Paper No. 95-7746
An ASAE Meeting Presentation

HARVESTING SYSTEMS FOR WESTERN STAND HEALTH IMPROVEMENT CUTTINGS

by

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Written for presentation at the
1995 ASAE Annual Meeting

Hyatt Regency
Chicago, Illinois
June 18-23, 1995

Summary:

A significant percentage of the forested area in the western United States is comprised of stands that have been altered over time by human activities, especially fire suppression, and are now being damaged by droughts, insect attacks, and wildfires. These stands should be returned to a condition where "biotic and abiotic influences do not threaten resource management objectives now or in the future." This paper compares and contrasts harvesting systems that have recently been tested on the east side of the Cascades, in the Sierra Nevada, and in New Mexico, with the objectives of reducing the hazards of catastrophic change of ecosystem structure and composition, and restoring critical ecosystem processes.

Keywords:

Ecosystem management, forest harvesting systems, fuels reduction

Introduction

Forest health has been defined as: "... a condition where biotic and abiotic influences do not threaten resource management objectives now or in the future" (USDAFS 1993). Stands which are not in this condition are common, especially in the western US. Substantial areas of forests are densely stocked, have poor vigor, and are susceptible to disease, insect attack, and fire. On the Colville National Forest, for example, over one-third of the forest area is overstocked and considered at risk (USDAFS 1992). Restoration of forest health is a national priority for the Forest Service, and has lead to the development by the Forest Service of the "Western Forest Health Initiative."

Methods to improve the health of overstocked stands can focus on reducing the number of trees per acre, under the assumption that the removal of trees in obviously poor health or having a high probability of dying in the near term would improve the vigor of the remaining trees, due to the reduction in competition for moisture, nutrients and light. This in turn should reduce the incidence of disease and insect infestation. Direct reduction in fuels loading during harvest, and reduced mortality in the treated stands, is expected to lower the probability of catastrophic wildfires.

Economical and environmentally acceptable harvesting systems are needed to restore forest health in these stressed forests. This paper reviews selected harvesting systems that have been tested for health cuttings. The systems offer a wide range of attributes for different stand, site, and utilization applications. Criteria that can be used when selecting equipment and systems are discussed. These include tree size, harvested volume, wood extraction distance, roading, potential products, ground slope, soil trafficability, and site impacts. Systems are limited to ground-based technologies and include feller/bunchers, skidders, harvesters, forwarders, stroke processors, flails and chippers.

Health Cuttings Studies

Three recent studies with which the authors have been involved have focused on stands and regions in the western US where restoration of forest health was a primary objective. All three were conducted during 1994-95, and therefore represent the latest understanding of the problems, harvesting prescriptions that were developed in consideration of multiple objectives including ecosystem characteristics, and the most recent harvesting technology. Most of the data summarized in this paper is taken from reports on the three studies, in Washington (Barbour et al 1995), California (Hartsough et al 1994, Hartsough & Zimny 1995) and New Mexico (Watson et al 1995). Characteristics of the study areas are listed in Table 1.

The California study was carried out on the Stanislaus National Forest, in a mixed conifer stand that had been partially logged by railroad in the 1940s and had naturally regenerated. The stand had a wide distribution of diameter classes and a range of species, but was overstocked. Many of the larger trees had been killed during the drought of the previous several years. A thinning prescription was developed with two primary objectives: enhance habitat for spotted owls, and reduce fuel loading. All live trees over 18" DBH and all snags over 16" DBH were retained. The understory was thinned, and pockets of small trees were left as wildlife screens.

In New Mexico, several selection silvicultural treatments were carried out on stands on the Mescalero Reservation, to reduce basal area, remove dying trees and those highly susceptible to mortality. The stands were relatively sparse even before treatment, but limited precipitation in the region dictated a reduction in stocking.

