volume over time using Scenario 16D.



In the above graphics J= juniper dominated stands and P=P and PJ stands. Thus PH = P and PJ stands of high density, PM = P and PJ stands of medium density and PL = P and PJ stands of low density.

Discussion of fiber supply analyses

General Silviculture

There are 8 main vegetation types within the project area. In the graphs in this report the following species codes are being used:
GN – Grasslands; RL – Riparian zones (willow, Arizona walnut, sycamore, cottonwood)
JH – Juniper with high stocking levels; JM – Juniper with medium stocking levels;
JL – Juniper with low stocking levels;
PH – Pinyon and PJ with high stocking levels; PM – Pinyon and PJ with medium stocking levels;
PL – Pinyon and PJ with low stocking levels.

For each of the juniper and pinyon vegetation classes, a harvest prescription and a silvicultural management regime was developed. Due to the scarcity of actual inventory data for these vegetation types within the project area, these are relatively simple prescriptions and management regimes. However, we believe they are sufficient to serve the purpose of assessing potential treatment opportunities.

In summary, for each vegetation type there is a natural regeneration regime which follows a harvest treatment. In these scenarios all of the pinyon-juniper stands were managed using selection harvest methods, since most ranchers wanted a thin scatter of larger pinyon and juniper trees left for shade and habitat purposes. The selection harvest regime for juniper-dominated stands removed up to 99% of the juniper. The selection regime for pinyon-dominated stands removed up to 80% of the pinyon. Natural juniper regeneration was deemed to be established within 10 years on 50% of the treated area within each juniper-dominated stand and natural pinyon regeneration was deemed to be established within 15 years on 30% of the treated area within each pinyon-dominated stand.

In years following 2041, some patch-cut harvest treatments were allowed as part of second-round treatments in order to maintain stands within the desired stocking guidelines. This type of treatment could only be applied to a qualifying polygon and could only be used to keep the polygon's residual stocking within the desired guidelines. In scenario 16D, this treatment only occurred on 2,800 acres, primarily in PJ stands, over the next 75 years. As a result it had minimal effects on scenario results.

Volume Estimation Issues

Based on the analyses from this study, it is critically important to recognize that there is a large difference between traditional cruise volume estimates, yield table volume estimates and biomass recovery estimates for pinyon-juniper woodlands. This difference arises from the differences in normal forest and woodland field data collection procedures developed for commercial forests and what is actually harvested and recovered in a biomass-based harvesting program. Traditional field procedures are based on timber cruising techniques which are focused on providing good, reliable estimates of recoverable solid wood volumes which can be used to make traditional wood products while biomass-based operations are based on recovering the maximum volume of useable biomass material regardless of piece size. Thus there can be huge differences between what is forecast as recoverable from normal forest and woodland inventory data and what volumes may actually be recovered, especially in juniper-dominated woodland stands.

Based on the results from the harvest test areas, the ratio between cruise volume/solid wood estimates and biomass recovery volume estimates ranged from 2.8 to 7.7. In other words the estimated actual biomass recovery volumes in ft3 was between 2.8 and 7.7 times the solid volume in ft3 as estimated from traditional cruise procedures. The following table is from the results in the test harvests.

Table 1: Comparison of Recovered Biomass Volumes vs Cuise Volumes

Ranch	**Cross U**	**Cross U**	**K4**	**K4**	**OO**	**OO**	**OO**
Harvest Block	**2A**	**2B**	**1A**	**1B**	**1A**	**1B**	**2A**
Harvest Volumes (ccf)	60	150	85	405	110	150	150
Cruise Volumes (ccf)	8	41	11	142	39	40	22
Ratio	**7.5**	**3.7**	**7.7**	**2.8**	**2.8**	**3.7**	**6.8**

The above ratios are primarily influenced by the harvest proportion and form of juniper trees being harvested which are relatively small, often multi-stemmed and more bushy in structure as compared to the form of normal, commercial tree species. In the cases of the high ratios, the junipers were smaller and much more bushy, while in the lower ratio harvest blocks, trees were larger (older) and also included some harvest of pinyon pine.

Yield table estimates are developed based on the same data as cruise estimates. Therefore yield table estimates of solid wood volumes can also be expected to under predict recoverable biomass volumes in a similar fashion for juniper. This large difference obviously needs more validation work as it indicates a potentially large disconnect between traditional field inventory data and actual recoverable biomass volumes. These differences are financially significant in terms of both capital investments and operating costs.

Pinyon pine while not a large tree, does normally have a central bole and structure similar to larger species of pine. Based on past work, the difference between estimated total tree bole volumes using traditional forest inventory field procedures and recoverable biomass volume estimates for normal commercial tree species should be around 30%, resulting in a ratio of 1.3. We have used a 1.3 multiplier for the pinyon pine volumes in this analysis and a ratio of 2.8 for juniper.

In light of the fact that this was a small study, harvesting approximately 100 acres in total, we have chosen to use yield table volumes as they are traditionally predicted and then applying the above expansion factors to those volumes to derive biomass recovery estimates. In this way it is easy to adjust biomass recovery estimates by simply adjusting the biomass recovery to solid wood ratios without having to rerun complex analyses.

To restate, we have used straight yield table solid wood cubic volume forecasts to estimate annual harvest levels in ft3 and BDT, recognizing that we are significantly under-predicting biomass recovery volumes. We have used a ratio of 2.8 for calculating juniper green biomass volumes and a ratio of 1.3 for pinyon green biomass volumes to estimate green tons/acre of biomass harvest. Based on limited data collected during harvest, biomass moisture content was estimated at 30% at time of harvest.

It should be noted that a more precise vegetation inventory should be conducted as well as further studies on the relationship between solid wood estimates and recoverable biomass volumes before any significant level of investment is made based on utilization of fiber/biomass in Arizona's pinyon-juniper woodlands.

Initial Yield Tables

As part of being able to develop reasonable forecasts of biomass recovery volumes over time, it is necessary to be able to apply growth and yield estimates to existing inventories of pinyon-juniper vegetation types. Even with slow growth rates, planning a management strategy designed to maintain desired vegetation conditions which also addresses on-going habitat requirements for various environmental and cultural objectives, requires attention to stand dynamics over time. In this analyses, we utilized information on individual tree volumes for pinyon and juniper from the work done by

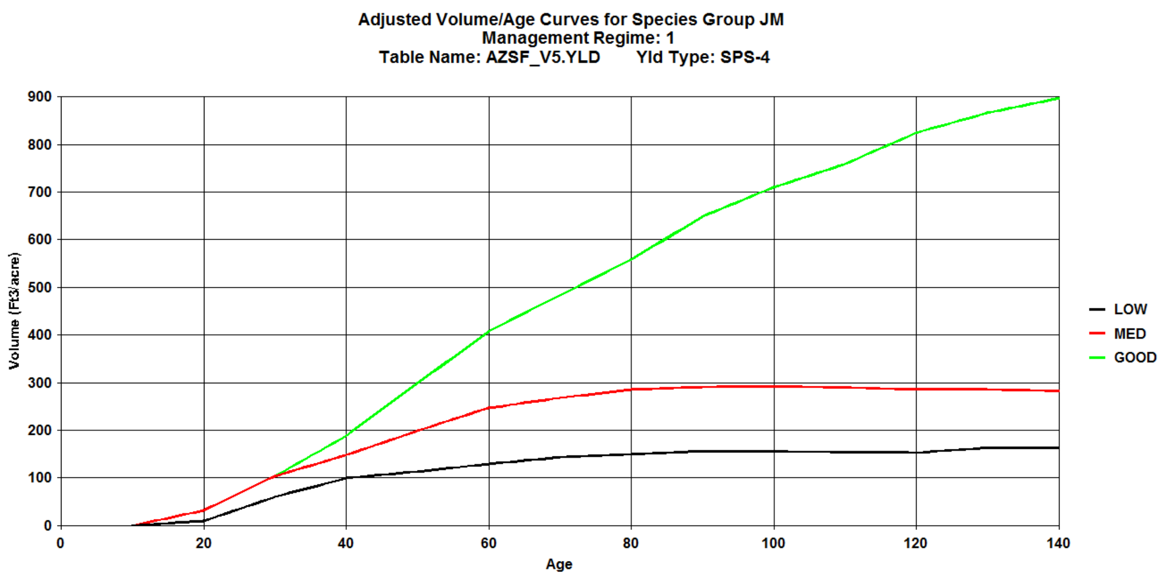
Chojnacky[1] and work done on growth and yield of pinyon-juniper woodlands done by Smith and Schuler.[2] From these data we developed on own yield table forecasts.

