Chapter 4	Mechanical Tools for Fuels Management

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Fuels management is an active term. It is an intentional, planned activity defined by consideration of fire behavior, silvicultural principles, ecological constraints, and the economic and technical limitations of the tools selected to implement the treatment. A forest operation is a tool used to manipulate vegetation or site condition in order to achieve some desired management objectives. Given the wide range of forest operations that can be employed to treat forest fuels, it is imperative to employ a tool that is well-matched to both operational needs and treatment constraints. Selecting a poorly-suited tool increases costs and reduces the effectiveness of the operation in achieving the desired outcomes. The selection of a forest operation also plays a critical role in determining the amount and type of cumulative effects associated with the treatment. A tool that is not matched to the terrain or job requirements will likely produce more undesirable impacts.

The purpose of this Chapter is to give a basic overview of forest operations for fuels treatments along with information to guide selection of appropriate technologies. Terminology is also important in this discussion. In the biological sciences we have learned that it is important to use scientific names of organisms, rather than common names, to avoid confusion. Unfortunately many forest operations acquire common names that are contradictory, regionally-limited, or non-specific. When someone speaks of a "hydro-ax" treatment, for example, they could mean a vertical-shaft brushcutter, a horizontal-shaft masticator, a shear feller-buncher, or a sawhead feller-buncher. These possible meanings represent very different costs, capabilities and fuel treatment outcomes. The reference listing at the end of this Chapter provides some standard definitions.

Forest Operations for Fuel Treatment

The objective of fuels treatment is to alter fire behavior and severity by modifying properties of various fuel strata in a stand (Graham et al. 2004). Treating one strata may improve fire behavior in one respect, but aggravate it in another. For example, activity fuels resulting from a thinning may reduce crown fuels but increase surface fuel loading. A clear fuel treatment prescription should consider effects on the total fire behavior response and clearly specify acceptable treatment outcomes. The primary challenge of selecting appropriate operations, then, is to match the task requirements specified by the fuels prescription to equipment capabilities within constraints of terrain and cost.

Because it should deal with all fuel strata, not just merchantable trees, a fuel treatment operation may involve activities such as mastication or raking that have different types of disturbance than conventional forest harvesting. The disturbance effects can be direct (scraping soil to reduce fine surface fuels, for example) or indirect (dozer piling resulting in high temperature burning with resulting hydrophobic soils and poor herbaceous regeneration). The selection of an operation will affect the spatial pattern of disturbance and the total extent of disturbance. The interaction between the type of operation and the sensitivity of the site affects the severity of disturbance and thus the temporal pattern of recovery or effect.

Forest operations for fuel treatment can be broadly divided into two types—in-situ treatment where no biomass or product removal occurs, and removal treatments that extract some amount of fuel loading for utilization or disposal outside of the stand. In-situ treatments are selected when there are no economically-viable markets for biomass material and it is technically-feasible to meet the fuel reduction goals with the material left in place. Removal treatments are selected when it is possible to recover additional value from the treated material or when it is not feasible to treat the fuels in the stand. Resource managers in the western U.S. have often faced a lack of biomass markets resulting in extensive in-situ piling and burning treatments. More recently however, growing restrictions on burning have motivated efforts to find economically-viable removal treatments.

In-situ Treatments

Fuels treatment can be accomplished within the stand by performing two basic functional tasks—(1) killing selected vegetation, and (2) reducing the resulting activity fuel loading to acceptable fire behavior conditions. The selection of an in-situ treatment is probably limited more by the second function than any other factor. Simply re-arranging high fuel loading in the stand may not be sufficient to lower fire risk. In fact, shifting fuel loading from ladder fuels or crown strata to surface fuels can significantly aggravate some aspects of fire behavior. Thus most in-situ treatment combines an initial vegetation cutting treatment with a follow-on burn to reduce the volume of activity fuels in piles or scattered slash under controlled burning conditions.