The Washington study, conducted on the Colville National Forest, was carried out in mixed species stands of a type that is common in northeastern Washington, northern Idaho and western Montana. These stands regenerated after severe wildfires in the 1930s and 40s, but fire has been excluded since then. Stocking averaged over 1000 stems per acre, and more than half of the trees were smaller than the minimum size required for conventional utilization at local mills. These stands were thinned to increase stand growth, reduce susceptibility to mortality, decrease fuel loading, create winter browse sites, and move the stands towards a late successional stage of development.

Table 1. Study unit characteristics. Numbers indicate ranges of averages for multiple units on each study.

Study region:	California	New Mexico	Washington
Average slopes, %	10-25	17-38	5-20
Species	white fir incense cedar sugar pine ponderosa pine	ponderosa pine Douglas-fir	western larch lodgepole pine Douglas-fir ponderosa pine western red cedar
Removals			
Tons/acre	52	19-34	26-54
Trees/acre	140	66-97	68-127
DBH, in	9.6	7.6-8.6	8.2-9.8
Tree weight, green lb	750	460-510	630-1100
Leave trees/acre	120	38-56	not recorded
Reserve BA, ft2/acre	150	not recorded	90

Harvesting Systems

Five different systems were used on the three studies. The systems used in each area were different, because they were selected for their potential in the specific study areas.

Feller/Buncher-Skidder-Flail/Chipper: This system was used in the New Mexico study. It was centered around the use of a Peterson-Pacific 5000 flail delimber/debarker/chipper to convert the roundwood into pulp quality chips. Three different feller/bunchers were used. A self-leveling tracked machine (Timbco) was used on the steepest slopes, an intermediate-sized track machine (Wolverine) on intermediate slopes, and a tri-trac wheeled machine (Hydro-Ax 221) on the least severe slopes. Rubber-tired grapple skidders (Timberjack 380 and 450) transported the felled whole trees to the flail/chipper. The small percentage of sawlog material was bucked out of the larger stems at the landing, by chainsaw. There was no market for fuel, so residues from the flail were piled by a crawler dozer (Cat D7H) at the landing. The dozer operator doubled as the chainsaw operator. The sawlogs were cold-decked and loaded out after the chipping was completed. A balanced system consisted of two feller/bunchers, three skidders, a flail chipper and a dozer. Costs for this system were sensitive to slope, because the more expensive feller/bunchers were required on the steeper ground, and system productivity was less on the steep slopes.

The next three systems described below were compared in the California study. All three systems produced small sawlogs and biomass (fuel) chips, there being no local market for pulpwood or pulp chips.

Feller/Buncher-Skidder-Processer-Loader-Chipper: All trees were felled in one pass by a Timbco T420 feller buncher, which piled the merchantable ones separately from the biomass. Merchantable trees were skidded hot (by Timberjack 450B and Caterpillar 528 grapple skidders) to the processor (Timberjack 90) at the landing. The processor decked the sawlogs and piled the tops for later chipping. Most limbs were returned to the woods by the skidders. After all sawlogs were loaded out, the chipper (Morbark 60/36) moved in, and the biomass bunches were skidded hot to the chipper. The skidders also moved the piled tops and limbs to be chipped.

Harvester-Forwarder-Loader-Chipper: The harvester (FMG Timberjack 1270 harvester with 762B head) delimbed and bucked the sawlogs from the merchantable trees. It also delimbed and bucked the biomass trees, and the biomass logs from the tops of the merchantable trees. The forwarder (FMG Timberjack 1010) usually carried a single product in any one load, and cold-decked the sawlogs and biomass logs separately. Sawlogs were loaded out before the chipper (Morbark 60/30) arrived. The subsequent chipping operation required a skidder to move material from the biomass decks to the chipper.

Feller/Buncher-Harvester-Skidder-Loader-Chipper: With this system, merchantable trees were processed in the stand, but the sawlogs and biomass bunches were skidded rather than forwarded. The feller buncher (Timbco 420) cut and bunched the biomass trees. The harvester (Equipment Repair EP200 harvester head on a Timbco T435 carrier) followed in a second pass, felling the merchantable trees and processing long sawlogs. It then placed the unlimbed tops on the biomass piles created by the feller buncher. Biomass felling, merchantable harvesting, sawlog skidding and biomass skidding were segregated and carried out in that order. Sawlogs were skidded hot to the loader. Biomass bunches were then skidded hot to the chipper (Morbark 60/30).