In addition, articles describing pilot biomass-based harvest testing of pinyon-juniper vegetation, such as one study in Nevada[3] provided some additional estimates on likely recoverable biomass volumes.

While none of the reviewed studies were in vegetation types exactly like that of the Upper Verde Watershed, we found the results useful for comparative purposes.

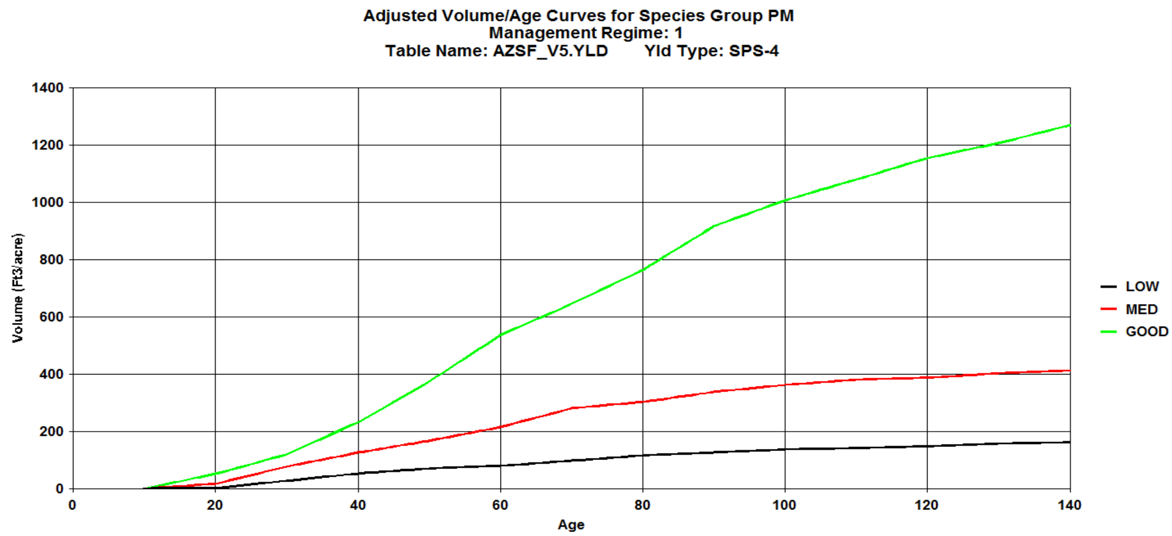
The following figures present the expected solid wood yields/acre for the pinyon-juniper woodlands vegetation types in the pilot area.

Figure 6. Solid Wood Yield Estimates for Medium-density Juniper-dominated Stands, Ft3/acre, by Site Class



[1] Juniper, Pinyon, Oak, and Mesquite Volume Equations for Arizona, David C. Chojnacky, USDA, Forest Service, Research Paper INT-391, May, 1988, 11 pages.
[2] Yields of Southwestern Pinyon-Juniper Woodlands, Frederick W. Smith and Thomas Schuler, West. J. of App. For. 3(3): pages 70-74, July 1988.
[3] Feedstock Security: The Million Acre Pinyon-Juniper Option in Eastern Nevada, presentation, Mike L. Baughman, International Biomass Conference and Expo, Orlando, FL., March 26, 2014.

Figure 7. Solid Wood Yield Estimates for Medium-density Pinyon and PJ Stands by Site Class



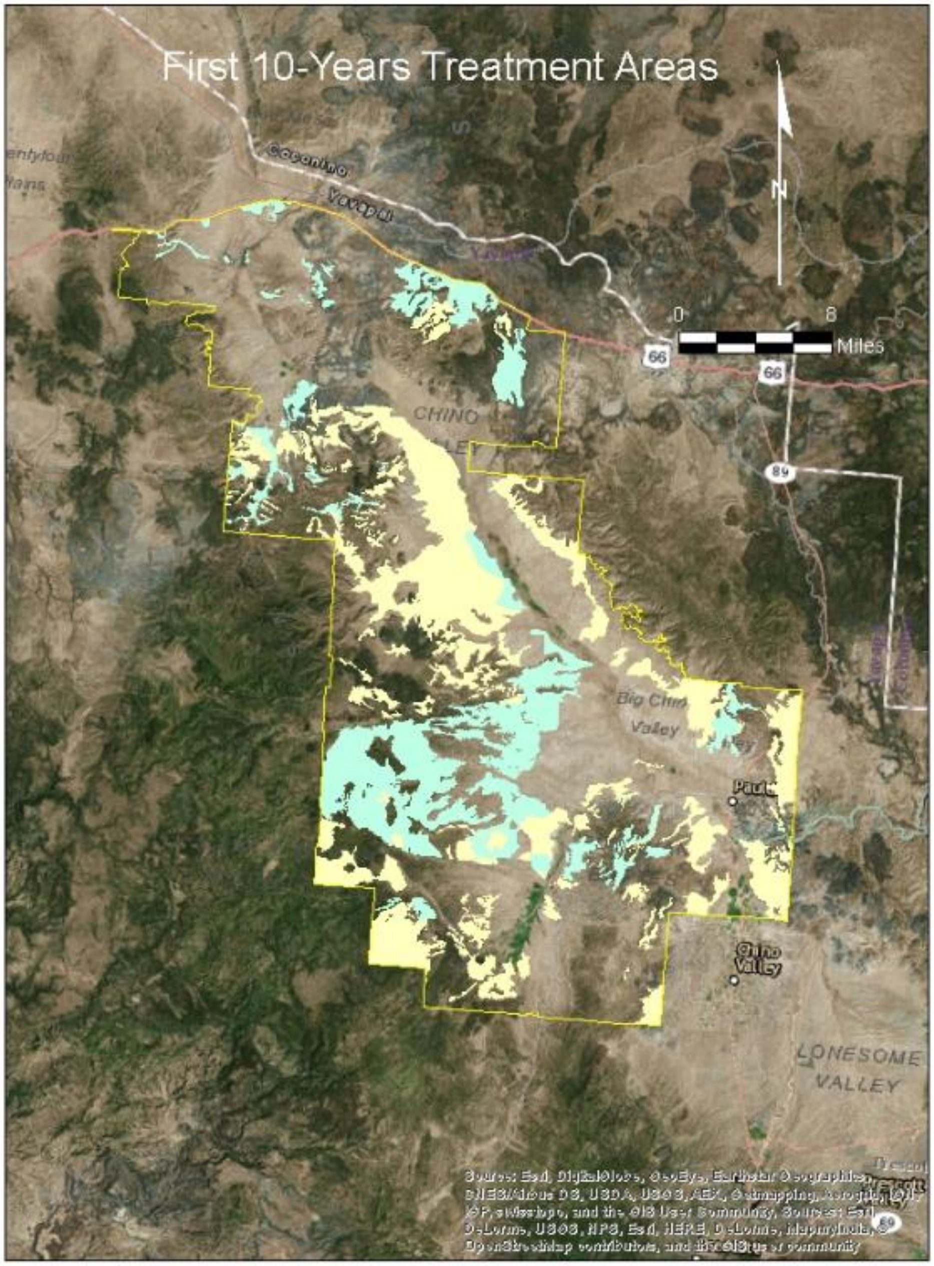
Medium-density was largely a subjective call by the vegetation typing crew. The stocking level was defined as 50% - 75% crown cover on 1:12,000 scale imagery. Site classes were defined as: Low = 0-22 ft at 50 years bhage, Medium = 23-27 ft at 50 years bhage and Good = 28+ft at 50 years bhage. For Low site we used SI=20, Medium we used SI=24 for juniper and SI=26 for pine and for good site we used SI=29 for both species.

