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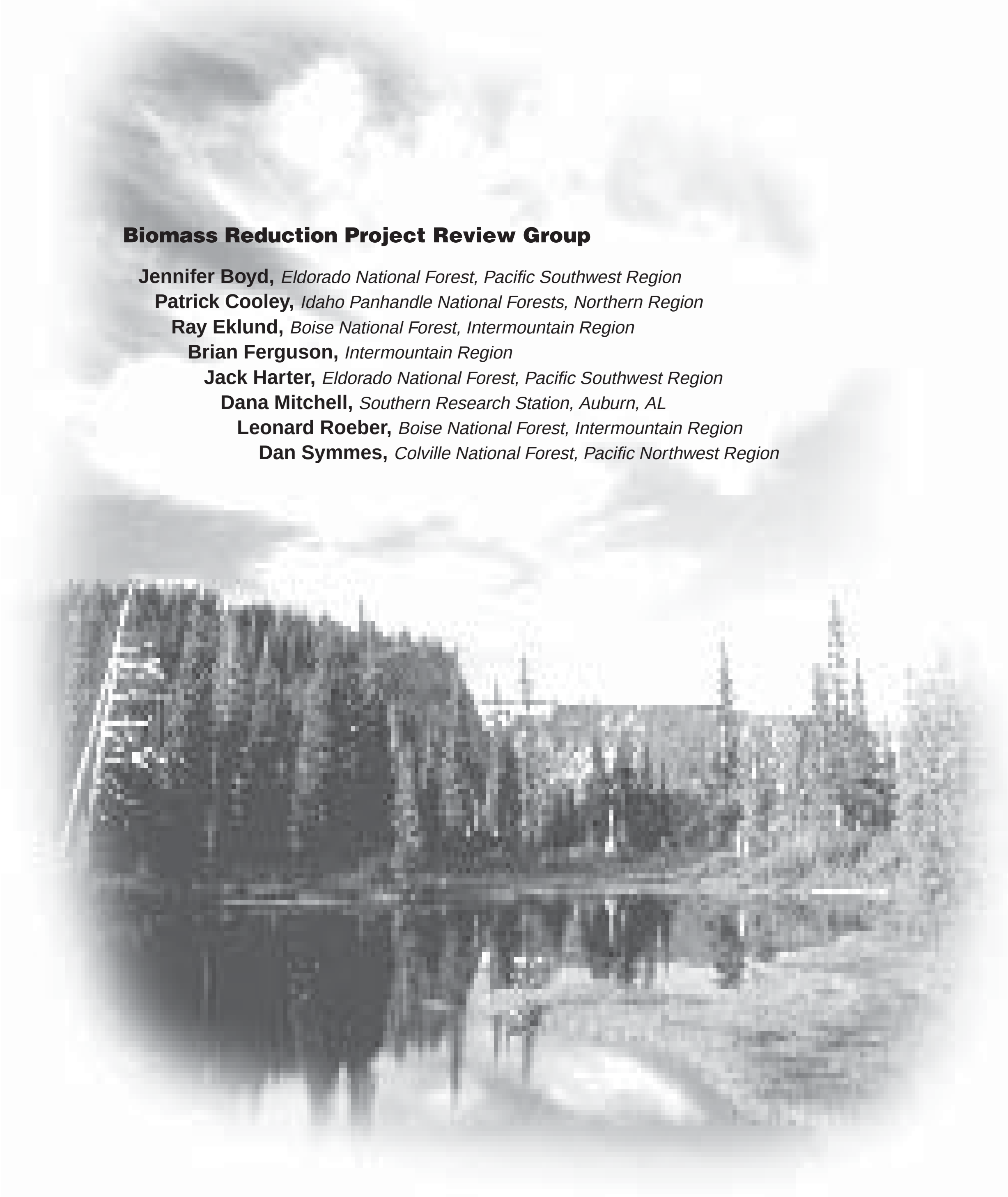
Understory Biomass Reduction Methods and Equipment Catalog

Acknowledgments

This publication was requested by a specially formed biomass reduction project review group. The group offered useful and informative input that has been incorporated into this report. In addition, the group reviewed several intermediate drafts. MTDC appreciates their contributions. The authors would also like to thank Sara Lustgraaf for her dedicated efforts in the extremely tedious task of laying out this report for publication.



Biomass Reduction Project Review Group

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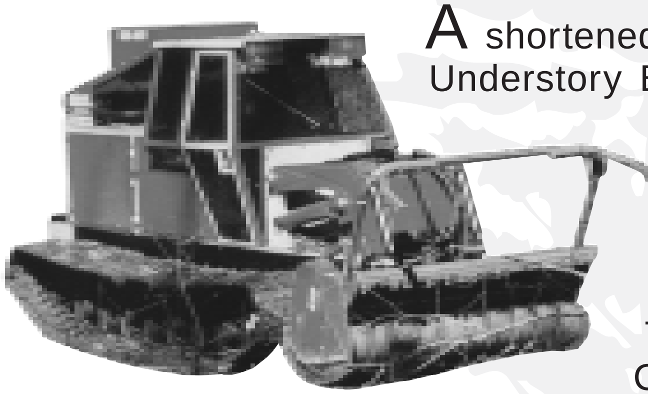


A shortened version of this report titled Understory Biomass Reduction Methods and Equipment (0051-2828-MTDC) does not include the 137-page Catalog of Machines and Specialized Equipment. It is available from the Missoula Technology and Development Center.

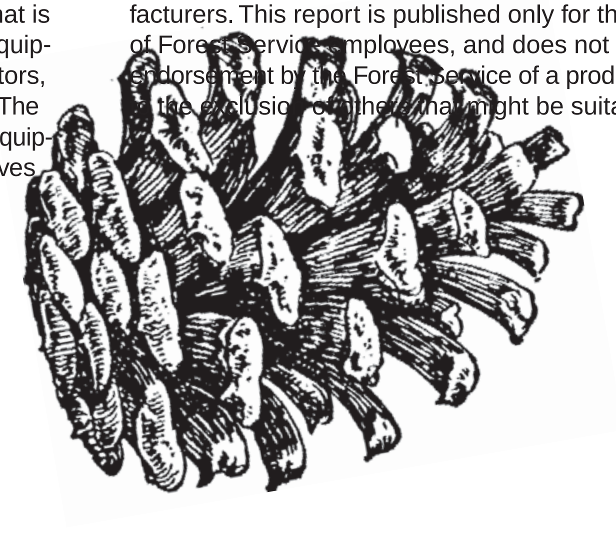
Introduction

This project began at the request of the Washington Office Fire and Aviation Management staff. They asked the Missoula Technology and Development Center (MTDC) to identify or develop equipment and techniques to help managers reduce extremely hazardous fuel-loading (biomass) conditions in ponderosa pine ecosystems where managers wanted to apply prescribed fire (wildland fire for resource benefit) on a landscape basis. The biomass reduction would facilitate the safe use of prescribed fire to maintain the health and vigor of these stands, and make it easier to defend them from wildfire. One project constraint given to MTDC requires that the biomass be considered unmarketable. This means that the sale of products such as wood chips or poles can't offset the cost of reducing the biomass. The methods and equipment identified in this project should apply in other fire-dependent ecosystems.