Harvester-Forwarder: Single-grip harvesters (Kobelco 142S with Keto 150 head, FMG 990) and forwarders (FMG 910 and 1010) were employed in the Washington study. In stands of smaller average diameter, two harvesters were needed to match the productivity of the forwarder. In larger diameter stands, only one harvester was required. Only sawlogs were produced, as no pulp or biomass market was available. Harvesting costs were very sensitive to average tree size in the various study areas.

Table 2. Characteristics of harvesting systems tested in the three studies, and summary of costs and product outputs.

Harvest System:	F/B-Skidder-Flail/Chipper	F/B-Skidder-Processer-Load-Chip	F/B-Harvester-Skidder-Load-Chip	Harvester-Forwarder-Load-Chip	Harvester-Forwarder
Equipment Mix	Feller/bunchers (2) Grapple skidders (3) Flail/chipper (1) Chainsaw (1) Dozer (1)	Feller/bunchers (2) Grapple Skidders (3) Stroke Processor (1) Loader (1) Chipper (1)	Feller/buncher (1) Harvesters (2) Grapple Skidders (3) Loader (1) Chipper (1)	Harvester (1) Forwarder (1) Loader (1) Chipper (1)	Harvester (1 or 2) Forwarder (1)
Capital Cost, $	1,200,000-1,500,000 (choice of feller/buncher depended on ground slope	1,800,000	2,000,000	1,300,000	600,000-900,000 (number of harvesters depended on avg tree size)
Hourly Cost, $/SH	530-650	540	590	380	120-180
Stump-Truck Cost, $/green ton of product	10-18 *	15	18	26	3-7 (harvesting only)
Product Mix	Clean chips (80-93%) Sawlogs (7-20%)	Fuel chips (54%) Sawlogs (46%)	Fuel chips (58%) Sawlogs (42%)	Sawlogs (59%) Fuel chips (41%)	Sawlogs

* Cost is per green ton of whitewood, e.g. clean chips and sawlogs inside bark. Costs for all other systems are per ton of material loaded onto or into trucks, e.g. sawlogs outside bark and fuel chips.

Criteria for System Selection

Factors which influence system selection are summarized in Table 3. Economics is a central issue in choosing a harvesting system. Because economic feasibility depends on several site-specific factors such as values of delivered products, transportation distances and tree sizes, focusing solely on the harvest system characteristics is inappropriate. A complete analysis should be carried out for each specific situation. With this stated, some general trends related to the systems can be mentioned. Harvester-forwarder systems are generally more expensive per unit harvested than feller/buncher-skidder systems. Systems that involve fewer pieces of equipment, e.g. the harvester-forwarder system, require less capital, fewer people and have lower move-in costs than other options. This makes them attractive for small contractors, and for use on small tracts or on sales where total volume is relatively small.

To be economically feasible, the systems that utilize chippers or flail/chippers require substantial volumes of chippable material on a unit to offset the move-in costs. Single-entry chipping systems, such as the flail/chipper alternative, also need a high flow rate of chippable (versus sawlog) material so that the high cost chipping equipment is well-utilized. The two-pass or cold-deck systems can operate with a wide range of product percentages. The tested flail/chipper system relied on a chainsaw to separate sawlogs from the whole trees before the remaining material was processed into chips. This configuration worked well because the sawlog percentage was low. A higher sawlog percentage would probably favor a system with mechanical delimbing and bucking of sawlogs, such as the processor-equipped system tested in California.

Forwarding eliminates the log breakage that results from skidding, especially of long whole trees. Skidding of logs, as in the feller/buncher-harvester-skidder system, would be expected to have an intermediate level of breakage. Because forwarders can't transport long logs, any long-versus-short sawlog value differential is forfeited. Many mills that handle the small-diameter logs that would come from most health cuttings do not, however, pay a premium for long logs.