Generally the least-expensive in-situ treatment is prescribed fire. Cleaves et al. (2000) found that average prescribed burning costs ranged from $22.80 to $121.00/acre (1994 $, excluding Region 5). Slash burning was generally about twice as expensive as management burning. Prescribed fire mimics many of the ecological functions of natural wildfire. However the use of this tool has significant limitations. The pattern of vegetative mortality is difficult to control, air quality is adversely impacted, there is risk of escape, and acceptable burning conditions may only occur in limited windows of opportunity. Perhaps the largest limitation to the use of prescribed fire is fuel loading.

Many forest areas in the western U.S. have such high fuel loading that fire is not acceptable without some initial pre-treatment (definition of Condition Class 3).

Chopping, or drum chopping, is a pre-treatment to knock down brush and small trees before broadcast burning. A large steel drum with cutting knives mounted on the face of the drum is rolled across a site. The drums can range in size from 8 to 12-ft wide and can be loaded with water for additional weight. The drum can be towed behind a wheeled or tracked tractor or it can be pulled on a winch cable. As vegetation is rolled over, the knives break limbs and stems into shorter pieces. Some trees may even be uprooted in the process. Chopping increases surface roughness by incorporating organic material into the soil, however there is little soil displacement associated with the treatment. When the drum is towed by a winch line this treatment can be used on steep slopes with little soil impact.

After several months of drying, the chopped material can be burned. Chopping lowers the fuel bed depth which reduces flame height. It also increases surface fuel density and continuity which can make it easier to carry prescribed fire across a site. While this treatment is most often used for residue treatment after clearcut harvesting, it has also been used effectively for fuels treatment in brush fields, understory control in open pine stands, and as treatment for wildlife habitat improvement.

Chaining is similar to chopping, although it is strictly a clearcut or open-field brush fuel treatment. A long heavy chain, often anchor chain, is connected between two tractors. As the tractors drive forward the chain knocks over or uproots the brush and trees between the machines. Soil disturbance results from uprooting and the movement of debris with the chain. Farmer, Harper and Davis (1999), however, showed that chaining for pinyon-juniper restoration actually reduced runoff and erosion compared to untreated areas. A variation of chaining uses a single tractor towing a heavy steel ball connected to the end of the chain. Operating cross-slope on hilly land, the heavy ball pulls the chain downhill and serves as the second anchor. Depending on the fuel loading, chained sites can be burned or left to decompose over time.

Grubbing also kills vegetation by uprooting and breaking plant vegetation to reduce growth. It is principally applied for hard-to-control species that will resprout from cut stumps (e.g., salt cedar (*Tamarix sp*.) or alligator juniper (*Juniperus deppeana*). Grubbing attachments vary from subsoil cutting blades to specially-designed grasping attachments for excavators. Extracted plants are piled for disposal or removal. A grubbing treatment creates more severe soil disruption where plants have been removed, but this soil disturbance is discontinuous compared to a chaining treatment. Grubbing is often the alternative to herbicide treatment.

Manual lopping is another pre-treatment for in-situ fuel management. Chainsaws, brush saws or manual loppers can be used to fell small trees and brush. Lopping can include a slashing requirement to reduce piece sizes to specified length or height. Depending on fuel loading, lopping can be combined with scattering (spreading activity fuels across the stand) or handpiling. Generally lighter fuel loads would be treated by scattering, while heavier loading would necessitate concentrating the slash into piles for burning. Manual lopping results in minimal site impact and can even be used on steep slopes. The primary disadvantages of this operation are safety concerns associated with chainsaws and the significant labor requirements to achieve modest production rates. Manual operations are also limited by piece size and stems per acre.

An alternative to manual lopping is to use a swing machine with a brushcutter or sawhead attachment. The approach is to cut small stems quickly and leave them scattered on the site. Feller-bunchers have been used in such applications, but the head is generally not designed to cut or grasp small stems effectively. Mechanical lopping has very little impact on the site. The machine cuts material to the front and drives on the felled mat of slash. This treatment can be applied on a wide range of slopes depending on the capabilities of the base machine. Self-leveling feller-bunchers, for example, are able to operate on 50% slopes. Non-leveling swing machines should be limited to lower slopes. Site disturbance is further reduced because a swing machine can access a 60-ft wide swath from one position.