When MTDC began gathering information about equipment suitable to treat landscape areas before prescribed burns, it quickly became apparent that a comprehensive catalog would not be feasible due to the volume of information, as well as the time and budget allotted to the project. To keep the size of the catalog manageable, the equipment that is commonly available and well known is not included (equipment such as chain saws, winches, skidders, excavators, loaders, nonleveling-cab feller-bunchers, and so forth). The catalog includes a variety of small and large pieces of equipment suitable for many different management objectives and budgets.

Because landscapes needing treatment may cover thousands of acres, machines with high production potential are highly desirable. Stand biomass that has no commercial value necessitates low treatment costs per acre. Some machines were included because they were inexpensive. Others were included because of their ability to operate on extremely steep slopes or rugged terrain (equipment such as self-leveling-cab feller-bunchers, extreme machines, monocable yarders, and so forth). Specialty equipment and systems of many types (low ground pressure machines) were added to the catalog, and so were attachments to commonly available equipment (such as excavator and skid-steer attachments that are particularly effective and efficient in reducing fuel loading).

The *Catalog of Machines and Specialized Attachments* section of this report is not a comprehensive source, but is a general overview of equipment available for manipulating fuel profiles before prescribed burns (or, in some cases, instead of prescribed burns). A reasonable effort was made to include most available types of equipment. The equipment and specifications come from data supplied by the manufacturers. This report is published only for the information of Forest Service employees, and does not constitute an endorsement by the Forest Service of a product or service to the exclusion of others that might be suitable.



Historical Perspective

With few exceptions, the condition of ponderosa pine stands in the American West has changed significantly since the turn of the century. With the arrival of European settlers, wildland fire began to be viewed as a threat to the land's new uses. Whenever possible, wildland fires were excluded from the landscape. This general policy remained in effect until relatively recently when the land managers began to recognize its harmful effects.

Fire has historically acted to control the regeneration and invasion of certain plant species. In the absence of fire, these species now occupy a much greater percentage of the landscape than they once did. Some of these species, such as Douglas-fir, are not entirely suited to the sites they have invaded and are now more susceptible to insects and diseases. Even on sites that are primarily ponderosa pine, trees can become stressed due to competition for moisture, light, and nutrients. Ladder fuels, provided by thick regeneration, now exist from the ground to the crowns of the mature trees. In addition to the increased biomass, the risk of high-intensity fires also has increased. This condition existed to some degree before 1900, but is so extensive today that it has become the norm in ponderosa pine stands.

The effect of these changes is that parent stands are now more vulnerable to fire. When a fire does occur, it will be of much higher intensity and longer duration than if the stand were in a more natural condition. Mature trees that would have survived periodic, low-intensity fires a century ago may be killed by today's high-intensity fires. A fire that would have been a low-intensity ground fire in a more natural stand might now become a stand-replacement fire.

The stands that require work before prescribed fire can be successfully reintroduced may be in the forest (multiple-use areas), at the residential/forest interface, or in wilderness areas. Treatment areas may have good road access or be roadless, and they may have been previously logged or may never have been touched. Slopes can range from flat to those that are steeper than the operating limits of the most sophisticated machinery.

Extent of the Problem

To help determine the extent of this fuel-loading problem, the Washington Office sent out a short field survey. Information requested included the approximate number of acres in ponderosa pine types that needed some sort of preburn treatment and a listing of equipment and techniques that have been used to reduce fuel loading. Some Regions noted that the answers to the questions on ponderosa pine-type acres needing preburn treatment were not readily available from recorded data. Some assumptions had to be made. Approximate reported acres needing preburn treatment were:

❏ Intermountain Region (R-4)—4,788,000 acres.

❏ Northern Region (R-1)—4,650,000 acres.

❏ Pacific Northwest Region (R-6)—3,655,000 acres.

❏ Southwestern Region (R-3)—846,000 acres.

❏ Rocky Mountain Region (R-2)—Substantial (4.4 million total acres in ponderosa pine or mixed stands, the percent needing preburn treatments was not stated).

❏ Southern Region (R-8)—Not applicable. However, due to recent storms, the treatment techniques can be applied to 40,000 to 80,000 acres of blowdown in the National Forests of Texas.

The equipment and techniques identified in the informal survey, along with associated costs and production rates, are summarized in Appendix A.

Project Constraints

Based on interviews with the project initiator, other fire and fuels researchers, and field personnel, this project has the following equipment and technique constraints:

- ❏ There is no current commercial value to site material.
- ❏ Continuous thinning slash is too hazardous to be left in place.
- ❏ Chemicals are not an option.
- ❏ Minimal soil disturbance is desired (displacement, compaction, and so forth).
- ❏ Minimal leave-tree damage is desired.
- ❏ Equipment included must be able to manipulate the unmerchantable material.
- ❏ Equipment included must be readily available.
- ❏ Equipment included must be reliable.

Because so many different management objectives are possible, this report is limited to suggesting several fuel-reduction approaches, identifying appropriate equipment, and making comments on the equipment's ability to meet project constraints. The reader is left to decide if the ideas or equipment presented in this report are suitable for local needs and if they meet applicable guidelines.

Revenue Considerations

Revenue-generating material would provide options to help reduce the treatment cost. When there is no product to generate revenue, the task boils down to finding the lowest-cost strategy to prepare the stands for prescribed fire. The acceptable preburn treatment costs are influenced by the value of the resources that must be protected from catastrophic fire. It is more acceptable to spend large sums near residences and developed areas than in remote forest lands. Care should be taken so monetary considerations do not adversely affect the overall objective. A "cheap" prescribed burn can burn up the resource. Even if a low-cost treatment leaves the desired vegetation, loss of intangible or intrinsic values such as sensitive wildlife habitat—especially for threatened and endangered species—may have costs that are difficult to quantify.

Some acres can be treated inexpensively because little or no preburn treatment is needed, slopes are gentle, and only a small burning and holding crew is needed. Other acres may cost much more to treat and must be averaged with the inexpensive acres to make the overall treatment cost acceptable. This typically occurs when breaks or buffers are created to make the more difficult areas safer to burn. Low-cost units are frequently burned first so Districts can stay within their budgets while meeting resource targets. This creates a potential problem, since low-cost units are not necessarily the ones that have the highest treatment priority. When the more difficult acres are tackled, fewer low-cost acres may be left to average with them.

Increasing concerns about environmental implications of past forest management practices have led to the development of ecosystem restoration and management techniques, where fire hazard and pest problems are addressed in conjunction with timber-production activities. Such cost recovery is beyond the scope of this report. For a discussion on evaluating restoration prescriptions in ponderosa pine stands and the degree to which the value of product removals might underwrite treatment costs, see Product and Economic Implications of Ecological Restoration by Carl E. Fielder and others, Forest Products Journal, Volume 49, Number 2.

Auxiliary projects, such as commercial and individual firewood gathering and post and pole operations, may help offset some costs but rarely get the job done and do not significantly impact revenues. If forestry equipment is already in the woods on another project, it may be considerably more cost effective to use the existing equipment rather than to bring in other machines.

Other Considerations

A particular machine or method may be used not only to meet objectives from a fuels standpoint, but can also assist in meeting silvicultural objectives (regeneration, thinning, and other resource values), NEPA (National Environmental Policy Act) requirements and mitigation measures. These considerations may even set parameters that dictate or highly influence the choice of suitable equipment or the right approach for a particular situation.

In some cases mechanical treatment may be the total treatment because of local regulations limiting smoke, as in California, where alternatives to fire must be considered. Where followup with prescribed fire would otherwise be the normal course of action, managers will have to be satisfied knowing they have made a difference in fire behavior by decreasing dangerous fuel levels.