In areas where wood fuel prices are high, the whole tree system (feller/buncher-skidder-processor-loader-chipper) would be a likely candidate. It recovers more fuel than either of the other two fuel-producing systems, which leave some or all of the tops and limbs on site. In the California study, the whole tree system was also less expensive than the feller/buncher-harvester-skidder or harvester-forwarder systems. The feller/buncher-skidder-flail/chipper system would also efficiently recover fuel, by addition of a tub grinder or similar device to further comminute the flail residues. This assumes the amount of flail residue would justify the move-in costs for a grinder, to be operated simultaneously with the flail or after the flail had left the site. In contrast, areas where no chip markets (pulp or fuel) exist would favor the harvester-forwarder system, or a harvester-skidder alternative.

Harvesting costs for all systems decrease as tree size increases, up to the design limits of the felling and processing machinery. Because diameters are generally small in overstocked stands which are the most likely candidates for health cuttings, equipment that can handle essentially every tree is available. Economics dictate that smaller and cheaper equipment be used with the relatively small trees. If equipment selection is not done carefully, a substantial fraction of the trees may be too large. (An occasional oversized tree can be felled with a chainsaw by the feller/buncher or harvester operator.) Feller/buncher-skidder systems are less sensitive to the number of oversize trees, because skidders can easily pick up the large trees felled by chainsaw, whereas forwarders may have difficulty reaching logs that are not piled along the forwarder track. Single-grip harvesters can have difficulty with the large branches on species such as ponderosa pine, but these are not usually a problem in overstocked stands.

Truck tractors with chip vans can't negotiate tight curves, therefore the systems that employ on-site chipping are restricted to higher standard roads in areas with steeper terrain. Road curvature is not generally a problem on gentler terrain. Forwarding costs are less sensitive to wood extraction distance than are skidding costs, so optimum road spacing is greater for a forwarder-based system. Most health cuttings cannot support the costs of new road construction, so forwarder systems may be advantageous in areas where existing road density is relatively low.

Table 3. Summary of selection criteria for the harvesting systems.

Harvest System:	F/B-Skidder-Flail/Chipper	F/B-Skidder-Processer-Load-Chip	F/B-Harvester-Skidder-Load-Chip	Harvester-Forwarder-Load-Chip	Harvester-Forwarder
Cost per unit volume	lower	lower	intermediate	higher, especially for fuel component	higher
Capital cost	intermediate	higher	higher	intermediate	lower
Harvest unit volume	high chippable volume and percentage required	high total and chippable volume required	high total and chippable volume required	high chippable volume required	can be low
Product considerations	can produce long logs, limited to low % of sawlogs	can produce long logs, maximum fuel recovery	can produce long logs, low level of sawlog breakage, high fuel recovery	short logs only, less fuel produced, no sawlog breakage during transport	short logs only, no sawlog breakage during transport
Tree size limitations	F/B diam limit	F/B diam limit	F/B diam limit, harvester diam & branch size limits	harvester diam & branch size limits	harvester diam & branch size limits
Wood extraction distance	distance impacts skidding cost	distance impacts skidding cost	distance impacts skidding cost	less sensitive to distance	less sensitive to distance
Roading considerations	need large radius curves	need large radius curves	need large radius curves	low roading density, need large radius curves	low roading density
Slope limits	50%	50%	50%	30%	30%
Soil strength requirements	intermediate	intermediate	intermediate	less than for skidders	less than for skidders
Soil surface disturbance	intermediate to high	intermediate to high	intermediate to high	minimal	minimal
Damage to reserve stand	low to high	low to high	low to intermediate	low	low
Residual fuel loading	least	least	very low	low	low
Residues at landing	can be substantial	negligible	negligible	negligible	negligible
Visual impact	low to intermediate	low to intermediate	low to intermediate	negligible	negligible

The costs of feller/bunchers increase with slope capability, but those with leveling cabs can operate on slopes of up to approximately 50%. Skidders and harvesters can also traverse relatively steep slopes. Forwarders are more limited by slope and aspect: on slopes greater than 20% or so, they must run on the fall line. Road location and trail layout on broken terrain is more difficult for forwarding than for skidding.