As expected there was a significant difference between medium and good sites. However, little juniper occurred on good site in the study area (2,700 acres out of over 200,000 acres in juniper types) and less than 24,300 acres were in good site pinyon-juniper types out of 140,000 acres in pinyon-dominated types. We expect to fine tune these yield tables with data from additional project work in pinyon-juniper types as data becomes available.

Distribution of Harvests in First Five and Ten Years

The following figure depicts the locations of the harvest activities in the first five years and the first ten years as forecast by Scenario 16D above. Database was randomized, so no priority was given to well-roaded areas or to ownerships. If desired, the input database into OPTIONS can be sorted to meet many different requirements. However, over time the whole landbase will need to be treated. Hence for this initial analysis it is necessary to understand the landscape potentials vs establishing specific development priorities.

Figure 8. Modeled Location of harvests for First Ten Years (2016-2020 in yellow and 2021-2025 in blue), Scenario 16D



All harvesting was only selection cuts. Keep in mind that in all scenarios every polygon has 12% of the polygon area restricted from any kind of harvest. So there are scattered trees and clumps throughout the harvest areas.

Part 2 - Woodlands Thinning Demonstration Technical Report

Introduction

This project is the result of private/public coordinated action. It was brought about by the co-leadership of the Cross U, K4 and Double O ranches, the Upper Verde River Watershed Protection Coalition (UVRWPC), Ponsse North America, Inc. and Arizona State Forestry.

The intent of the project was to demonstrate that forestry machines can be used to successfully harvest excess woody biomass from the pinyon-juniper woodlands with productivity estimates established.

Harvested areas represent the larger Grassland Savannah Pre-investment Watershed Analysis (GSPWA) landscape with pinyon and juniper tree stocking on relatively low sites with corresponding short trees of low volume per tree. Harvesting operations were conducted in March and April of 2016.

Pilot Harvest Objectives

1. Develop and implement Best Management Practices.
2. Formulate and implement woodlands restoration strategies.
3. Conduct public outreach and support on-going efforts to utilize biomass.
4. Field-test a prototype shear attachment.
5. Estimate harvested biomass.
6. Document machine productivity and estimate harvesting and forwarding costs.
7. Monitor soil disturbance, vegetative prescription, erosion mitigation, and understory.
8. Outputs from harvest trials to be used in the GSPWA analyses and forecasts.

Methodology

Site Selection

The selection of demonstration sites was based on:

- sampling working conditions across a variety of ground and vegetative conditions;
- examples of geographical dispersion within the GSPWA area;
- integration with previous biomass harvest and analysis efforts; and,
- permission / support from ranchers.

Hand Crew

Approximately five acres on the Cross U ranch were thinned and chipped by an AZSF fire crew at an average production of approximately one acre per day and at a cost of $2200.00/acre. Harvested material included small and medium sized juniper trees and oak and Manzanita brush.

This operation yielded about one cord of firewood and 2560 cubic feet of chips. Cutting operations were kept to within 100 feet of existing roads where solid wood was concentrated and activity slash was chipped. A few larger junipers were felled downslope and away from the road. The main stem was left in place with all other material dragged to road side for chipping.

A leave tree/bush mark was flagged to designate harvest material. An advantage to the hand crew is that there is no limitation to the size of material to be cut either too small or too large as well as the ability to merchandise solid wood. The main disadvantage in using a hand crew is that all harvested material has to be drug by hand to the side of road. Limiting this distance to about a chain (66 ft.) is necessary in order to keep productivity reasonable.

The initial idea in having a hand crew working with the machine team was to open the face of the harvest tree so as to allow the shear access into the stems. This turned out to be unnecessary as the machine operator was able to make the first move into the stems above the lower restricting limbs. The machine team (harvester and forwarder) was complimented with the AZSF fire crews who cut material too large (>15" stem diameter) and too small (<2" stem diameter) to be sheared by the harvester as well as certain residual low horizontal lateral limbs which proved difficult to grapple and shear. All machine productivity information should be considered in light of this complimenting function by the hand crew.

In addition, the crews placed biomass harvest slash in erosion channels for silt dams and on machine lanes for the protection of soil and newly established understory plants. Merchandising solid wood from slash was also done by the hand crew on certain harvest units to estimate the proportion of recoverable solid wood, residual slash, and recovered biomass. Crews also collected post-harvest soil disturbance data.

Machine Team

Machine team selection was based on: fuel efficiency; rubber tired, low ground pressure; 30' extendable crane with 260 degree turning angle; and available technical support and experienced operators. On that basis a forwarder (Ponsse Buffalo King) with biomass grapple and (Ponsse Bear harvestor) equipped with a pendant rotational shear were selected. Ponsse provided experienced operators and corporate support. These operators provided mechanical know-how in maintaining their machines. This includes paying attention to the machine while operating to identify and correct any problems with the machine as needed. Examples with the prototype shear include correcting a loose wiring harness, correcting a hydraulic fitting leak, and correcting a hydraulic cylinder leak. Operators had their own company pickup truck with all necessary tools, equipment, parts, and supplies. Standard shipping accommodated the needs of the team for repair and maintenance items not locally available.

The corporate support from Ponsse North America, Inc. included development of the prototype shear and support and presence by senior management during the field work.

Operations

Operations on State Trust land included the determination of cultural sites and avoidance where specified. Land owner objectives provided the basis for silvicultural prescriptions which included identifying which trees to retain and what to do with harvested material and activity slash. Landings were identified for each harvest unit. Harvest lanes were established to maximize inter-lane distance and used in such a way so as to minimize cross-slope turns. Machines were cleaned after operations and before transport to the next ranch.

Silvicultural Prescriptions

Restoration strategies for the former grasslands, savannahs, and woodlands include the removal of excess woody biomass and the promotion of understory grasses and forbs. Retained woody biomass generally included pinyon pine and a few feature or shade junipers. Larger oak trees and all riparian species (sycamore, walnut) are retained as well. These levels of retained trees equate to approximately 5% - 25% of biomass volume depending on location and site specifics. Brush was typically removed. Silvicultural prescriptions were refined for each Harvest Unit (HU) and applied using the Designate–Harvest–Verify system[4]. This allows for the real-time integration between the prescription and the designation of harvest trees. Operator select requires species identification. General rules included the removal of juniper and the retention of pinyon pine. Exceptions to the rule were marked with flagging as leave tree juniper and cut tree pinyon pine. The majority of harvested material was concentrated at specified landings for drying and utilization or disposal burn. Some of this material was placed on site for erosion mitigation and micro site protection. Follow up broadcast burning is to be implemented as soon as practical.

Findings from Pilot Harvest Tests

1. Best Management Practices

Woodland harvesting BMP's focused on protecting soil, mitigating erosion, and promoting desired understory plant establishment and growth were developed. These identified practices predicated on the use of a low-impact wheeled machine team (harvester and forwarder) each configured with extendable cranes and pendant rotational attachments. Closure of machine lanes at the intersection with open activity / ranch roads will discourage future vehicle traffic on the lane. Placement of heavier limbs serves this purpose. Lighter organic material (slash) applied at a <6" depth to heavier impacted portions of machine travel lanes affords micro-site protection for the establishment of grasses and forbs.

[4] Designate-Harvest-Verify (DHV) is a silvicultural management system developed and pioneered by Rich Van Demark of Southwest Forestry Inc. for use in forest and woodland restoration programs.

2. Woodlands Restoration Strategies

Woodlands restoration strategies are based on land owner objectives and current vegetative conditions. A common straight-forward strategy on the pilot harvest test areas was to retain pinyon pine and remove the juniper and brush. Follow-up treatment of a broadcast burn of the treated area was a common strategy as well.

3. Public Outreach

Four demonstration days were hosted by the UVRWPC on three ranches with attendance from more than 80 people. Invited guests included local ranchers, civic leaders, land and resource management agencies, private industry, academics, environmentalists, and the press. This effort has led to development of a power point presentation and video which are available via the internet.