When hazardous biomass is reduced, all down wood or live vegetation other than ponderosa pine does not have to be removed. Other vegetation and down wood will contribute to diversity and the long-term sustainability of these ecosystems. Brian Ferguson, regional silviculturist from the Intermountain Region, recommends considering mosaics that allow diversity instead of getting rid of all vegetation. Mosaics can reduce fire potential across landscapes by breaking up fire patterns. In some areas, down wood can be left to provide opportunities to meet forest management plan long-term productivity standards for coarse woody debris (greater than 3 inches diameter), provided the debris does not contribute to excessive fuel loading. Machines could be used to distribute the debris.

Brian stated that recent discussions with staff from the Rocky Mountain Research Station (Moscow, ID) resulted in recommendations to rearrange fuels on the forest floor and to use broadcast burns instead of firing concentrated piles. According to this perspective, the use of extremely hot prescriptions and burning large piles can be detrimental to site productivity and nutrient recycling. Broadcast burns result in more uniform distribution of nutrients.

Treatment Concepts

The focus of this report is fuel treatment in a stand of ponderosa-pine overstory with a dense ponderosa-pine understory and/or Douglas-fir encroachment. The concepts are applicable (with or without adaptation) to other stand configurations. The condition of the stand is defined as overgrown with excessive ladder fuel. Ground fuel loading may or may not be excessive. Pockets of dense, small Douglas-fir create an additional problem that's difficult to treat with prescribed fire alone.

Given these conditions, potential treatments will be divided into three categories:

- Special prescribed-fire techniques.

- Mechanical treatment.

- Fuel reduction during harvest (Note: This approach is precluded by project criteria but is included here to assist managers in taking advantage of the opportunities to reduce other fuel-treatment costs.)

Special Prescribed-Fire Techniques

Before considering expensive mechanical treatments, it's important to review possible ways to deal with excessive fuel loading by deviating from the traditional preferred prescribed fire. A preferred prescribed fire, for purposes of this report, is defined as a single burn that removes all the desired fuel with very little risk of escape and little or no problems associated with smoke management. After treatment, the stand can be put into a more historically based burning cycle. The next couple of sections present some schemes that make use of the extreme ends of the burning window and may require a short time interval between burns. Some of the concepts presented are fairly common. Others are speculative, and may or may not be practical or advisable given local circumstances.

Series of Short-Interval Prescribed Fires

A series of low-intensity prescribed fires could be attempted in some stands to use crown scorch to kill undesirable saplings and seedlings. Subsequent burns would consume dead material killed during earlier burns. A minimum of two burns in close succession would be needed. Several burns could be required to get the stand into a condition where a preferred prescribed fire could be safely applied at a landscape level. Some fire personnel have indicated their biggest problem has been getting enough suitable burn days for this technique because of narrow burning and smoke management windows.

John Waverek, Fire Management Officer at the Missoula Ranger District (Lolo National Forest), has had good results with short-interval prescribed fires, even when substantial ladder fuels were present. He generally conducts the first burn on the wetter side of the prescription. Natural barriers are used to contain the fire perimeter, whenever possible. Best results are obtained with some preparation, such as fuel augmentation. If fuels need to be augmented, the use of chain saws should be considered. Sawyers can move quickly through the stand, creating pockets of fuel to be burned. The helitorch is used to burn during wetter periods. This equipment allows burning in wetter conditions than would be possible with ground ignition or with the plastic sphere dispenser. The helitorch works very well in remote, inaccessible terrain where crew safety is a factor in determining whether the project can be accomplished by hand ignition.

The Missoula Ranger District burned 900 acres using this technique for under $14 per acre (cost of first burn, no holding lines constructed). For this approach to be used successfully, the burn boss and crews must be very knowledgeable. An inexperienced crew could end up with results that are less than desirable. Since wetter material has a tendency to smolder and produce smoke, air quality must be carefully monitored. The lack of smoke dispersal can meet with public disdain. Future treatments involve coming back on short intervals (perhaps every 2 years) until site conditions meet management objectives. A little more of the undesirable accumulated fuel and duff layer is removed with each burn.

Although some districts are treating stands exclusively with fire, their work appears to be based only on experience (trial and error). Mick Harrington, a researcher at the Rocky Mountain Fire Sciences Laboratory in Missoula, MT, indicated that very little research, if any, has been done in the area of thinning stands with fire. Research could lead to operational guidelines that would help promote this concept.

Slashing Douglas-fir and Allowing It to Dry

Fire managers in the Northern Region note that dense stands of small Douglas-fir don't burn until the site is fairly dry. Pockets of these trees that are usually found in moister areas of the stand have been known to create barriers that prevent a prescribed fire from carrying. An informal local theory holds that the short needles of Douglas-fir compact tighter than ponderosa pine needles in the duff. This characteristic, combined with the dampness in these pockets, does not produce enough heat to scorch the young Douglas-fir during a prescribed fire. By the time these pockets are ready to burn hot enough to scorch the young Douglas-fir, the ponderosa pine is very flammable and the stand is often out of prescription. Northern Region fire managers have suggested that slashing some of the dense pockets of the Douglas-fir and letting the trees dry will widen the treatment window—a procedure that also works with whitebark pine. A variation is to fell the larger Douglas-firs into the patches of the young firs and let them cure before burning. This would eliminate a large seed source, reduce the ladder fuels and encourage scorching, killing young Douglas-fir seedlings (assuming Douglas-fir regeneration is undesirable).

Burning Duff

Karen Jones, a silviculturist for the Truckee Ranger District on the Tahoe National Forest, mentioned that they occasionally burn the litter/duff layer at the base of pines after snow has melted at the base of the trees, but while snow is still on the ground between the trees. They use a drip torch to ignite the dried litter layer. Snow patches between the trees prevent fire escapes and help control treatment intensity. This approach also reduces flame lengths and fire intensity around tree bases when the crew comes back after snow-melt and burns strips between the trees. This approach may not be adequate to deal with the ladder-fuel problem on the more heavily overgrown sites considered in this report. It can also lead to loss of nutrient cycling and long-term productivity.

Steve Arno, a researcher at the Rocky Mountain Fire Sciences Laboratory, expressed concern that burning the thick duff layer at the base of mature trees could damage root systems. He mentioned that some tree mortality has been attributed to this problem. Raking the duff layer from the base of mature leave trees before burning has been suggested. Steve says that raking the duff around mature trees is also costly and not realistic on large landscape-type burns. The Pacific Southwest Experiment Station is conducting a multiyear study on the effects of burning around large mature sugar pines on the Eldorado National Forest (Pacific Southwest Region). Effects of raking around the base of trees, season of the fire, and fire duration are among the elements being analyzed.

Burning During Snow Season

The Bitterroot National Forest sometimes goes into an area twice in the same year. If there is too much fuel on the ground, crews go in while the unit is still wet or has snow remaining and does a jackpot burn. Jackpot burning ignites ground-fuel concentrations remaining from a slashing operation or from natural fuel buildup over the years. Burn crews return the same year under drier conditions for a followup burn.

A technique used in the past by private timber companies was to wait until the first snowfall before burning. A small crew would traverse the unit using drip torches to ignite anything that would burn. Nature put out the fire during the winter. The concept was to reduce the fuel loading and create a mosaic in the unit at a reduced cost. Some States, such as Montana, have state air pollution laws that generally do not allow fires that will burn for several days to be ignited between November and March. Some exceptions are allowed.