Lopped material can also be mechanically piled using either a brush rake or a grapple. Brush rakes mount on the front of a wheeled or tracked machine to facilitate pushing debris. The rake teeth on the lower edge of the blade catch residues while minimizing the amount of soil displacement that occurs. However, dozer or tractor piling still causes significant soil disturbance just from debris movement. Fuel loading and pile size constraints will determine the number of piles per acre and the amount of trafficking that is required. Grapple piling is an alternative method that uses a swing machine, either a knuckleboom log loader or a modified hydraulic excavator, to grasp and pile residues. Because grapple piling lifts the material rather than pushing it, soil disturbance is negligible. The resulting piles have very little soil and rock and can be built higher than tractor or hand piles.

Chopping, lopping, and piling are all pre-treatment activities that require subsequent burning to reduce fuel loading. If burning is not possible, however, there are still two options for in-situ fuel treatment—chipping and mastication. Both of these mechanical treatments convert existing fuels into smaller size classes with the objective of removing forest fuels through decomposition. Chipped or masticated material is spread on the forest floor and, as a result of more direct soil contact, has significantly different fuel moisture and burning characteristics than typical forest fuels. It may be possible to use chipping or mastication as a tool to reduce fuel loading prior to a prescribed burn, but more commonly these techniques are used in lieu of burning.

Mobile chippers can be self-propelled or towed machines that reduce trees into chips through slicing. The chips are relatively uniformly-sized due to the process and are projected into the stand through a discharge spout. Chippers are fed by a loader and will be most productive if the felled material has been pre-bunched. Towed chippers are typically limited to roadside processing, while self-propelled tracked chippers can operate in the stand. Chipping would be a good alternative to burning if piles had already been constructed.

The direct impacts of chipping include trafficking by the machine and the direct impact of spreading material on the soil surface. Trafficking effects are limited since most of the undercarriage systems produce a ground pressure of less than 7 psi. The effects of the chipped material on soils and water quality are more uncertain. Given the density of wood chips, 20 bone dry tons spread across an acre would be a layer about 1" deep. Chips could exclude herbaceous regrowth, alter soil moisture regimes, and change nutrient cycling processes. Chips may also reduce soil exposure to rainfall and thus reduce erosion.

Mastication equipment shreds, rather than chips, standing trees and brush. Unlike mobile chippers, masticators are generally able to fell material. Windell and Bradshaw (2000) provide a thorough review of the range of machines that can be used. There are two basic types of attachments—vertical shaft and horizontal shaft. Either of these can be equipped with pivoting flail-type cutters or rigidly mounted cutting teeth. Masticators can be mounted on every conceivable carrier including tracked, wheeled, swing machine, drive-to-tree, or even a walking excavator. Johnson (1993) described the use of a walking excavator to masticate material on the Olympic National Forest with slopes exceeding 60 percent. While the shredded material is highly variable given the range of attachments, it is generally coarser and more irregular in shape than chips.

The principle impact of mastication will result from the trafficking of the base machine and the work area defined by the attachment configuration. Direct-mount cutters must traverse nearly the entire stand to implement a treatment. This would approximate the extent of trafficking by a feller-buncher in a clearcut harvest. Boom-mounted cutters, on the other hand, have limited trafficking and soil impact. The type of trafficking disturbance is also a function of the type and size of tire or track that are used. A wheeled machine with wide tires may actually have lower ground pressure than a tracked machine with standard tracks. Careful consideration should be given to the specification of appropriate base equipment for particular soil conditions.

Removal Treatments

If the activity fuel loading from a particular treatment is going to exceed acceptable levels, or if there are marketable products that can be recovered, a removal fuel treatment may be required rather than an in-situ treatment. Like conventional forest harvesting, a removal treatment will involve felling and extraction. However, the type of material removed in a fuel treatment may make the operation radically different in terms of effects and cost than traditional product recovery. For example, skidder load sizes could be smaller and the total number of trips into the stand may be greater when removing small-diameter thinnings. In a fuel treatment, material may be brought out of the stand simply for roadside disposal without the need for product merchandizing that would occur in a sawlog harvest.

