Off-Road Transport of Pinyon/Juniper

John Klepac and Bob Rummer[1]

Abstract: A 8-wheel forwarder was observed while transporting pinyon pine (*P. edulis*) and Utah juniper (*J. osteosperma*) from woods to landing in southern Utah. The forwarder was part of a 2-machine system used to treat pinyon-juniper stands. Trees were felled using a rubber tracked skid steer with a shear head, then transported to a collection point with a Ponsse Buffalo King 20-ton forwarder. A total of 47 cycles of the forwarder operating were captured on video and evaluated using time-and-motion study methods. The forwarder averaged 25.8 minutes per cycle at a mean total distance of 786 feet. Total travel distance ranged from 349 to 1851 feet. Total in-woods travel between stops while loading averaged 312 feet per cycle with 7.3 stops. Mean load size was 54.6 trees per load which translated into a payload of 5.08 green tons. The forwarder treated approximately 0.42 acres per hour and had a fuel consumption rate of 3.3 gallons per hour. Forwarding costs and productivity are compared to other alternative methods of off-road transport of pinyon and juniper.

Keywords: biomass, forwarder, time-study, productivity, off-road transport, pinyon, juniper.

Introduction

Pinyon pine (*pinus edulis*) and juniper species *(juniperus spp.)*, often referred to as PJ, are endemic throughout the western US. Miller and Tausch (2001) estimate that over the last 150 years PJ woodlands have expanded tenfold and currently occupy at least 60M ac. Not only has coverage increased, but the density per acre has also increased. There are many negative ecological implications associated with the juniper encroachment and land managers are actively seeking to restore ecological values by removal of PJ. Typical treatments include burning, lop-and-scatter, and some minor utilization for firewood or niche products. Our ability to effect ecological restoration however is limited by the cost of non-removal treatments and lack of viable utilization options.

Because of the widely accepted need for ecological treatment, PJ is a significant potential resource for biomass utilization. The Western Governors' Association assessment of biomass supply (Skog et al. 2008) suggested that PJ accounted for about 1/3 of the available woody biomass (7.5 to 11.5M dry tons per year) in the western US—more than any other single woody feedstock in the region. There are two key barriers however to realizing potential utilization—1) reducing the cost of harvest and processing, and 2) finding conversion processes that are compatible with the properties of this material.

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The WGA report estimated the cost of felling, skidding, and chipping PJ at about $70 per dry ton. Most of this cost is a result of low volume per acre and low volume per tree. Extraction (skidding) is often inefficient because of the difficulty of collecting enough volume to make an economically-viable payload. Baughman (2004) timed a grapple skidder and front-end loader system in PJ and found a production rate of about 6 green tons per hour at a cost of about $7 per green ton. The Yankee Group evaluated grapple skidders working in western juniper in Oregon and found productivity ranging from 3.8 to 4.9 green tons per hour with costs up to about $11.50 per ton. Dodson (2010) found skidding costs of $30 to $60 per green ton at a distance of about 450 ft.

There are alternative methods to move material to roadside. For example, one system tested in California chipped trees at the stump and moved chips to roadside using modified forwarders. Another option is to simply increase the payload space/capacity by using large bunks on a forwarder. Both of these solutions are attempting to improve the economics of extraction by increasing the payload volume of the skidding function. The objective of this project was to evaluate the performance, productivity and cost of a large capacity forwarder moving PJ biomass from a woodland restoration treatment. The results are useful in comparing the relative efficacy of alternative approaches to PJ extraction.

Study Location and Treatment

The project is part of a larger treatment area managed by the Bureau of Land Management south of Beaver, Utah. The forwarder test was conducted on approximately 20 acres of generally north-facing slopes in Nevershine Hollow. At this site elevation is 6500 ft (1980 m) above sea level and averages 12-14 inches (305 - 356 mm) of rainfall per year. Mean annual air temperature ranges from 45-48°F (7-9°C). Slopes range from 5 to 30 percent.