Another burning opportunity occurs in the spring when crews can burn at and below the snow line. Larger fuels are still saturated with moisture. The snow line acts as a natural barrier, preventing escapes. The crew returns to the unit repeatedly as the snow line recedes and the fuels dry out. Spring burning may not be practical because of the smoke management problems associated with smoldering, damp fuels.

Aerial Options

A variation of the last two concepts is to use aerial ignition (helitorch or plastic-sphere dispenser). A major drawback to the helitorch is that vegetation is burned indiscriminately. Occasionally, torch fuel lands on desirable leave trees. A concern when using the plastic-sphere dispenser in wet conditions is the possibility that plastic debris and residual chemicals from the spheres will not be consumed by the fire.

In general, aerial ignition is associated with lower costs. Costs can be reduced further when new treatment areas are near areas that received previous burn treatments. If the helitorch is used, the helicopter can treat the new areas and treat older areas a second time while working from the same helispot. A variation on this approach is to burn smaller blocks on the perimeter of a larger block. The smaller blocks can act as a safety buffer so the interior can be burned under more intense conditions at a later date.

Fireproofed Perimeter With Hot Center Burn

A more radical approach is to fireproof a perimeter and then conduct a hot burn in the middle. Very little preparation takes place in the interior and some crowning will occur. This treatment will occasionally cause intense burns that create mosaics in the stand. Some desirable trees will be lost, but it is to be expected. This approach involves burning under hot prescriptions and making maximum use of the natural barriers like ridgetops or rock outcroppings. The possibility of an unplanned increase in target acres should be discussed and addressed through contingency planning. Increased biomass reduction during the initial burn should reduce the number of times the area has to be burned to achieve the desired end result. If the fire does not escape, this approach should result in lower overall treatment costs. Although fuel-reduction treatment costs may be lower, they must be weighed against possible reduction of stand diversity and long-term productivity. There is also the potential for suppression costs associated with fire escapes. Managers must consider these risks and compare them to the costs and extreme site damage associated with a wildfire during the height of the fire season. This approach is not acceptable near the forest/residential interface, but may be acceptable in more remote areas. Some field units have used this approach successfully on wildlife burns and have kept the treatment costs well within $100 per acre.

Residential/Forest Interface

Although some homeowners in residential/forest interface areas may object to fire treatments because of smoky conditions or blackened ground, these effects usually are short lived. Homeowners need to know that the greatest reductions in fire behavior or flame lengths—short of removing fuels from the site—come through prescribed burning. A well-written burn plan should keep undesirable visual effects to a minimum. The Forest Service's liability is not to be taken lightly. More money may need to be invested in preburn mechanical treatments in stands close to populated areas. Mechanical treatments can range from none to total when they are used instead of, or in conjunction with, fire. Chipping may be an effective option here. Recently, more consideration has been given to breaking up fuel patterns across large areas away from the residential/forest interface, areas that would otherwise be economically unfavorable to treat. The extent of mechanical treatments has to be worked out between fire managers and homeowners.

Mechanical Treatment

When fire alone is judged to be too risky or ineffective under acceptable prescriptions, partial mechanical treatments can be considered. Current treatment cost information is limited and site specific. Slope, stem diameter, stems per acre, and treatment objectives are just some of the factors that make it difficult to predict accurate costs. Cost per acre varies greatly. Appendix A includes some historical mechanical costs as reported in the initial field survey. There probably will be a need for some of the costlier mechanical preburn treatments presented in this section, especially at the residential/forest interface.

Using mechanical methods to rearrange the fuel profile can mitigate the risks of fire escape during prescribed fires. Only the vegetation that directly threatens the survival of the desirable leave trees (taller ladder fuels and concentrated fuel pockets), or vegetation that significantly increases the chance of fire escape, should be treated mechanically. Prescribed fire will kill the smaller standing ponderosa pine and the widely spaced Douglas-fir trees (stems less than 2 to 3 inches diameter).

To minimize preburn treatment costs, mechanically treat only the areas where the fire is most likely to go into desirable leave-tree crowns and perimeter areas surrounding the major area to be burned, especially any residential/forest interface. Once the perimeter areas have been fireproofed, the central area could be burned under a hotter prescription that would reduce the undesirable vegetation more quickly. Costs of the partial mechanical treatment should be spread through all the acres that are burned.

Tracks Versus Wheels

To meet the project's criteria, any machine used in the preburn treatments must not cause excessive soil disturbance (compaction, displacement, and so forth), must not damage leave trees, must be readily available, and must be reliable.

Because tracked machines typically have lower ground pressure and are more maneuverable on slopes, they meet the project's site disturbance concerns better than wheeled machines. (A potential exception may be some of the latest cut-to-length wheeled harvesters working on slash mats. This concept could use further study.) Soil compaction can be mitigated by working on snow or frozen ground, working on slash mats, or working when the soil is very dry. Although equipment with boom-mounted implements requires the operator to constantly reposition the machine, the overriding advantages are that the boom can reach over difficult areas the prime mover can not traverse. In addition, some ground is not compressed by the machine's weight. The boom can work in spaces tighter than the machine can travel through, but the operator must occasionally stop cutting and reposition the prime mover. In a telephone interview, Rick Toupin, a Logging Systems Specialist for the Pacific Northwest Region, mentioned that soil compaction is a significant issue there, and that using ground pressure exclusively to indicate soil compaction is misleading because of other interacting factors. Region 6 uses the amount of ground covered rather than pressure as an indicator of soil compaction during logging operations. This approach would favor a machine with a boom.

Some of the mechanized brush cutters commonly used to clear power line rights-of-way have wheels. Although the wheeled machines are very productive and usually less expensive to purchase and operate, they typically have higher ground pressures and are limited to gentler slopes than their tracked counterparts. Tracked machines would be more versatile in a typical forest setting. Exceptions may be wheeled vehicles equipped with over-the-tire tracks (see catalog section).

Methods to Modify Fuels Profile

Lop and Scatter

The most widely used slash treatment method for precommercially thinning pine stands in eastern California is lopping (with a chain saw) and scattering. Weatherspoon (1982) notes that this is one of the least expensive methods used, but it is also the least beneficial slash treatment for hazard reduction. Weatherspoon says that it can be an effective pretreatment, facilitating subsequent use of prescribed fire in certain stands. This approach will not work in stands of densely packed trees if the thinned slash will cause the fire to scorch leave trees and possibly start a crown fire (see *Project Constraints*). In more open areas lopped material could be scattered in openings. In such cases, the thinned slash might even be needed to carry the ground fire.

Cut With Chain Saw, Hand Pile, and Burn

When cutting the material with chain saws and hand piling it, quite a bit of large woody material can be left scattered onsite to meet guidelines for coarse woody debris. In many cases only the tops and some branches need to be piled. Small winches could be used if larger materials are to be moved. The piles can be burned when convenient and when fuel moisture is too high to carry a ground fire. Some districts cover the piles with tarps to make them easier to ignite in really wet conditions. The use of chain saws should be considered and compared to any machine felling and piling systems before making a decision. Minimal preburn treatments may favor chain saws and hand piling. Extensive preburn treatments may favor heavy machinery. Using chain saws and hand piling may be the only option on steeper slopes. On the flip side, consideration should be given to the effects of pile burning on soil nutrient depletion.