Felling for removal can use chainsaws, feller-bunchers, or harvesters. Manual felling is effective for a wide range of tree size and terrain. However, as the number of stems per acre increases, mechanical options become more desirable. Mechanized felling can also move felled material into concentrated bunches for more effective extraction. It is also easier to control the direction of fall and minimize residual stand damage with machines. Like other forest operations, the primary impacts of felling will be determined by the type of carrier (wheeled or tracked) and the type of attachment mounting (drive-to-tree or swing-to-tree). Swing machines can operate on steeper slopes and can access a larger area with minimal traffic. Drive-to-tree machines are generally more appropriate for flatter terrain.

Felled material can be removed from the stand using skidders, forwarders, cable systems, or helicopters. A basic functional difference among these methods is how the load is moved—skidders drag one end of the load, forwarders carry the load on a wheeled frame, cable systems drag the load but without wheel traffic, and helicopters lift the load completely above the ground. Cost per ton removed increases with increasing extraction distance. This cost-distance curve is a function of load size, operating costs, and travel speed. Skidders will generally be used at distances less than 400 ft, forwarders and cable systems can work effectively at distances of 800 to 1000 ft, while helicopters can move material several miles.

With any extraction system where repeated cycles are necessary to remove material, the cost per acre is strongly influenced by load size. Collection and removal of slash and brush is particularly challenging because small pieces make it hard to get full payloads. A forwarder load of biomass limbs and tops is about 1/3 the bulk of a load of logs. If the fuel reduction treatment requires slash removal, the least expensive approach is skidding whole trees. By taking limbs and tops to roadside attached to the main stem, activity fuels are minimized and the number of trips into the stand to accomplish the treatment is reduced.

Cut-to-length (CTL) systems require special consideration. In CTL, trees are felled and processed at the stump using a harvester. Each tree is cut into log lengths which are piled by product. The forwarding function then collects the logs and carries them to roadside. In some CTL operations trees may be processed in front of the harvester, creating a mat of slash for the machines to travel on. The slash mat, coupled with forwarding, significantly reduces soil disturbance and compaction with CTL. Harvesters also minimize soil impacts by using a boom-mounted attachment to cut and process the trees. CTL is considered the lowest impact ground-based harvesting system. In small-diameter treatments, special harvester heads may be needed to effectively handle material.

Material brought to roadside may be separated into product classes in a process called merchandizing. Various log categories can be bucked into specified lengths; pulpwood logs may be debarked and chipped; fuelwood and residues may be processed through a grinder. Non-merchantable residues can be disposed of at roadside by piling and open burning or with an air curtain incinerator. Roadside merchandizing increases the area of landings and heavy traffic. The more product options involved, the larger the area required for loading, processing, stacking and transport. Processing operations also create additional disposal problems—sawdust, bark, butt cuts and other miscellaneous forms of biomass. Depending on site constraints and the amount of this material it may spread on-site or collected for trucking to off-site disposal.

Roadside processing operations can be limited by available area, road access, or the total volume brought to individual landings. If this occurs, trees and biomass can be directly loaded onto a variety of truck types and hauled to a concentration point or woodyard for processing. This “two-stage” hauling can improve operational efficiency by increasing volume and minimizing setup times. Woodyards also reduce in-woods impacts associated with erosion and soil disturbance. If the processed volume is high enough, measures such as gravel surfacing and stormwater management may be warranted.

The final function in removal treatments for fuels management is transportation. Forest roads are recognized as a primary contributor to the water quality impacts associated with forest management. Some type of road access is necessary for all of the operations discussed in this chapter. In-situ treatments are possible with a minimal amount of roading and with lower standard roads. Removal treatments impose additional constraints on road spacing and standard. Road spacing affects, or is affected by, the type of extraction system. Skidding requires closer roads while helicopters can operate at longer distances. The type of product and processing operation determines requirements for road standard. Chipping and grinding produce low-density products that necessitate large transport containers. Tight corners or steep grades may exclude this kind of transportation system and thus limit treatment options. The important point to keep in mind is that the road system is part of the forest operation. Transport and access have to match the type of in-woods operation and the impacts of the total system must be considered.

Conclusions

There are many options for forest fuel treatment. Specifications of the prescription, particularly slope requirements and treated material size, may easily exclude some operations from consideration. However there will generally be a range of feasible alternatives for the resource manager to review. As a project develops, a manager must know:

1) that all feasible alternatives are under consideration (are any options missing),
2) what are the performance attributes of each option,
3) what are the tradeoffs among alternatives, and
4) what is the treatment cost associated with each option.