Nevershine Hollow includes about 5500 acres of PJ treatment with tree densities of 100 to over 400 trees per acre. A stewardship contract covered the test units and was designed to: 1) reduce hazardous fuels, 2) restore forest health, 3) reduce tree density and 4) improve biodiversity. The thinning treatment specifies spacing guidelines to leave about 30 small (<8-in dbh) and 8 medium (8 to 18-in dbh) trees per acre. Non-merchantable biomass had to be treated on site to less than 2 feet above ground. Merchantable material was defined as anything larger than 8-in DGL, larger than 3-in top end, or longer than 6 feet and all such material was required to be removed.

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[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement of any product or service by the U.S. Department of Agriculture or other organizations represented here.

The contractor's conventional operation was to use a skid-steer with shear (CAT[2] 297C) in operator selection thinning. Without skidding equipment, the conventional operation was limited to product removal where piles could be created within a reasonable distance of the cutting area. Generally this limited product removal to areas within 200 feet of an access trail or landing.

For this study a large-capacity forwarder was added to the contractor's conventional system. Felling proceeded as normal using the skid-steer shear machines. In some areas the felling operation also created bunches of material by pushing up felled trees. The forwarder operator identified travel paths to best access felled material. On moderate slopes (<20 percent) the forwarder operated relatively freely. As slopes exceeded 20 percent the operator kept travel paths perpendicular to the slope for stability and safety.

A large Ponsse forwarder, a Buffalo King 20-ton forwarder (Figure 1), was selected for this study. To maximize payload the machine had extended bunks (variable load space) that provided an additional 20 percent load space compared to the conventional bunk option (Table 1). This machine was chosen to test the payload capacity of large bunks carrying PJ biomass.

Figure 1. Ponsse Buffalo King 20-ton forwarder.

Table 1. Specifications of large capacity forwarder.

Feature	Specification
Engine, horsepower	Mercedes, 275 hp
Total machine weight	22 tons
Tires and tracks	8, Nokian 710/45 (front), 750/55 (rear)
Load space cross-section	64.6 ft^2
Bunk length	16.7 ft w/o extension; 19 ft with extension
Boom reach	31.2 ft maximum

Methods

Productivity and Costs

Operation of the forwarder was recorded on digital video to analyze time study elements. Elements evaluated included travel empty (travel from landing to first in-woods stop), load (swing to pile or tree, grapple and place on forwarder), intermediate travel (travel between piles or trees), travel loaded (travel from woods to landing), and unload (grapple trees in load and place in pile at landing). A Garmin V GPS unit mounted inside the cab recorded traverse data and aided measuring long travel distances. To estimate short travel distances the tires on the forwarder were marked with paint to aid in estimating short travel distances to record the number of revolutions traveled between stops. During loading, the number of swings was recorded along with an estimate of the number of trees and the butt diameter of each tree contained in each swing. For unloading, only the number of swings and trees per swing were recorded.

Machine hours were noted at the beginning and end of each day for estimating gross productivity. Fuel consumption was determined by re-fueling at the end of each day. Acres treated per day were estimated by traversing areas worked each day using a Garmin V GPS unit.

Volume Estimation

As noted above, during loading the butt diameter of each piece was visually estimated. These butt size classes were converted to piece volume using equations developed from this study. The equations converted DBH into volume based on a regression developed from 43 trees sampled from the site. Sample trees were weighed with a Salter Brecknell CS2000 2000-lb capacity digital scale attached to the forwarder boom. Trees were selected to represent a range of diameter classes. For each tree, DGL (diameter at ground line), DBH (diameter at 4.5 feet above ground), crown width, height to the base of the live crown, and total height were recorded. For multi-stemmed trees only DGL was measured. Data from these measurements were used to develop regression equations for estimating whole-tree weights.