Cut, Machine Pile, and Burn

A tracked machine with a boom can be used to cut and pile undesirable biomass, manipulating the fuel profile. Equipment should be sized to the vegetation. The feller-buncher is an attractive choice for brush cutting if the machine is already in the area and the saw head can be removed so that a brush head can be quickly installed. If all material is to be burned, the pile can be compacted with the machine, if desired, and left to cure.

One advantage of pile burning is that the piles can be burned during wet weather. This treatment should be done on the perimeter units where there is risk of fire escape. Once a safety buffer surrounding the main area has been mechanically treated and burned, substantially reducing the fire hazard, the main area can be burned. With a safety zone around the main area (either manmade or natural barriers), hotter prescriptions can be considered. For instance, ladder fuels could be thinned exclusively with fire in densely packed stands. Disadvantages to pile burning include the possible negative effect on soil nutrient depletion and collateral damage due to scorching of leave trees.

During the course of an interview with Steve O'Brien, a Northern Region logging engineer, discussion centered on a basal area reduction treatment that is being used by a large commercial logging company on some of its land in the Pacific Northwest. The following scheme is slightly outside the scope of this project but is included because it is a sensible approach if merchantable logs can be taken to offset costs during the course of the fuels treatment. The company's basic idea is to cut the merchantable and "weed" trees at the same time with a feller-buncher head mounted on a boom, and pile all trees (including weed trees). The use of this "hot saw" (continuously running disc saw with accumulator) significantly increases the logger's productivity compared to using a processing head. In another operation the merchantable material in the piles built by the hot saw is fished out and processed into cut-to-length pieces with a second machine equipped with a processor head. The merchantable material is taken out by a forwarder. The limbs and tops are left in the forwarder trail to be driven over.

After the forwarder removes the merchantable material, the unit is burned. The merchantable material provides income to help offset the cost of the preburn and burn treatments. This treatment thins the stand to increase site productivity and reduce the fire hazard.

The advantage to this company's approach is that the operator can work around the base of the leave trees with minimal damage and pile the burnable biomass a safe distance away. The hot saw can handle larger material with no problem. If equipped with a boom, the machine does not have to traverse every inch of ground, minimizing soil disturbance. The weed-tree piles could be concentrated and compacted with the machine if desired. Because the burning window is longer for pile burns, the piles could be burned when it's convenient. Firelines could be easily constructed around the piles if they began burning during a wildfire. Excavators and feller-bunchers are common machines, so this approach could be widely practiced. On gentle slopes, a tracked skid-steer or similar machine with a feller-buncher head may work.

Cut and Trample

A hot saw on a feller-buncher could cut down the trees. The machine could then move the cut material away from the base of the leave trees and run over the cut material. This approach eliminates the need to come back and burn piles before a prescribed fire, and helps break down the slash and put it closer to the ground. The resulting slash mat should also minimize soil disturbance by the machine traveling over it. This method raises questions about defense against wildfire while fuels are scattered on the forest floor. Trampling may reduce the hazard to acceptable levels. This possibility will have to be evaluated on a site-by-site basis. Prescribed burning of fuels that are crushed too finely and mixed with dirt may lead to incomplete combustion (smoldering) and smoke management problems. The amount of crushing must be carefully monitored. If burning later becomes prohibited, decomposition of the trampled slash will be slower on dry sites than on wet sites.

Crush and Chop

Another treatment method is to knock down the young standing trees, brush, and slash (logging and blow down) and crush or chop it up. When ladder fuels are removed or reduced, prescribed fires are easier to manage. The same equipment could be used for fuel augmentation. Weatherspoon (1982) notes that machine crushing can be an effective pretreatment for prescribed burning in some stands. Several papers on the use and productivity of chopping and crushing equipment were found and are referenced in Appendix B. (Anonymous 1967; Bryan 1970; Hopkins and Anderson 1960; Miyata and others 1983).

Crushers such as the Tomahawk in Figure 1 (Young Co., no longer made), the T.G. Schmeiser Co., Inc.'s Till n' Pak, or Hakmet USA's Meri Crusher should work between widely spaced leave trees. Rolling choppers (Figure 2) are commonly used for land clearing and site preparation in the Southeast (Marden Industries, Inc., Savannah Forestry Equipment Co., and Rockland Manufacturing Co.). None of these implements work very well with material that is supple, such as green seedlings. The equipment works better with dead material (slash) or during the winter months when material is frozen. This approach would probably also have to include a method or piece of equipment to get the standing material down. Large dozers with tree shearing blades (Savannah Forestry Equipment Co., Rockland Manufacturing Co., Rome, and Sharpco) have been used for land clearing operations. This equipment train would require a large turning radius, so tree spacing would be a consideration. Detrimental soil disturbance and damage to leave trees are also concerns with these machines (see the Catalog of Machines and Specialized Attachments).

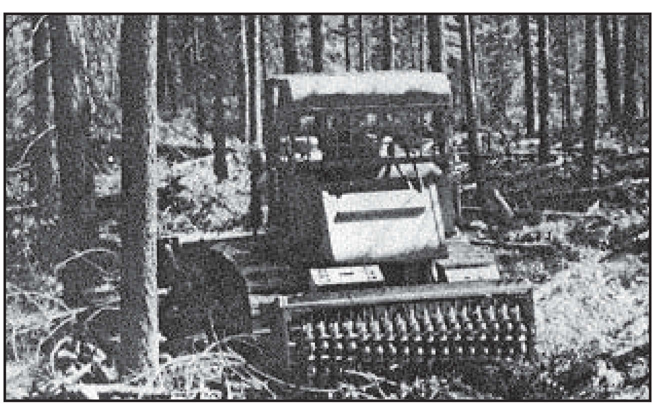


Figure 1—Tomahawk crusher.

Brush-Cutting, Thinning, and Shredding Machines

When a fire escape would be astronomically expensive, such as when residences are nearby or when the time required for sequential partial burns is not acceptable, mechanical treatments such as brush cutting, precommercial thinning, or shredding may be necessary. A wide selection of machines is available (see Catalog of Machines and Specialized Attachments). Many machines have been developed specifically to dispose of logging slash, but they can be costly to use.

If the objective is to reduce the vegetation in place, several mobile brush cutters and shredders can do the job. Mechanical brush-cutting equipment may have a vertical or horizontal shaft and the head may have fixed or free-swinging cutters. The heads may be machine mounted, boom mounted, or machine pulled. Some equipment manufacturers distinguish between an integrated machine and a specialized attachment, as we have done in the catalog section of this document. Many excellent publications on this subject are available (Karsky 1993; McKenzie and Makel 1991; Ryans and Cormier 1994).