4. Ponsse Prototype Shear Attachment

A prototype shear attachment developed by Ponsse North America was tested for over 100 hours. Ponsse invested considerable time and effort in the design and fabrication necessary to integrate the mechanical, electronic, and hydraulic systems of a modified shear for use with Ponsse harvesting machines for this project. The Ponsse shear has two sets of bunching arms which were effective in the juniper being worked. Limitations included harvest of stems with a maximum stem size of >15" and difficulties in harvesting small (<2") supple stems. Neither of these limitations had a significant effect on results.

Operations were interrupted by blown o-rings, hydraulic fittings, and attachment cylinders, not an unusual situation with new, prototype equipment. All issues were quickly and satisfactorily resolved. Opening and closing speeds of the shear were fairly consistent regardless of stem size; five seconds close and three seconds open. The bunching arms allowed the shear to be pulled into the stem and vice versa – very useful in harvesting juniper. Having the cutting attachment pendant from the crane and being operated in a rotational manner was invaluable. These key features enabled the operator to maintain machine position and make numerous moves on one or more trees within the range of the crane (30 feet) in a 260 degree arc without moving the harvester.

Efficient harvesting techniques included first moves into many medium and large trees at mid crown slanting diagonally to the base. The crane with the pendant rotational attachment enabled this technique. While some limbs were lost in the swing of the cut tree from the cut to the bunching pile, the lost volumes were very low with the occasional limbs serving as ground cover.

5. Harvested Biomass

Harvested biomass was estimated by tracking loads forwarded to specified landing locations for each harvest unit. The forwarder payload space is 1000 cubic feet or 10 cunits (ccf). Loads were identified as slash (10 tons/load), whole tree (12 tons/load), and solid wood (15 tons/load). Imputed green biomass density values for each load type are 20, 24, and 30 pounds per cubic foot respectively on a payload space basis. Bone dry solid wood was pegged at 46 lbs/ft3[5] - Proportion of slash to solid wood ranged from 2:1-5:1. Project average was 1.4 loads of total harvested biomass per acre.

Systematic and unbiased post-harvest plots were located within six identified harvest units totaling 75 acres. In each 1/10 acre circular plot the number of stems by diameter and total tree height (interpolated from the stand) was recorded. These data were then used to estimate total stem volume in cubic feet of solid wood to a 1" diameter (Chojnacky et al, 1988). Calculated results show a weighted average of 404 Ft3/acre of solid wood biomass harvested with a range of from 152 to 528 Ft3/acre.

The following table compares the total estimated load volume to the total estimated cruise volume. The ratio reflects the estimated volume of forwarded loose whole tree biomass to the estimated cruise volume of solid wood to a 1" stem diameter.

Table 2. Comparison of Recovered Biomass Volumes vs Cuise Volumes

Ranch	**Cross U**	**Cross U**	**K4**	**K4**	**OO**	**OO**	**OO**
Harvest Block	**2A**	**2B**	**1A**	**1B**	**1A**	**1B**	**2A**
Harvest Volumes (ccf)	60	150	85	405	110	150	150
Cruise Volumes (ccf)	8	41	11	142	39	40	22
Ratio	**7.5**	**3.7**	**7.7**	**2.8**	**2.8**	**3.7**	**6.8**

Selected juniper trees were harvested, chipped, and measured to estimate pounds per cubic foot of green biomass (30% MC) for both trees and loose-packed chips (10% MC). These trees were selected from the K4 ranch Harvest Unit 1B and represent small (S), medium (M), and large (L) sized trees. The results are presented in the following table.

[5]The physical characteristics and utilization of major woodland tree species in Arizona. Barger, R.L. and Ffolliott, P.F., USDA, USFS, Rocky Mt. Forest and Range Experiment Station, RP RM-83., 1972. 80 pages.

Table 4. Comparison of Cruised Tree data to Chipped Volume and Weight (K4 Ranch)

CRUISED DATA						CHIPPED RESULTS			
Size	Stems	DRC	EDRC	HT	Volume	Weight	Volume	Wt/ft3	
S(tree#1)	1	5	13.7	15	6.5				
	2	7							
	1	8							
S(tree#2)	1	8	12.8	15	5.4				
	1	10							
Sum of both S trees						1040	92	11.3	
M(tree#3)	1	18		22	21.9	1760	132	13.3	
L(Tree#4)	2	6							
	1	12							
	1	17	22.5	21	27.0	2560	218	11.7	
L(Tree#5)	1	7							
	2	12	18.4	22	20.0	2380	150	15.9	

Biomass moisture content is estimated to be 30% for harvested material.

Additional samples of juniper from HU2 and oak from HU3 were collected and chipped on the Cross U ranch approximately three months after harvest. Those sample results show that loosely packed juniper chips weigh on average 14 pounds per cubic foot at 10% mc. and oak chips weigh 19 pounds per cubic foot at 10% mc. Again an approximate 30% reduction in volume was achieved by chipping the raw material.

The Yavapai County Vermeer HG 1000 high-speed grinder was used on the Double O ranch demonstration site to manufacture <2” particle size from HU1A and HU1B. The grinder operated for approximately 12 hrs. and converted a landing pile of whole tree juniper biomass of approximately 260 ccf on a payload volume basis, harvested from 20 acres. Volume was reduced by 30%.

If a ft3 of chips weighs 14 lbs at 10%MC, then with a 30% reduction in occupied volume implies 1000 ft3/acre x 14 = 14,000 lbs = 7 BDT/acre was harvested on a per acre basis. This fits reasonably well with our yield table forecasts with respect to weight/acre for stands of this size of medium-stocked juniper.

6. Machine Productivity and Operating Costs

Team productivity for the project averaged 1.6 hours per forwarder load. The Machine Production Summary presents this information for each harvest unit. Machine productivity was determined by a number of factors with the harvester being influenced to a higher degree than the forwarder.
The Harvest Unit Summary provides information for each harvest unit with influencing factors relevant to productivity.

The machine team was well matched with the harvester averaging from on-half to one acre per hour and the forwarder averaging closer to an acre an hour. The articulated design of the carrier on both machines (8 wheel drive in 4 x 4 articulated design) enabled safe and effective movement across adverse slope positions; both positive and negative. The rubber tired and designed weight distribution of the machines provided low soil impact. The crane enabled the operator to maintain machine position and make numerous moves on one or more trees within the range of the crane (30 feet) in a 260 degree arc without moving the harvester. This same crane feature enabled the forwarder to use the same lanes as the harvester.

Harvest Operations

The harvester was influenced most by the character of the harvest tree. Studies of time and motion from direct observation and from the review of video coverage, show this relationship at the Harvest Unit or stand level as well as along the harvest lane. The Summary of Harvester Time and Motion (see Appendix Table A1) provides detail on average seconds per tree. A greater number of smaller stems took longer to harvest than fewer larger stems. Trees of multi-stem character took more moves the larger the tree. Small trees required 1-2 moves; medium-sized trees 2-4 moves; large trees required 4+ moves. Each move includes the approach into the tree, the shearing of the tree, grappling and bunching the material in a pile. Total elapsed time for this sequence averaged approximately 13 seconds for single stem small trees and 41 seconds for multi-stem medium and large trees. The approach into the tree ranged from 1-7 seconds; the shear took 5 seconds; grappling was a matter of seconds and was often combined with the approach into a second tree; and swinging the material to a pile ranged from 1-7 seconds. Machine advance times ranged from 1-16 seconds and represented 5-30% of total harvest time. Multi stem trees with numerous small stems slowed production considerably. As much as a 50% reduction in productivity was observed in stands with numerous small, multi-stemmed trees.

A second factor that influenced harvester productivity was the amount and arrangement of residual trees. Operator select was based on the silvicultural prescription for each harvest unit. Thinning away from keep trees, minimizing damage to them, and finding suitable bunching pile locations all contributed to the time and effort needed to thin within an existing stand.