Site Disturbance and Soil Moisture

Post-treatment soil surface disturbance was quantified using a point transect method (McMahon, 1995). With this method, soil disturbance was classified at points along transects that were oriented perpendicular to the major direction of forwarder travel. Distance between transect lines was 50 feet and 20 feet between observation points. Compass and pacing were used for direction and distance. Disturbance was classified as either undisturbed, trafficked with litter in place, trafficked with mineral soil exposed, dragged, or deeply disturbed.

Soil samples were collected on four different days for quantifying moisture content. The litter layer was removed and samples were removed to a depth of approximately 2-inches and placed in plastic bags. Samples were weighed wet, dried in an oven at 105 °C until a constant weight was obtained and then weighed dry.

Results

Productivity and Costs

A total of 47 cycles were recorded (Table 2). The forwarder treated an average of 3.2 acres/day and averaged 7.6 PMH (Productive Machine Hours)/day. Fuel consumption averaged 25 gallons/day. Occasionally, the skid-steer gathered felled trees and consolidated them into piles. This reduced the number of stops during a cycle, which enhanced the forwarder's production. More than half (53.8%) of the total cycle time was spent loading. A breakdown of the percent of total cycle time required to perform each element is displayed in Figure 2. With a payload of 5.08 green tons the forwarder only hauled 25% of its potential weight capacity.

Table 2. Summary of elementary statistics for the Ponsse forwarder.

Variable	N	Mean	SD	Min	Max
Travel empty (min)	47	3.07	1.161	0.9	6.9
Load (min)	47	13.86	3.450	6.7	25.5
Interm. travel (min)	47	3.25	2.018	0.05	8.6
Travel loaded (min)	47	1.86	0.993	0.6	5.7
Unload (min)	47	3.61	1.091	0.3	5.9
Move during unload (min)	14	0.32	0.661	0.04	2.6
Total time (min)	47	25.75	5.577	14.7	41.7
No. of stops	47	7.3	4.00	1.0	17.0
Travel empty distance (ft)	47	517.4	246.38	175.0	1604.0
Interm. travel distance (ft)	47	312.0	238.85	4.0	1191.0
Travel loaded distance (ft)	47	269.0	145.31	99.0	636.0
Total distance (ft)	47	786.4	331.12	349.0	1851.0
Travel empty speed (mph)	47	1.95	0.510	0.8	3.2
Travel loaded speed (mph)	47	1.68	0.381	1.1	2.7
No. of swings to load	47	20.5	6.11	10.0	39.0
No. of swings to unload	47	9.1	2.26	4.0	15.0
No. of trees	47	54.6	14.94	22.0	93.0
Payload (green tons)	47	5.08	1.395	2.9	8.6
Productivity (green tons/hr)	47	12.1	3.36	6.2	20.5

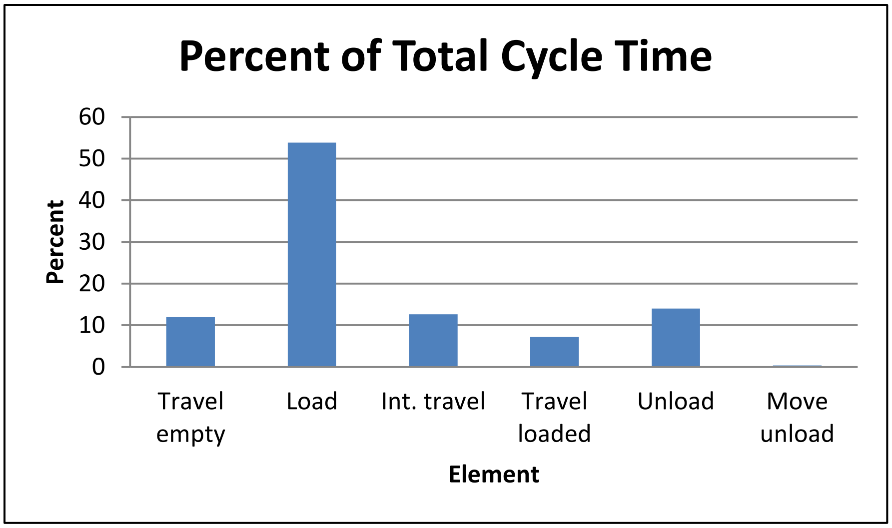

Figure 2. Summary of time study elements for the Ponsse forwarder.