Because forwarders travel on a mat of slash left by the harvester and transmit less shear force to the soil, they can operate on soils of lower strength than can skidders. This means they can work on wetter sites, and over a longer timespan on seasonally wet sites. Because harvesters and forwarders travel on straight paths and forwarders carry their loads off of the ground, disturbance to the soil surface is minimal. Tracked feller/bunchers, and skidders, commonly remove the surface organic material and can move substantial amounts of mineral soil, especially on steeper terrain.

Harvesters cut trees to short lengths and the loading booms on forwarders can manipulate the short logs around reserve trees. Skidders must be extremely careful to avoid damage to residual trees when accumulating loads, and skidding of longer sawlogs and especially of whole trees or tree lengths almost always results in more damage than forwarding. In the California study, however, which had both high removals and relatively dense reserve stands, the percentages of residual trees that were damaged were 15 percent or less for all three systems. The harvester-forwarder system produced the least damage, 10 percent.

Harvesters leave tops and limbs in the woods, so residual fuel loadings are higher than with whole tree methods. This is obviously a concern in health cuttings if background levels of fuel are high. If slash is placed in the trails and driven over and compacted by the forwarders, however, it contributes less to the fuel "ladder" than would the same volume of material left by a manual thinning operation. While the feller-buncher-skidder-flail/chipper system removes limbs and tops from the site, it creates piles of residues (including bark) at or near the landings. These piles can take up substantial areas if the removal density is high. Forest managers in New Mexico were concerned about fire hazard with the concentrated residues at the landing. In the future, they will skid residues back into the stand rather than piling residues at the landings. The feller/buncher-skidder and feller/buncher-harvester-skidder systems tested in California both include fuel chipping, and obviously leave little residue at the landings or in the stands.

Discussion and Conclusions

Many alternatives other than those summarized in this paper are possible. For example, the Colville study team is investigating three additional systems for producing primarily small sawlogs (McNeel 1994):
1) Horse logging (chainsaw felling and processing to log length, horse skidding),
2) Chainsaw-Prebunch-Skidder (chainsaw falling and partial limbing of whole trees, prebunching with a winch-equipped tractor, skidding, manual or low-cost mechanized processing at the landing), and
3) Feller/Buncher-Skidder-Flail (feller/buncher, grapple skidding of whole trees, flail delimbing, chainsaw bucking and topping to log length)

The first two are very low capital systems that may be applicable on small harvest units or where removal volume per acre is low.

A case study of a cable system on flat terrain in eastern Oregon was conducted in 1994 (Kellogg and Brown 1995), and the PNW Research Station will sponsor a comparative study of cable and tractive systems in 1996. Material to be removed is mostly dead, down and dying trees from mixed conifer stands. The main product will be chip logs, and sawlogs will constitute a minor portion of the total volume. The jackstrawed material must be reoriented and aligned before skidding or yarding, to minimize log breakage and damage to the reserve stands, and this requirement points to the use of harvesters rather than feller/bunchers. Soil disturbance and water quality are critical factors because of the proximity of the stands to salmon spawning streams, and this is the justification for investigating a

cable system even though the terrain is accessible by tractive equipment. The two systems to be compared are:
1) Harvester-Skidder (single-grip harvesting to short or long logs, grapple skidding)
2) Harvester-Cable Yarder (single-grip harvesting to short or long logs, cable yarding with intermediate supports)

In conclusion, the choice of harvest system depends on many factors, and a large number of alternatives are available. Even when the range of conditions is narrowed to relatively flat ground and small trees in overstocked stands, there is no one "optimal" system. Unit characteristics, removal volumes and piece sizes, products and ecological objectives must all be considered. Operations planners need substantial experience in order to match situations and systems. Fortunately, the range of options makes it likely that a good one can be identified in most cases.

Acknowledgement

This paper was partially funded by the Forest Products Laboratory Wood Utilization for Ecosystem Management Research Project, USDA Forest Service Research. Numerous organizations provided support for the underlying studies, and these groups have been recognized in the cited references.

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