A third factor that influenced overall productivity was the design and use of lanes. Landings were placed along existing ranch roads which were also used as primary forwarder lanes when possible. In certain areas at the toe of the slope, harvester ghost trails were used effectively to reduce forwarder impact and concentrate material. Improved layout incorporated lanes parallel with slight drainages and minimal upper slope turns. This was done to eliminate soil disturbance caused by the upper slope turn and required the harvester to back down the lane further reducing productivity.

Placement of cut material as a preparation to cross a slight drainage (creation of a slash mat / silt dam) and the opportune placement of cut material in drainages and at head cuts reduced the rate of harvest as well.

The forwarder was influenced most by the character of the material to be loaded. The harvester operator did an excellent job concentrating or bunching material in "handfuls" for the forwarder. Whole tree and slash typically loaded faster than solid wood because of the relatively short piece length. As expected, smaller scattered pieces took longer than larger concentrated pieces. Split loads of solid wood and slash took longer to load and unload. Measured cycle times in minutes ranged from:
28 minutes per turn (slash) broken down as: return 4; load 18; forward 2; and unload 4.
55 minutes per turn (mixed) broken down as: return 5; load 35; forward 5; and unload 10.
Number of moves per load ranged from 35 to 60.

The Summary of Forwarder Time and Motion (see Appendix Table A2) provides this detail and includes advance times as part of loading time. Average forwarding distance for the harvest units ranged from 200 feet to 1000 feet. Close-out of lanes by scattering light slash from the last turn of the forwarder was tested on selected lanes. Opportune placement of activity slash from the forwarder was also accomplished at selected drainage crossings. These erosion control measures reduced the production rate of the forwarder as well.

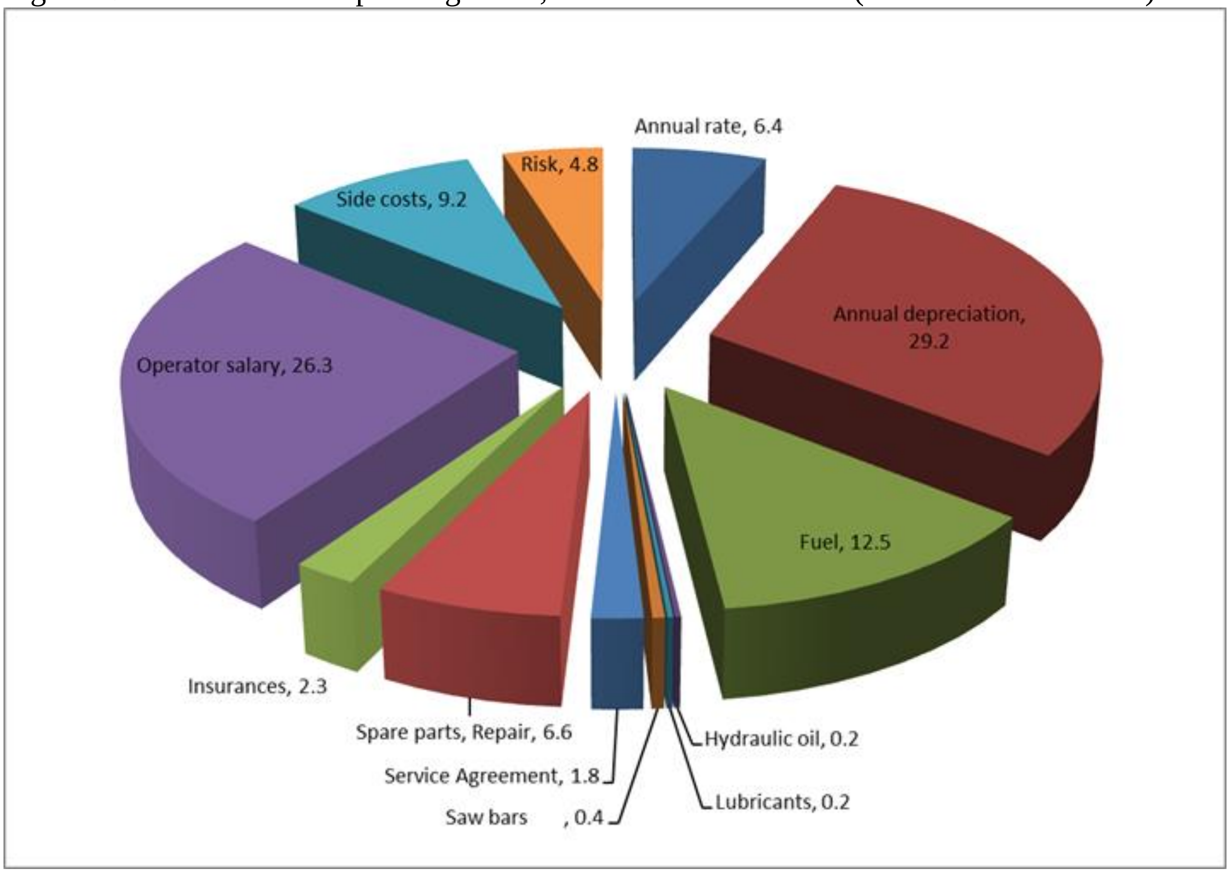
In addition to the productivity influences identified for each machine, there are other factors worth noting. These include transportation costs to harvest sites, value and quality of the machines, down time, operator experience and level of talent, predilection for the abuse or care of the machine, and product support. The productivity estimates from the demonstration project represent a small sample covering about one month of harvesting and forwarding work.

The results show the harvester produced 9 tons/hour and the forwarder transported 15 tons/hour on average. The low end of the range in harvesting productivity included estimates of 5 tons per hour influenced primarily by individual trees with numerous stems (6+) of small diameter and corresponding low volume. Time and motion studies on the Double O ranch showed this with numerous moves of the harvester being necessary to cut a single tree. With each move being approximately 10 seconds, some trees took longer than 10 moves! Other influencing factors on this ranch include moderate slopes with rock benches and moderate levels of keep trees. The other end of the productivity range (>10 tons per hour) was studied on the K4 ranch which showed 3-5 moves per tree characterized by a few stems of larger diameter and corresponding greater volume. Slight slopes with few residual trees characterized the harvest units. Forwarder productivity was influenced mostly by loading time which is determined by the number of moves necessary to load the basket. With open lanes and material concentrated along the lane, the loading took on average 15 to 20 minutes per basket. One load was put together in as little as six minutes (as done on the K4 by a highly skilled operator in a big pile of wood). Longer loading times (30+ minutes) were influenced by merchandised slash and solid wood arranged as numerous small piles (as measured on the Cross U). It simply took the operator more moves to grapple and load the material. Split loads of slash and solid wood were forwarded together in order to reduce the number of passes on the lane. This technique further slowed the loading as well as the unload time.

Estimated operating costs were less than $ 20/ton to harvest and forward and are based on good used machines as were run on the demonstration project. This includes the prototype shear attachment on the harvester. A used forwarder of the quality used on the demonstration project will cost about $225,000 and a similar used harvester will cost about $275,000. These estimated machine prices are used along with the following information to estimate operating costs. Available operating hours per year is 1800 (225 days at 8 hrs./day) with 90% expected operating hours or 1620 productive hours per year. Machine costs include: operator salary; annual depreciation; fuel; side costs (operator fringe benefits including insurance, vacation, truck, etc.); annual loan interest rate; spare parts and repair; risk (reinvestment); insurance; fixed operating costs; knives for the harvester; lubricants; and hydraulic oil.

The following pie chart represents the cost breakdown in % for a $275,000 harvester producing 9 tons per hour.