A General Linear Models Procedure (SAS, 1988) was used to determine which independent variables were the best predictors of the dependent variables travel empty, load, intermediate travel, travel loaded, and unload times. These equations are summarized in Table 3.

Loading time started when the machine came to a stop and included all of the activity to collect and load material at a given location. Since the individual trees were relatively light the operator worked to pick up more than one piece at a time. Sometimes this involved bunching pieces together prior to lifting to the bunks. Bunk length and piece size required the operator to build a good payload by careful placement and packing of the material. Each swing was oriented to place the grapple load in the best hole in the payload. The load was built as high as possible above the stakes until the operator judged that additional pieces would not be secure. For loading, the total number of swings required per load and the total number of stems per load were both significant at predicting load time (CV =12.72%, R^2=0.75). Load time increased with more swings and with more stems.

Intermediate travel included all machine movement between stops. It started with wheel movement after the operator secured the boom from the last swing and ended when the machine came to a stop at the next loading location. Generally the operator would be facing the load (the rear of the machine) and driving the opposite direction, looking over his shoulder. The best predictors for intermediate travel time were total intermediate travel distance and the number of stops made during a cycle. The number of stops does not include the first stop made at the end of travel empty, but all stops afterwards. Every 100 ft of intermediate travel added about 30 seconds to the cycle time, every stop adds about 12 seconds. These two factors explained 90 percent of the variability in intermediate travel time (CV =20.26%).

Travel loaded began when the operator left the last stop to travel into the landing. Generally the operator would swing the seat around and drive in a forward-facing position with the boom pressed down on the load to the rear. Travel loaded time was best modeled using travel loaded distance as the independent variable. Because of the load, travel loaded speed was about half of travel empty speed. Every 165 ft of distance added 1 minute to cycle time. For this model, the CV was 25.31%.

At roadside the forwarder unloaded and stacked material into large piles. Piles ranged from 12 to 20 ft tall and 40 to 90 ft long. The best estimate for unload time was the mean value of 3.61 minutes. Confidence interval limits at the 95% level (t=2) were calculated and ranged from 3.29 to 3.93 minutes. Unloading was not affected by the number of pieces in the load or total load volume.

The regression equations in Table 3 were used to estimate productivity as a function of total distance and using mean values for all other variables. A mean of 7 stops, 312-ft intermediate travel distance, 55 stems per load, 20 load swings, and a 5.08 ton payload were used. Using an hourly cost of $91.53/PMH resulted in the cost curve for the forwarder (Figure 3).

Table 3. Regression equations for predicting elemental times and productivity for the Ponsse forwarder.

Regression equations for time element, (min)	R^2	Mean Square		F Value	Pr > F
		Model	Error		
Travel empty = 0.003842015*tedist[a] + 1.081161	0.66	41.218587	0.46258	89.11	< 0.0001
Load = 0.3509478*lswings[b] + 0.0780867*stems[c] + 2.416484	0.75	205.31166	3.11022	66.01	< 0.0001
IT = 0.00569537*itdist[d] + 0.19817789*stops[e] + 0.02581422	0.90	84.06132	0.43444	193.49	< 0.0001
Travel loaded = 0.00604292*tldist [f] + 0.23092257	0.78	35.470087	0.22074	160.69	< 0.0001

[a]tedist = travel empty distance (ft); [b]lswings = number of swings to load; [c]stems = number of stems loaded; [d]itdist = intermediate travel distance (ft); [e]stops = number of stops per cycle; [f]tldist = travel loaded distance (ft).