A brush-cutter head mounted on a tracked excavator may offer a reasonable solution on slopes up to 35%. When a brush cutter head (many are commercially available) is mounted on a tracked feller-buncher with a self-leveling cab, the slope steepness may be increased to 50% or slightly more. The tree spacing must be considered. The tail swing on conventional excavators may damage leave trees, but it is negligible on zero-tail-swing feller-bunchers. Even if this equipment permits some kind of treatment on steep slopes, cost will be a factor. Some forests use the Slashbuster head

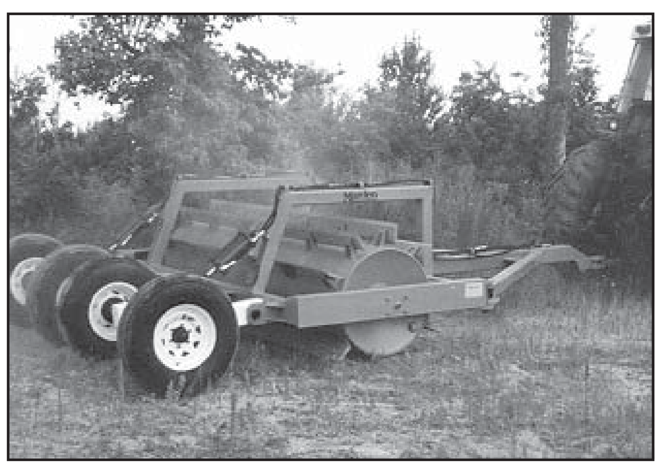


Figure 2—Rolling chopper used for land clearing.

(D&M Machine Division, Inc.) on an excavator for fuel treatment and have indicated costs range from $220 to $270 per acre. One forest mounted the Slashbuster on a self-leveling-cab feller-buncher and estimated costs at $600 per acre. (Appendix A has additional information on equipment and techniques for this project as reported by forests.)

Vertical- Versus Horizontal-Shaft Machines

Most of the literature reviewed indicated that vertical-shaft machines are more productive than horizontal-shaft machines (Figures 3 and 4). Vertical-shaft machines produce a coarse, splintered stem and require a larger safety zone than the horizontal-shaft machines. Ryans and Cormier (1994) mention studies that show it is cheaper to cut stems with a vertical-shaft brush cutter and come back and stack the stems than it is to grind the stems with a horizontal-shaft machine. Some forests commented they thought there was more damage to leave trees when they used a vertical-shaft design with free-swinging cutters than when they used a drum shredder with free-swinging cutters. For equipment examples of both

Figure 3—The cutting head on the Kendall Cutter is a typical vertical shaft with free-swinging cutters.

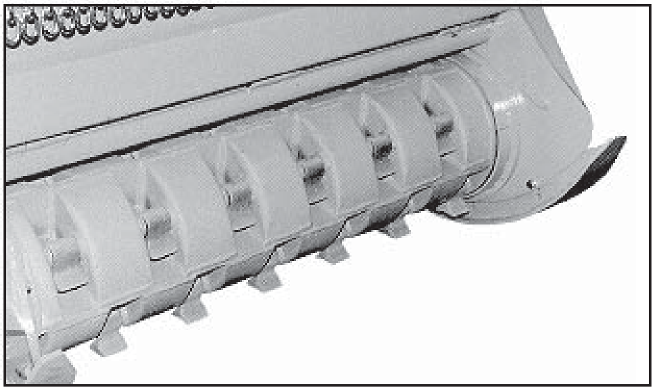


Figure 4—Seppi M drum shredder with free-swinging cutters.

types, see the *Catalog of Machines and Specialized Attachments*. Table 1 compares the two designs.

The Slashbuster is a vertical-shaft design with fixed teeth (Figure 5). This head allows vegetation to be mulched in place. The head is also available with a “thumb” that allows vegetation to be piled. An excavator attachment called the VH Mulching Head (West-Northwest Forestry, Inc.) has an optional prototype tool head that uses replaceable carbide teeth and rotates very slowly compared to the Slashbuster. It also comes with a large thumb for piling vegetation. The Shar 20 by Shur Shar Manufacturing (Figure 6) is a specialized machine with a vertical-shaft, fixed-tooth disk, also available with free-swinging cutters on a disk. This machine and similar designs, such as the Lucky Logger (no longer available) and Timbermaster TM-20 (no longer available), have been used successfully on Forest Service lands in the past (McKenzie and Zarate give production data on several machines used for precommercial thinning and slash treatment in *Field Equipment for Precommercial Thinning and Slash Treatment—Update*, Project Record 8424-1204-SDTDC). Drawbacks include huge initial cost for the machine and the limited number of machines currently available. The machines are long and may have difficulty maneuvering in tight spots.

Table 1—Comparison of vertical- and horizontal-shaft reduction heads (McKenzie and Makel 1991).

VERTICAL-SHAFT HEADS—			
Advantages		Disadvantages	
• Low horsepower requirements • Cuts even when dull • High kinetic blade energy	• Low blade life • Low energy consumption per ton of chips produced	• Can leave high stubs • Small bearing area at blade attachment points—can accelerate wear here.	• Large safety zones required • Can have poor operator visibility • Machine may be longer overall
HORIZONTAL-SHAFT HEADS—			
Advantages		Disadvantages	
• Capable of cutting close to ground • Can be closer-coupled machine • Can have good operator visibility • Can have large blade bearings	• Both ends of blades usually supported • Can have high kinetic drum energy (flywheel effect)	• Higher power needed to drive cutters • Usually low kinetic blade energy • Blades can be difficult to change	• Poor cutting when the blade is dull (low kinetic blade energy)

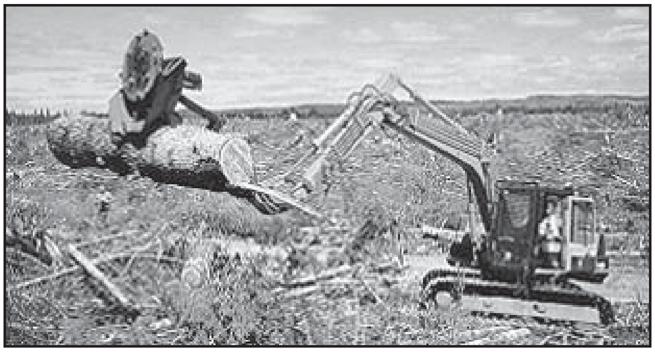


Figure 5—The Slashbuster has a vertical shaft and fixed teeth.

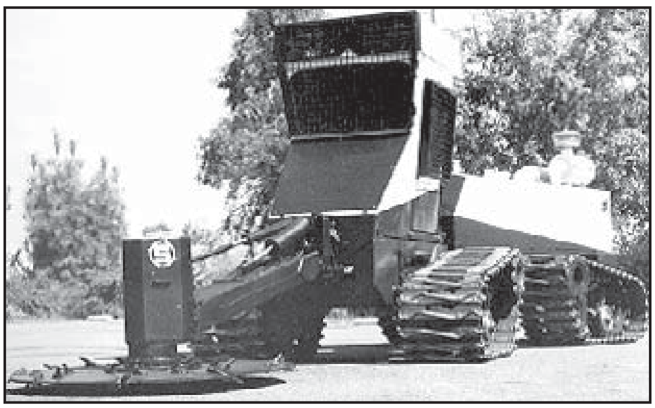


Figure 6—The Shar 20 has a vertical shaft and a fixed-tooth disk.

Tracked machines with booms and slashing heads like the Slashbuster, KDX mulching head (Kemp West, Inc.), Brushco (Figure 7, Quadco Equipment, Inc.), Pro Mac (Pro Mac Manufacturing, Ltd.), and Grizzly Tree Cutter (Alamo Industrial) can reduce fuels in place (see *Catalog of Machines and Specialized Attachments).* Some of these heads are available with a thumb to pile debris. This approach can be costly per acre unless it is used sparingly and the cost is spread over all acres to be burned. The Eldorado National Forest of the Pacific Southwest Region (R-5) has had good results using their Slashbuster in a variety of situations. They added a modified bar with cutting surface to the head, which helps to masticate smaller standing stems. Park-like effects can be achieved by a combination of machine work and successive burns. Park-like results may or may not be desirable from a cost standpoint.