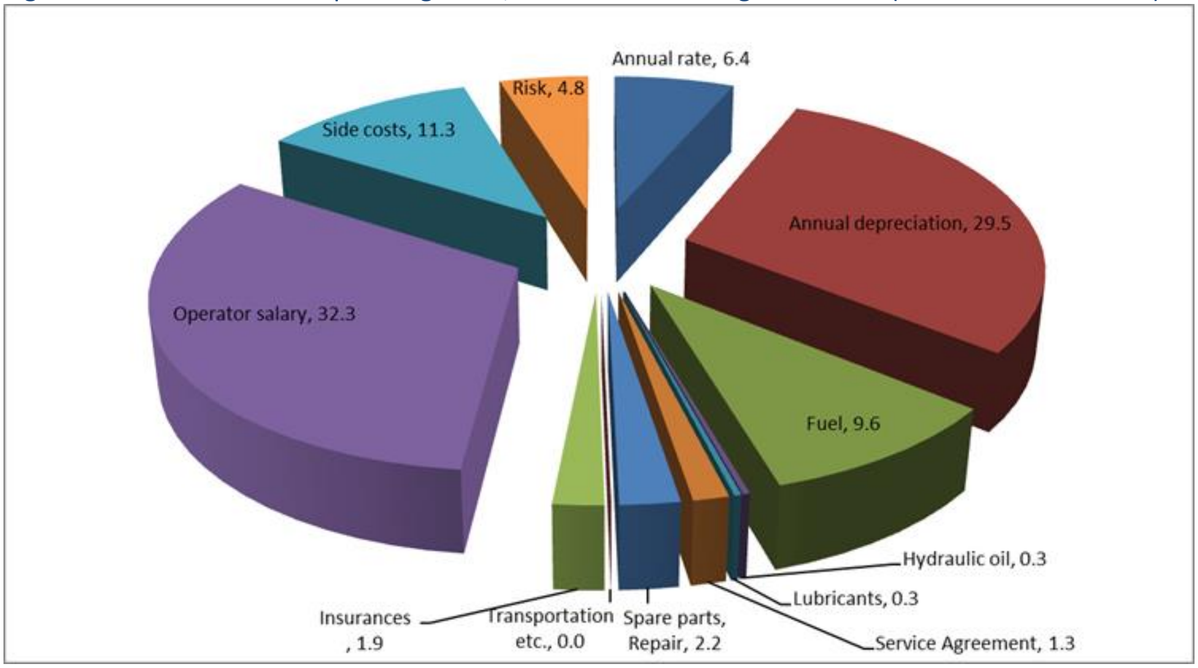
Figure 9. Distribution of Operating Costs, Ponsse Bear Harvester (Good Used Condition)[6]



The following pie chart represents the cost breakdown for a $225,000 forwarder producing 15 tons/hour.

[6] These data supplied by Ponsse North America

Figure 10. Distribution of Operating Costs, Ponsse Buffalo King Forwarder (Good Used Condition)[7]



Corresponding hourly cost to operate each machine is less than $100 with the harvester being slightly more expensive/hour than the forwarder. A $200/hour team cost without profit margin and transportation would correspond to a treatment cost of from $200 - $400/acre based on the project results.

7. Monitoring Program

Post-Harvest Verification

A number of systematic and unbiased 1/10 acre circular post-harvest plots were installed across the harvest units. Inter plot distance was typically three chains or approximately 200 feet. Data on harvest and residual trees was collected. Summary information provided by the post-harvest monitoring plots indicates that juniper trees were harvested as designated and trees were retained as per the silivicultural prescription for the harvest unit. Some plots showed that juniper regeneration sized trees were not cut by the harvester and that some poor form and low vigor pinyon pine trees were also not marked for cut and thus were not cut.

A copy of the data from the recon and post-harvesting monitoring plots is available upon request.

[7] These data supplied by Ponsse North America

Soil Disturbance

Soil disturbance surveys were conducted using a grid of 50 feet between lines and 20 feet along lines (Adopted from McMahon, 1995). Information was collected at each sample point and summarized using the following soil disturbance categories:

1 – Undisturbed;
2 – Track with litter;
3 – Track with mineral soil;
4 – Dragged;
5 – Deeply disturbed;
6 – Stump; and,
7 – Live tree or bush.

The results are as follows:

Ranch	Disturbance Category	1	2	3	4	5	6	7	Total
K4	# feet in category	818	137	122	4	4	23	56	1164
	% of sample	70	12	10	.5	.5	2	5	
OO	# feet in category	428	82	102	0	5	17	19	653
	% of sample	66	13	16	0	1	2	2	

Erosion Mitigation / Understory Plant Establishment

Erosion mitigation and micro-site protection was implemented over much of the harvest units. Follow up monitoring should be done after the summer monsoon season to document the effectiveness of these measures. Comparisons may be made between travel lanes with and without placed organic material as well as drainage locations with and without silt dams. Informal monitoring on the Cross U ranch indicates understory plant establishment and regrowth has already been initiated after harvest (2 months) and before monsoon rains.

References

Baughman ,Mike L. 2014. Feedstock Security: The Million Acre Pinyon-Juniper Option in Eastern Nevada, presentation, International Biomass Conference and Expo, Orlando, FL., March 26, 2014.

Chojnacky, D. 1988. Juniper, pinyon, oak, and mesquite volume equations for Arizona. USDA Forest Service Intermountain Research Station

McMahon, S. 1995. Accuracy of two ground survey methods for assessing site disturbance. Journal of Forest Engineering, 6(2):27-33.

Smith, Frederick and Thomas Schuler. 1988. Yields of Southwestern Pinyon-Juniper Woodlands West. J. of App. For. 3(3): pages 70-74.

Summary

The pilot project area in the Upper Verde River Watershed encompassed 492,800 acres, of which approximately 100,000 acres were in grasslands and 340,000 acres were in pinyon-juniper savannah vegetation types (200,000 acres in juniper-dominated stands and 140,000 acres in pinyon-dominated stands). A biomass harvest level of 1.8 million ft^3/year, equivalent to an estimated 97,100 green tons/year, could be supported for 25 years within the pilot project area. Following that initial harvest across the operable landbase, the project area could support an on-going harvest level of 400,000 ft^3/year (21,600 GT/year) for at least an additional 75 years. While these estimates are considered conservative but reasonable, considering the limited inventory data available, the lack of validated yield tables, and the limited actual biomass harvest data available, these estimates must be considered as pre-investment only.

Approximately 100 acres were harvested for biomass using Ponsse equipment provided by Ponsse North America. Based on these results, it is feasible to expect to harvest biomass and place it at roadside at a rate of treating ½ acre to 1 acre per hour at a baseline cost which covers all operating costs, but no allowance for profit and risk, of $200/hour for a machine team of a harvester and a forwarder. This equates to a cost of $200 – $400/acre, assuming the test harvest blocks are representative of the general range of conditions across the pilot project area. The Ponsse equipment was outstanding in flexibility and capability with respect to harvesting the juniper and pinyon vegetation types efficiently and with minimal ground disturbance.

Based on this pilot analysis, subject to the limits of applicability of the pilot area to the rest of Arizona's pinyon-juniper savannahs, it appears that it is feasible to harvest biomass and restore pinyon-juniper watersheds within current accepted guidelines of stand treatments and within normal funding levels associated with landscape recovery using equipment with capabilities and costs similar to that of the Ponsee equipment used in this project.

Harvesting PJ stands with equipment configured like the Ponsse equipment used in this pilot (wheeled, boom-equipped sheer head) resulted in minimal ground disturbance. As a result, erosion effects of harvesting is expected to be minimal and recovery of understory vegetation should be well distributed across the harvest areas.

Recommended next steps include:

1. improve the available inventory information for Arizona's PJ woodland types
2. in anticipation of being able to harvest and forward PJ biomass within reasonable funding/cost limits, begin investigating potential market opportunities for PJ biomass as commercial markets will be essential components for successful long-term expansion of this restoration work and achievement of Arizona's management goals for the savannah woodlands in the State.