In general, cost considerations dictate treating fuels as close to the stump as possible. Removal must be justified by fire risk considerations or product values. Forest operations for fuel treatment must satisfy the often conflicting demands of ecological compatibility and economic viability. Minimal impact can be achieved but nearly always at higher cost. Project managers need to balance anticipated impacts of the operation against estimated impacts of the “no treatment” alternative as they select appropriate tools for fuel treatment.

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Terminology

As described in ISO 6814 (ISO 1999), forest machines are defined primarily by the function performed (e.g., skidder), then by additional adjectives defining mode of operation (e.g., grapple skidder) and mobility method (e.g., tracked grapple skidder). Some of the following terms are from Stokes et al. (1989).

Air Curtain—a machine that uses forced air to improve combustion of wood in a fire pit or fire box

Bone dry ton—a quantity of wood or biomass weighing 2000 lbs at zero percent moisture content (also called ovendry ton). This is the typical basis for defining forest fuel loading

Brush rake—a blade for a skidder or crawler tractor with teeth extending down from the bottom edge

Cable system—an arrangement of winches, rigging, and wire rope used to pull trees or parts of trees from the stand

Chaining—the process of knocking over brush and small trees by dragging a length of heavy chain between two tractors or a tractor and a heavy weight.

Chipping—the process of reducing trees into uniformly-dimensioned pieces by slicing

Chopping—the process of knocking down and rolling over brush and small trees with a heavy towed drum that has blades mounted across the face of the drum

Clambunk skidder—a machine that drags trees or parts of trees from the woods to a landing grasping the load in a large inverted grapple on the back of the machine (a specialized form of a grapple skidder)

Clean chips—chips with very low bark content, generally produced by chipping debarked logs. Clean chips are marketable for pulp production or high-quality pellet fuel

Cut-to-length—a harvesting system that fells trees, processes in the woods into product lengths, and uses a forwarder rather than a skidder to move wood to roadside

Dirty chips—chips produced by chipping whole trees (also called whole-tree chips)

Dozer piling—the process of pushing residues or felled stems into a pile with a crawler tractor. The tractor may be equipped with a straight blade, brush blade or a brush rake

Feller-buncher—a machine that fells trees and accumulates the felled stems into a pile using either a shear head or a sawhead attachment

Forwarder—a machine that carries trees or parts of trees from the woods to a landing

Grapple piling—the process of placing residues or felled stems into a pile with a knuckleboom loader or hydraulic excavator

Green ton—a quantity of wood or biomass weighing 2000 lbs at field moisture content

Grinder—a machine that coarsely reduces wood or biomass through a shredding action

Grubbing—the process of pushing or pulling to extract most of a plant's root system from the ground

Harvester—a forest machine that fells, delimbs, and bucks trees

Harwarder—a machine that combines the functions of a harvester and forwarder

Hog fuel—coarsely reduced wood material that is intended for direct combustion use

Horizontal grinder—a grinder with a horizontal infeed table

Hotsaw—a high-speed continuous rotation sawhead. Hotsaws are attached to feller-bunchers.

Knuckleboom log loader—a swing machine with a hydraulically operated boom and a log grapple attachment to lift and position trees or parts of trees

Lopping—felling stems to leave them laying on the ground

Mastication—the process of reducing standing trees and brush by shredding or grinding

Merchandizing—the process of separating trees or parts of trees into specified product categories by sizing and sorting

Mobile chipper—a towed machine that reduces trees or parts of trees by chipping
Processor—a machine that takes a felled tree and delimbs and bucks the tree
Raking—the process of pushing slash or residues into piles, generally windrows, with a brush rake or a towed rake implement
Self-propelled chipper—a tracked chipping machine that can move from place to place
Skidder—a machine that drags trees or parts of trees from the woods to a landing, using either cables or a grapple to grasp the load
Strokeboom delimber—a machine that processes trees into delimbed lengths using delimbing knives and a sliding boom

Tub grinder—a grinder with a circular rotating top-loaded infeed tub