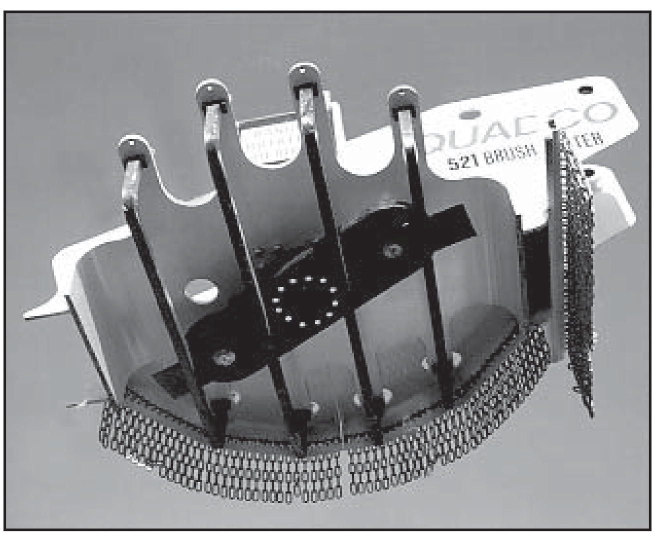


Figure 7—The Brushco brush-cutter attachment (made by Quadco) for excavators.

At one time, the San Dimas Technology and Development Center proposed a concept machine that had a horizontal-shaft drum with fixed teeth (McKenzie 1991). The head was an integral part of the machine, which was intended to thin and mulch trees in strips. The concept machine was never built and tested. Since that time, two companies, Fecon and Rayco, have each developed this type of machine (see Catalog of Machines and Specialized Attachments).

Chip

Another approach is the use of a self-propelled whole-tree chipper (Morbark Mountain Goat and Bandit Industries' Track Bandit in Figure 8, see Catalog of Machines and Specialized Attachments) to reduce fire hazard. Although this may be a feasible approach if a chip or hog fuel market is viable or if burning is prohibited, there are some drawbacks. A self-propelled whole-tree chipper can chop trees at the stump. A machine that cuts the trees must precede the chipper. The use of a felling machine or manual felling in addition to the chipper increases the cost of the operation. If a market for chips is present, provisions must be made to get the chips off the landing or out of the forest. Leaving chips spread out in the forest (assuming they could not be sold) would be a very expensive option, but it may be advantageous from a soils management perspective. The cost of the specialized chipping machines and the number that are available are also concerns. Although the Beckwourth Ranger District, Plumas National Forest in R-5, liked the concept of a feller-buncher working ahead of the Morbark Mountain Goat, they indicated that the Mountain Goat experienced a large percentage of downtime during a demonstration. Concerns about availability and dependability of the self-propelled whole-tree chippers make this approach less than ideal.

Figure 8—Track Bandit Model 1900 self-propelled whole-tree chipper.

Chipping has been done on a limited basis in the residential/forest interface on the Gila National Forest (R-3), Dixie National Forest (R-4), and the Bridger-Teton National Forest (R-4). On the Dixie National Forest, chipping was also used in conjunction with a project to reduce the spruce beetle infestations in camping areas where fire was not an option. Although tied to larger objectives, the projects were still costly. For chipping operations on landings, trailer-mounted whole-tree chippers should be considered.

Remove Biomass

Removing the undesirable biomass from a site involves handling every piece more than once, driving up treatment costs. Even though this report assumes material on the site has no current commercial value, for the sake of a broad discussion let's assume a viable chip or hog-fuel market is present, or that we want to move the biomass to a landing and wait for the market to become more favorable. In this case we need to consider options to get the material to the landing. When terrain permits, skidding material offsite with a rubber-tired skidder is more cost effective than using other logging systems such as cut-to-length and cable yarding. The cost of cable-yarding systems typically runs three times the cost of ground-based systems, according to interviews conducted for this project.

Whole-Tree Skidding

Whole-tree skidding (where the limbs are still attached) is especially cost effective and gets more of the biomass out of the unit. But whole-tree skidding at times has been found to cause undesirable soil disturbance and compaction. The Weyerhaeuser Company has reduced soil impact from rubber-tired skidders by using super-wide tires and studded chains rather than ring chains. Skidding over snow or frozen ground can also mitigate this problem. Whole-tree skidding increases the potential for damage to leave trees. In addition to skidding costs, the material must be cut in a separate operation.

A concern with this technique is nutrient recycling. Weatherspoon (1982) notes that "most nutrients contained in trees are concentrated in foliage and small branches. Removal only of material larger than 3 inches in diameter, therefore, removes relatively little of the nutrient capital of the site." With whole-tree skidding, all branches and tops are taken off the site where the nutrients would not be available for future forests.

Foresters on the Eldorado National Forest have been practicing whole-tree skidding on a number of sales over the past few years and report no adverse effects to date. The forests in the region have a relatively rich litter layer that remains intact when whole trees are removed. Limbs and debris that fall off during the thinning process are not cleaned up afterward. With repeated treatments, detrimental effects might be measurable. However, it was noted that with a 120-year rotation and thinning once every 20 years, trees will continue to produce, and nutrient stores should be maintainable or even increased. Pines hold their needles for 3 years, leaving 17 years for the needles to add to nutrient stores.

Although whole-tree skidding can be one of the cheapest ways to get the material out of the unit, it is often rejected because of soil disturbance, potential leave-tree damage, and additional handling costs. If there is no chip or hog-fuel market, the removed biomass will have to be piled and burned on the landing. The landing might need expansion to make room for the large piles.

Cut-to-Length Systems

Another harvesting technique gaining popularity is the cut-to-length system. This method causes less site damage than traditional rubber-tired skidding. The harvester lays the branches and tree tops in the forwarder's travel path to minimize soil disturbance. The forwarder crushes the branches and tops to reduce fire hazard. The shorter log lengths also reduce damage to leave trees. This approach is popular with some because it leaves more nutrients onsite. Drawbacks include equipment expense and lack of a high-value commercial product.

Girdle

A preburn treatment concept suggested to MTDC was to girdle undesirable trees. Girdled Douglas-fir trees would shed their needles after about 1 year. Ponderosa pines would do so after about 2 to 3 years. A prescribed fire on the wetter end of the prescription could remove the needle layer. Periodic prescribed fires would be passed through the unit as dead trees toppled over in a period of years. Youth crews could perform the work. Manual girdling equipment would have to be used because many youth crews are not allowed to use chain saws.

The girdling concept was discussed with fire researchers who thought the girdled trees would add to the fire hazard. When the needles were cured and still on the tree, ladder fuels would be extremely flammable. After the needle layer was burned off, it would be harder to get subsequent ground fires to carry through the unit, especially on the cooler prescriptions. During subsequent prescribed fires, standing dead trees become burning snags that could cast sparks across containment lines.

Some Equipment Options to Minimize Soil Disturbance on Steeper Slopes

Cut With Chain Saw and Hand Pile

Manual cutting with chain saws and hand piling may be the only feasible mechanical treatment possible on some steep slopes. Refer to the previous discussion in Methods to Modify Fuels Profile. Any other treatment considered should be compared to this one.