Appendix

Figure 11. Cross-U Ranch Harvest Areas

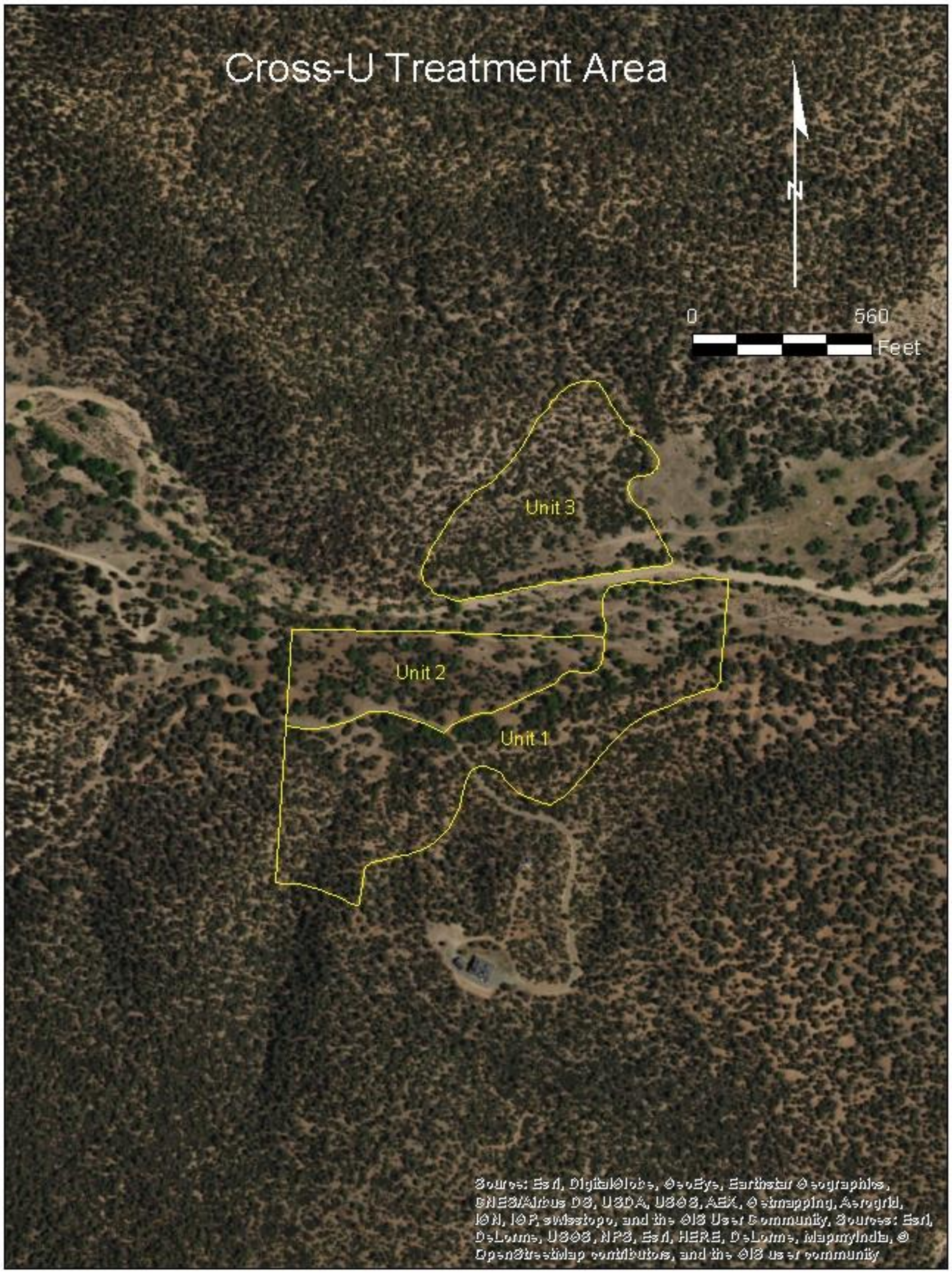


Figure 12. Double - O Ranch Harvest Areas.

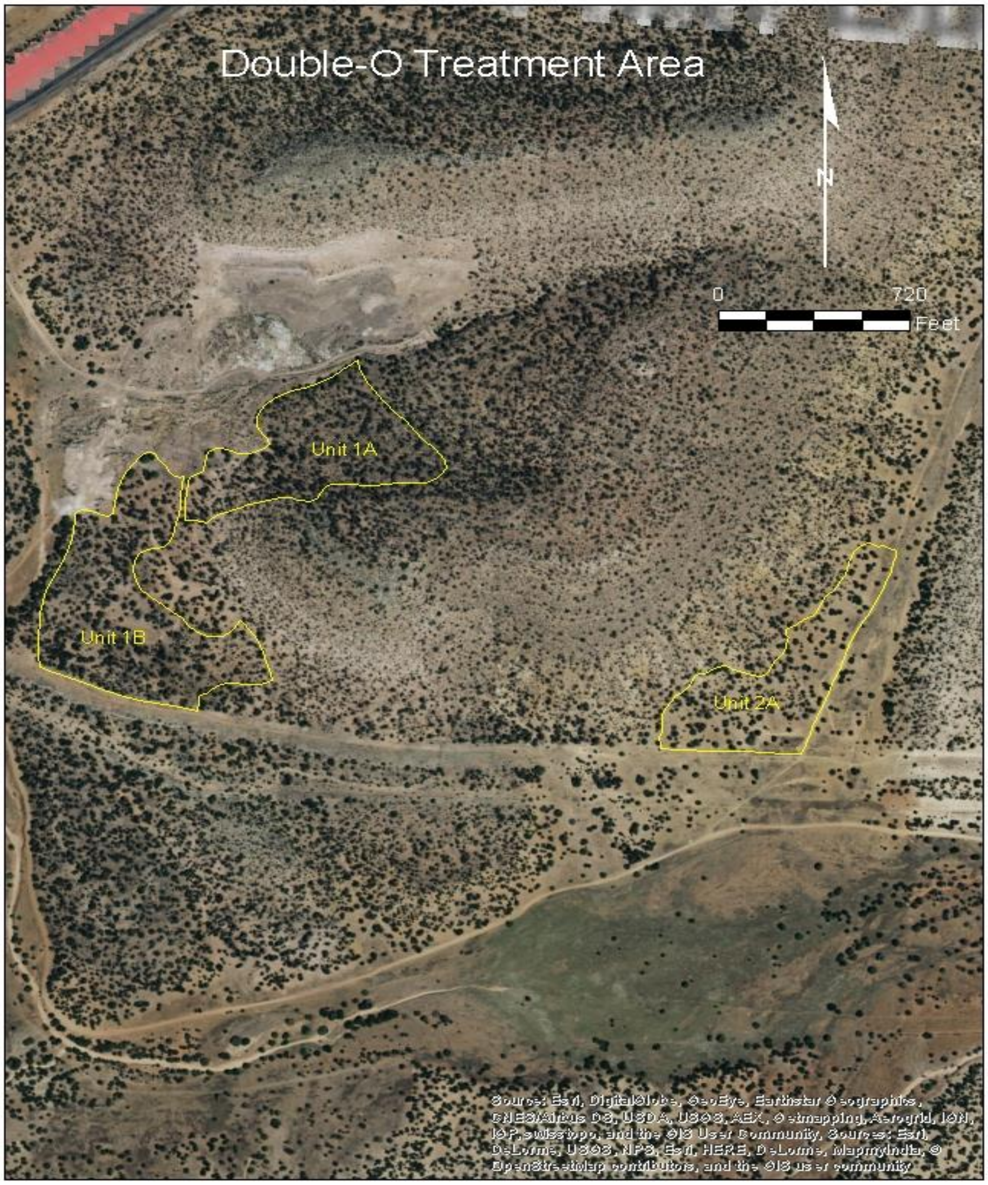


Figure 13. K4 Ranch Harvest Areas

Table A1. Summary of Harvester Time (seconds) and Motion

Ranch & HU	Cruise Data										
	Tree#	# Stems	DRC		Move	Shear	Grapl.	Pile	Adv.	Total	Sec/ Tree
OO	1	3	6		5	5	2	3			
1A		1	8		3	5	3	2			
(1/10 acre)				4	5		4		41		
	2	2	6		4	5	2	3			
		2	8		5	5		2			
					6	5	1	4	4	42	
	3	1	6		4	5		3			
		1	8		6	5		5			
		2	10		4	5		2			
					4	5		4		52	
	4	3	8		4	5	4	3			
		1	10		5	5	3	4			
					4	5		6	3	48	
	5	3	8		6	5		4			
		1	6		4	5	2	3		29	44
OO	1	3	4		4	5		4			
1B		2	6		3	5	2	3			
(1/10 acre)				4	5	1	3		39		
	2	3	6		4	5		2	2		
		1	8		3	5		4		23	
	3	2	8		5	5	1	3			
		2	6		4	5	2	5	4	30	
	4	2	4		4	5	2	3			
		2	6		5	5		4			
		1	8		3	5	1	3		40	
	5	2	6		4	5		4			
		1	4		3		3	3	5	21	
	6	2	8		5	5		5			
		2	6		4	5		4			
		1	10		6	5		4		38	34