Costs to operate the forwarder were based on a machine rate analysis (Miyata, 1980). These costs reflect the average owning and operating costs over the life of the machine. Using the purchase price, machine life, salvage value, insurance and interest rate, the AYI (Average Yearly Investment) and annual ownership cost was determined. Operating costs were based on machine horsepower, fuel consumption rate, repair and maintenance, tire cost, lube, oil, and fuel cost. Labor cost was calculated using a wage rate per SMH (Scheduled Machine Hours) plus benefits. Data used for these variables are summarized in Table 4.

These data resulted in the costs summarized in Table 5. These costs do not include an allowance for profit and overhead, or consideration of after-tax effects. Using a production rate of 0.42 acres/hr resulted in a transport cost from woods to roadside of approximately $218/ac. With a production rate of 12.1 green tons/hr, transport cost of the forwarder was $7.56/ton.

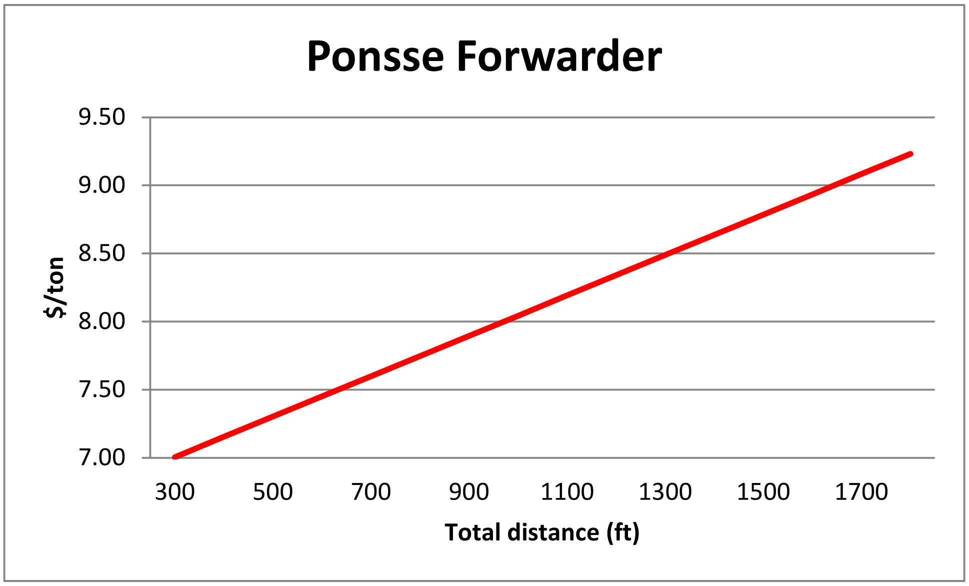

Figure 3. Cost curve for the Ponsse forwarder.

Table 4. Summary of machine rate input variables for the Ponsse forwarder.

Variable	Input Data
General assumptions	
SMH (Scheduled Machine Hours per year)	2000
Fuel cost ($/gal off-highway diesel)	3.50
Interest rate (%)	10
Utilization rate (%)	90
Ownership variables	
Purchase price ($ - less 8 tires)	430,000
Salvage value (% of purchase price)	20
Insurance rate (%)	1.0
Life (years)	7
Operating variables	
Horsepower	250
Fuel consumption (gal/hr)	3.3
Lube and oil (% of fuel consumption)	6
Repair and maintenance (% of depreciation)	35
Tire cost ($)	30,000
Tire life (PMH)	12000
Labor	
Wage rate ($/SMH)	15.00
Benefits (% of wage rate)	30

Table 5. Cost summary for the Ponsse forwarder.

Item	($US)
Ownership costs ($/SMH)	
Capital	39.63
Insurance	1.41
Total Ownership	41.04
Operating costs ($/PMH)	
Fuel	11.51
Oil and lube	0.69
Repair and maintenance	9.56
Tires	2.50
Total Operating	24.26
Labor ($/SMH)	19.50
Total costs	
($/SMH)	82.38
($/PMH)	91.53

Volume Estimation

A total of 20 pinyon pine and 23 junipers were weighed during the study. Data from measurements of DGL and DBH were used to develop a linear regression equation to predict DBH as a function of DGL. Both species were combined for developing a regression equation to predict load volume based on DBH. Regression analysis showed that DBH squared provided the best prediction of green tree weight and is displayed in Figure 4.