Multipurpose, Low-Ground-Pressure, Rubber-Tracked Machines

Some new, smaller, rubber-tracked machines may warrant a closer look. One is ASV, Inc.'s Posi-Track (Figure 9). It is reputed to be very stable on side slopes, but does not have a boom. The manufacturer rates it at 33% gradability on a sidehill. It has very low ground pressure (2 psi for the MD 70 with front loader, 3 psi for the HD 4500 and HD 4520 with front loaders). The Posi-Track can use any skid-steer imple-

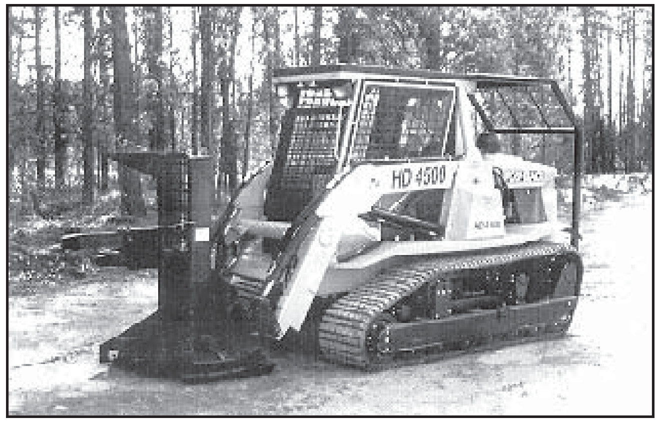


Figure 9—The ASV Posi-Track is a smaller, rubber-tired machine that shows good stability on slopes.

ment. A feller-buncher head can be mounted, but the machine does not have enough power to operate the larger brush-cutting heads. LMC Corporation makes a similar machine, the Trackmaster 85 rubber-tracked crawler, that also has very low ground pressure (less than 2 psi with a bucket.) The Trackmaster's power source is smaller than the Posi-Track (88.5 hp compared to 115 hp). Davco Manufacturing, Inc. makes a 14-inch cutting-capacity hot saw for the Posi-Track. New Dymax, Inc. makes a 14-inch tree shear with accumulator for skid-steer machines. Hahn Machinery, Inc. and Davco Manufacturing, Inc. make small processor heads that could be used with the Posi-Track. A small nonpowered tree cutter with accumulator (E-Z Implements, Inc.) is available that can handle a maximum tree diameter of 8 inches (see the *Catalog of Machines and Specialized Attachments* for more small tree-cutting equipment options and skid-steer attachments). A grapple and stacking forks are just two of the implements that can be used to create piles in the unit.

Feller-Bunchers With Self-Leveling Cabs

The private logging company's approach discussed earlier (see Cut, Machine Pile, and Burn under Mechanical Treatment, Methods to Modify Fuels Profile) could be expanded to steeper slopes (up to 50%) by using a feller-buncher with self-leveling cab (Timbco, Prentice, and Timberjack; see Catalog of Machines and Specialized Attachments). Even though common excavators can operate brush-cutting equipment on slopes up to 50%, the self-leveling cab feature is necessary when using a felling head so that there is proper tree orientation when cutting, and stability while moving with a cut tree on steep slopes. These machines also make excellent platforms for mounting brush-cutting heads. The performance of the early model Timbco feller-buncher (Figure 10) is documented in Stokes and Lanford (1983).

"Cutting upslope and bunching to the front was the single most productive pattern, and cutting downslope and bunching to the rear was the least productive," reported Stokes and Lanford. "To have continuous cutting the most productive pattern involved cutting across-slope and bunching uphill with the butts facing downhill."

Figure 10—Timbco T445C feller-buncher with the Quadco 22-inch disk saw.

Cable Yarders

Slash can be cable yarded on steep slopes with skyline grapples (Figure 11) or rakes (Krischuk and Miyata 1986). Once the material is on a landing, it can be piled and burned, or chipped. Unfortunately, the only commercial skyline grapple-rake designs that MTDC was aware of have been discontinued. An interesting option found in the literature is open-pit burning with a wind-generating machine called an air curtain destructor (Lambert 1972). This machine caused the material to burn so hot that smoke emissions were reduced substantially. Although it is possible to reduce the biomass in the unit using this approach, it would be extremely expensive to yard all the material to a landing.

Another possibility on steeper slopes is to concentrate the slashed trees into corridors and use a small cable yarder to yard the material to the landing for pile burning. If a market for small wood develops, small yarders like the Bitterroot Mini-yarder, a double-drum skyline and mainline yarder (Figure 12), or a monocable yarder can be considered. One commercial monocable system is the Howe-Line Monocable System (imported under the name Truckhowe, CC), which is not yet widely available in the United States, shows promise (Figure 13). It has a distinct advantage over zigzag-style monocables because it can yard in straight lines using specialized blocks and doubletrees to suspend the cable (see *Catalog of Machines and Specialized Equipment*).

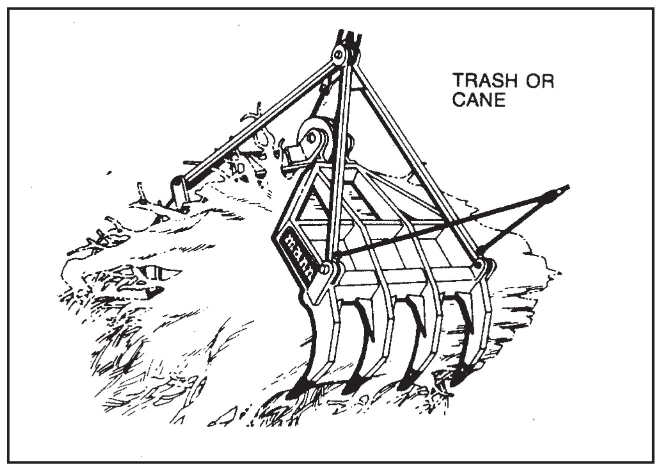


Figure 11—A skyline grapple rake can yard slashed trees that have been collected into corridors. (This model no longer available.)

Cable Chippers

Extra handling of the biomass drives costs up. One variation would be to cable a chipper around the unit and chip the biomass as you go. (See On-Site Chipper for Reduction of Forest Residues, Technical Report 8451-1207-SDTDC.) Drawbacks include the need to cut the material before it goes into the chipper and the possibility that nitrogen will be used by organisms that decompose the wood chips rather than being available for plants if the chips are left in concentrated piles.

Figure 12—The Bitterroot Miniyarder would be suitable for yarding smaller wood.

Figure 13—Eucalyptus clearfell harvesting with Howe-Line monocable system. (Photo courtesty of Professor Loren Kellogg, Oregon State University.)

Extreme Machines

Few machines will allow the operator to comfortably operate a mechanized shredder/brush cutter on slopes steeper than 50%. The Kaiser Spyder, Schaeff Climbing Backhoe, Menzi Muck, and Allied Systems' ATH 28 can operate on these steeper slopes, but they are very expensive to purchase and maintain and are not available in quantity (Figure 14). Johnson (1992–1993) reports spending $987 per acre on 2.4 acres to shred slash with a Kaiser Spyder on slopes steeper than 60%. When the cost was spread over the entire 14-acre burn unit, it was $161 per acre (see Catalog of Machines and Specialized Attachments for specifications on these extreme machines).

Figure 14—The Menzi Muck with a feller-buncher head is one of few machines that can operate brush cutters on slopes greater than 50%. They are cost prohibitive to run and are not readily available.