Table A1. Summary of Harvester Time (seconds) and Motion(continued)

Ranch		Cruise									
HU	Tr#	# St	DRC		Move	Shear	Grap.	Pile	Adv.	Total	Sec/Tr
+U	1	1	8		2	5		1		8	
2B	2	1	8		2	5	1	5	5	13	
	3	1	8		5	5		3		13	
	4	1	6		4	5					
	5	1	6		1	5		4	7	19	
	6	2	6		3	5		3			
					2	5			1	18	
	7	3	6		7	5		3			
					2	5		4			
					7	5		3	1	48	
	8	1	8		3	5		4	5	12	
	9	1	6		2	5					
	10	1	6		4	5		5		21	
	11	1	6		3	5		5	10	13	
	12	1	8		3	5		3		11	
	13	2	6		3	5		3	12	11	
	14	2	6		2	5		3	3	10	
	15	3	6		2	5					
					1	5		3		16	
	16	1	8		5	5		4		14	
	17	1	8		4	5		5	1	14	
	18	1	6		2	5		2	6	9	
	19	1	8		2	5					
	20	1	8		3	5		2	2	17	
	21	2	6		4	5		4		13	
	22	1	8		2	5		1		8	
	23	1	6		5	5		2	`	12	15*

* Total average time per tree includes advance time. Small mostly single stem trees averaged 11 sec/tree and the medium sized multi-stem trees took 48 seconds.

Table A1. Summary of Harvester Time (seconds) and Motion (continued)

Ranch		Cruise									
HU	Tr#	# St	DRC		Move	Shear	Grap.	Pile	Adv.	Total	Sec/Tr
+U	1	1	8		3	5		3		11	
3A	2	2	6		3	5		2	2	11	
	3	1	8		2	5		2		9	
	4	1	8		3	5		1	3	9	
	5	2	6		2	5					
	6	1	8		2	5		3		17	
	7	2	6		2	5		1	2	8	
	8	1	10		3	5		3	4	11	
	9	1	6		1	5		2	4	8	
	10	2	6		3	5		3		11	
	11	1	6		1	5		2	3	8	
	12	2	8		4	5		3		11	
	13	1	8		3	5		4			
		2	6		5	5		2			
					5	5		3		43	
	14	1	10		4	5		4	8	13	
	15	2	8		6	5		3		14	
	16	1	12		5	5		2			
		1	10		2	5		2	6	21	
	17	1	10		4	5		4		13	
	18	1	12		6	5		5			
					4	5		4	5	29	
	19	BRUSH		2	5		6		11		
	20	BRUSH		6	5		7		18		
	21	BRUSH		4	5		3		12		
	22	BRUSH		7	5		4	4	16		
	23	1	8		4	5		5		14	
	24	1	10		6	5		4		15*	

* Total average time per tree includes advance time. Small mostly single stem trees averaged 14 sec/tree and medium sized multi stem trees averaged 43 sec/tree.

Table A1. Summary of Harvester Time (seconds) and Motion (continued)

Ranch		Cruise									
HU	Tr#	# St	DRC		Move	Shear	Grap.	Pile	Adv.	Total	Sec/Tr
K4	1	1	10		6	5	1	2		14	
1B	2	1	12		3	5		2	12	10	
	3	1	8		2	5		1			
							4	2			
							7	2	16	23	
	4	1	12		3	5		4		12	
	5	1	10		5		4	6		15	
	6	2	10		2	5	12	2	5		
							6	2		29	
	7	1	10		4	5		2	6	11	
	8	1	14		6	5		4		15	
	9	1	12		5	5		3		13	
	10	1	12		4		3	2	10	9	
	11	2	10		2	5		4	6	11	
	12	1	10		3	5		4	3	11	
	13	1	12		3	5		3		11	
	14	1	8		6	5		2	16	13	
	15	1	8		3	5		5			
		2	10		6	5	3	3		30	
	16	1	14		4	5		3		12	
	17	1	12		3	5		4			
		1	14		4	5	3	2	8	26	
	18	1	10		3	5		2	12	10	
	19	1	14		5	5	3	1			
		1	12		4	5		3			
					5	5		5			
					4	5	8	4	10	62	
	20	2	8		4	5		1	2	12	
	21	1	12		3	5		2		10	
	22	1	10		4	5		2		11	
	23	1	12		4	5		3	5	12	
	24	1	14		5	5		3			
		1	12		6	5		3		27	
	25	2	8		4	5		2	2	11	21*

* Total average time per tree includes advance time. Medium mostly single stem trees averaged 12 sec/tree and large multi stem trees averaged 33 sec/tree.

Table A1. Summary of Harvester Time (seconds) and Motion (continued)

Ranch		Cruise									
HU	Tr#	# St	DRC		Move	Shear	Grap.	Pile	Adv.	Total	Sec/Tr
K4	1	1	12		2	5		3			
		1	10		3	5	2	2	4	22	
	2	1	8		3	5		2	8	10	
	3	1	10		5	5		3	4	13	
	4	1	12		3	5		4			
		1	8		6	5		4		29	
	5	1	12		4	5		2	6	11	
	6	1	6		3	5		2		10	
	7	1	12		4	5		3		12	
	8	1	12		8	5		5	10	18	
	9	1	12		10	5		6			
		1	14		3	5		2			
					6		2	2			
					4	5		3	5	53	
	10	1	14		4	5	4	2			
					4		5	3		23	
	11	1	10		3	5	4	2		14	
	12	1	8		2	5		3		10	
	13	1	8		6	5	5	4	7	20	
	14	1	12		5	5		6	8	16	
	15	2	12		12	5	6	5			
		1	14		6	5	8	5			
							6	3	10	59	
	16	1	10		3	5		4	2	12	
	17	1	10		4	5		3		12	
	18	1	12		8	5		3		16	
	19	1	12		3	5		7	7	15	
	20	1	12		6		4	2			
		1	14		3	5		2			
					4		2				
					5	5		4	4	42	
	21	1	8		4	5		3		12	
	22	1	12		4	5	2	3	8	14	
	23	2	10		5	5	4	4			
		1	12		8	5		5			
		1	14		8	5		4			
					6	5		3	13	67	
	24	1	8		4	5		3		12	
	25	1	12		4	5		4		12	25*

* Total average time per tree includes advance time. Small and medium mostly single stem trees averaged 14 sec/tree and large multi stem trees averaged 44 sec/tree.

Table A2. Summary of Forwarder Time (minutes) and Motion

Ranch		Return	Load	Load	Forward		Total	
HU	Type	Empty	Time	Moves	Full	Unload	Distance	Time
K4 1A	Solid	4	25	50	3	6	750	38
K4 1A	Slash	4	18	45	2	4	750	28
K4 1B	Whole	7	15	35	5	5	900	32
K4 1B	Whole	8	17	40	6	5	900	36
OO 1A	Whole	5	15	40	7	5	800	32
OO 1A	Whole	6	14	42	4	4	800	28
OO 1A	Whole	5	20	48	2	5	800	32
+U 2B	Mix	5	35	60	5	10	900	55
+U 3A	Slash	4	25	52	3	5	500	37

Figure 14. Picture of Forwarder placing juniper slash for erosion control.

Figure 15. Example of treated area Cross-U Ranch, Harvest Area 1. Residual trees are primarily pinyon-pine with the exception of a single large juniper leave tree in far right of picture.

Figure 16. Picture of harvester placing juniper slash as an erosion control feature for silt dam. Note the ease of doing this work using the boom and shear head.

Figure 17. Cross – U Ranch Treatment Area 2 - 3 months after treatment. Note some understory vegetation is already established.