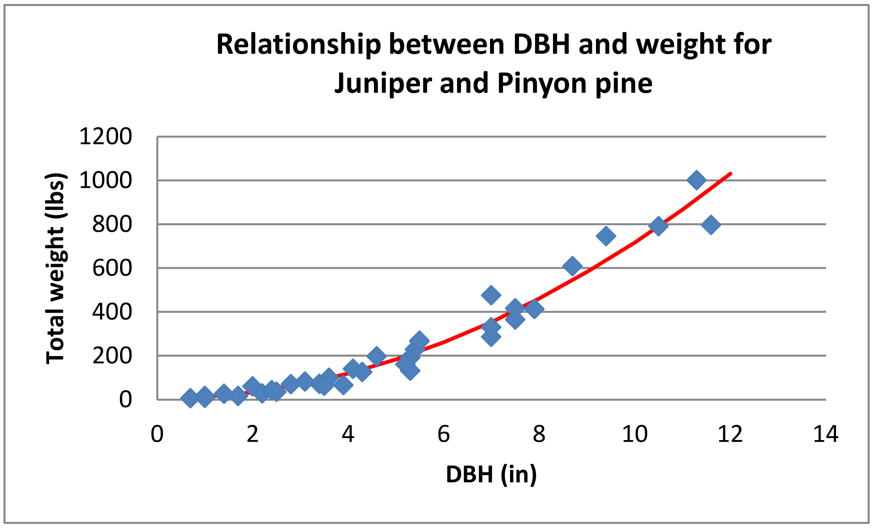

Figure 4. Model to predict total green tree weight as a function of DBH.

Model to predict total green tree weight as a function of DBH:

$$Weight\ (lb) = 7.12439304 * DBH^2 + 5.01720013$$

$n = 35$; $R^2 = 0.96$; CV = 21.56%

Site Disturbance and Soil Moisture

A total of 645 observations were collected from the soil disturbance survey. Results of the survey (Figure 5) reflect ground disturbance of the total system; skid-steer and forwarder combined. The system left slightly over one-third of the area (35.2%) undisturbed. Trafficked area totaled 61.4%; 30.1% with litter in place and 31.3% with mineral soil exposed. Only 1.4% of the area had significant disturbance which was classified as deeply disturbed.

Soil moisture content during the operation ranged from 12.5% to 18.9% and averaged 15.7% (oven-dry basis) across the four units.

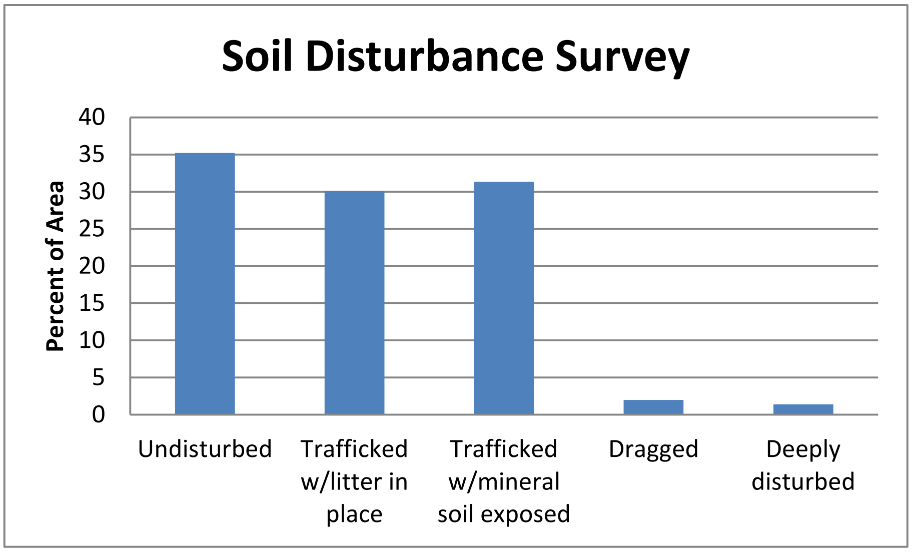

Figure 5. Summary of the soil disturbance survey using the point transect method.

Discussion

The forwarder concept represents one of the simplest approaches to reducing extraction costs to roadside. Bunk volume can be increased by mechanically extending the bunks to each side and by increasing height. In the relatively open PJ thinning treatments overall machine width is not a limiting constraint. This test showed that it is not necessary to add additional bunks to hold short PJ material. Pieces were packed into the load with the crane and the operator demonstrated some skill in achieving large accumulations. Even with the crane packing material with the grapple, the net load density (payload divided by bunk space) was around 9.4 lb/ft^3. This is less than one-half the density of wood chips and just over one-fourth the density of solid wood.

Forwarding productivity is dominated by loading time. Bunched material was loaded in fewer swings and fewer stops and bunching clearly reduces the cost per ton for forwarding. However this comes at the cost of felling productivity. System analysis is needed to ascertain the optimal degree of bunching to minimize total cost to roadside.

Forwarding biomass has a relatively flat cost curve as a function of distance. The longest distance in this study was about 1600 feet and the travel empty time was about 7 minutes. Other forms of biomass extraction that have smaller load sizes are much more sensitive to total extraction distance. This performance attribute of forwarders allows treatments over larger units with fewer roads and landings. A 1600-ft radius from one landing covers an area of 184 acres. It also enhances the concentration of material at the landing to improve the productivity of subsequent chipping and loading. Assuming 10 tons per acre removal a 184-acre unit would have about 1800 green tons of material in one place.

Utilizing a forwarder to transport pinyon/juniper trees from woods to landing appears to have potential as being an effective tool for treating areas under these conditions. Low moisture content of the wood coupled with wide crowns on the juniper trees resulted in a low payload (5.08 tons). Samples collected from trees on a neighboring site revealed wood moisture contents (wet basis) that ranged from 35% to 40%.

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References

Baughman, M. 2004. Pinyon-juniper biomass utilization study for Lincoln County, Nevada. Caliente, NV: Lincoln County Regional Development Authority. 20 p.

Brinker, R.W.; Kinard, J.; Rummer, B.; Lanford, B. 2002. Machine rates for selected forest harvesting machines. Circular 296. Auburn, AL: Alabama Agricultural Experiment Station. 29 p.

Dodson, E.M. 2010. A comparison of harvesting systems for western juniper. International Journal of Forest Engineering. 21(1): 40-47.

Grier, C.C.; Elliott, K.J.; McCullough, D.G. 1992. Biomass distribution and productivity of Pinus edulis-Juniperus monosperma woodlands of north-central Arizona. Forest Ecology and Management 50: 331-350.

Matthews, D.M. 1942. Cost control in the logging industry. New York: McGraw-Hill. 374 p.

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

Miyata, E.S. 19080. Determining fixed and operating costs of logging equipment. Gen. Tech. Rep. GTR CN-55. St. Paul, MN: U.S. Department of Agriculture, Northcentral Forest Experiment Station. 16 p.

SAS Institute Inc., *SAS/STAT User's Guide, Release 6.03 Edition*, Cary, NC: SAS Institute Inc., 1988. 1028 pp.

Skog, Kenneth E.; Patton-Mallory, Marcia; Rummer, Robert R.; Barbour, R. James. 2008. Strategic assessment of bioenergy development in the West. Biomass resource assessment and supply analysis for the WGA region. Final Report. Denver, CO: Western Governor's Association. 38 p.