FIRE, LOGGING, AND DEBRIS DISPOSAL EFFECTS ON SOIL
AND WATER IN NORTHERN CONIFEROUS FORESTS

Norbert V. DeByle, Principal Plant Ecologist
U.S. Department of Agriculture, Forest Service
Intermountain Forest and Range Experiment Station
Ogden, Utah 84401, U.S.A.¹

SUMMARY

Many seral northern coniferous forest types are dependent upon periodic
wildfire for their perpetuation. Man partially mimics the role of wildfire by
clearcut logging of these forests and often by subsequent burning of the logging
debris. Mineral soil is exposed and conditions are provided for forest
regeneration.

Impacts on the environment sometimes are associated with these sudden dis-
turbances. Most obvious, and best documented, are increased soil erosion, channel
cutting, and siltation of streams. Some more subtle impacts are: decreased evapo-
transpiration and increased streamflow, increased insolation and altered micro-
climate, induced water repellency of soils by fire, changes in the nutrient
cycling processes, and flushes of dissolved materials out of the system and into
the aquatic environment. Most subtle and difficult to measure is the possibility
of long-term site quality changes.

Particularly during the past decade there has been unprecedented concern
about these impacts. This concern has resulted in much research, some of which
is summarized and interpreted in this paper. An explanation is given that shows
why, under some conditions, clearcutting or fire has severe impacts on the environ-
ment and why, under others, the impacts are minimal or not even detectable. The
variables of soils, geology, topography, climate, and forest type are considered.

Keywords: wildfire; clearcutting; forest residues; site quality; water
quality; nutrient cycling.

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EFFETS DES INCENDIES, DE L'ABATTAGE DES ARBRES ET DE LA DISPOSITION DES DEBRIS SUR LES TERRAINS ET LES EAUX DANS LA FORET DE CONIFERES BOREALE

Norbert V. DeByle
Principal Plant Ecologist
USDA Forest Service
Intermountain Forest and Range Experiment Station
Ogden, Utah 84401, U.S.A.

RESUME

Plusieurs types de forets de conifères boreales, lesquels types de forets sont transitionnels, dependent, pour leur perpetuation, des incendies de foret periodiques. L'homme mimique le role des incendies en abattant des portions de ces forets et le plus souvent, en brulant les debries ainsi obtenus. Le sol minéral est, de cette facon, exposé, fournissant les conditions necessaires pour la regénération de la foret.

On associe parfois certains effets sur le milieu environnant a ces perturbations soudaines. Les effets les plus manifestes, et ceux sur lesquels on s'est le mieux documenté, sont l'augmentation de l'érosion du terrain, un ravinement dense et l'envasement des cours d'eaux. Quelques effets plus subtils sont: un decroissement de l'évapotranspiration et un accroissement de l'insolation et alteration du micro-climat, une impermeabilite du sol causee par le feu, un changement dans les processus cycliques de nutrition et l'expulsion de materiaux dissous hors du systeme et dans le milieu aquatique environnant. L'effet le plus subtil et le plus difficile a mesurer est le changement potentiel a long terme de qualite du site.

Particulièrement pendant les dix dernières années, ces effets ont cause une inquietude sans precedent. Cette inquietude a resulement en beaucoup de recherche, dont une partie est résumee et interpretee dans cet article. Il y est donne une explication qui montre pourquoi, dans certaines conditions, l'abattage des arbres ou l'incendie de foret a des effets graves sur le milieu environnant et pourquoi, dans d'autres conditions, les effets sont minimes et meme indetectables. Les variables telles que terrain, geologie, topographie, climat, et type de foret sont considerées.
FIRE ECOLOGY

The information in this paper applies to many forest types in the circumboreal forests and conifer extensions to the south. Most of the citations come from North America, from the boreal conifer forest, the eastern temperate pine-hardwood forest, and the western temperate conifer forest. Many tree taxa in these forests are "fire types." They have evolved through many centuries to reproduce in abundance and colonize freshly burned areas with even-aged seral stands.

The principal boreal tree taxa are spruces, firs, larches, birches, and aspens (Picea, Abies, Larix, Betula, and Populus spp., respectively). The spruces, birches, and aspens are most widespread; the latter two are typical fire species under the right conditions, so is spruce. The principal temperate forest taxa to the immediate south are pines, oaks, beeches, and maples (Pinus, Quercus, Fagus, and Acer spp., respectively). Many pines are fire species; this discussion particularly applies to them. However, many temperate zone hardwoods, notably oaks, also reproduce vegetatively following fire (Spurr and Barnes 1973).

In North America, the forests discovered and utilized by the European settlers were frequently even-aged stands of seral species. They found these to be the most valuable timber producers and, as a result, we have continued to manage much of our forested land to assure a sustained supply of them. These seral species require full sunlight and minimum competition to effectively colonize and dominate a site. Some require exposed mineral soil for seed germination and seedling survival. These conditions historically were provided by periodic wildfires and, in some areas, particularly near the coasts, by periodic high winds which caused extensive blowdown. At times, severe insect or disease outbreaks may open these forests sufficiently to permit regeneration of intolerant seral trees. But wildfire has been by far the most important regenerative agent in the coniferous forests of North America.

The northern conifer forest builds up a stockpile of organic matter over a long period of time after stand establishment (Olson 1963). As it does, on the mesic sites particularly, it becomes increasingly predisposed to destruction by wildfire. Barring intervention by man, most sites ultimately will burn. They may be burned frequently by low-intensity fires that consume only fine surface fuels, as in many ponderosa pine (Pinus ponderosa) stands of the mountainous western United States. Or they may burn infrequently, but with such severity that the entire stand is killed. In the latter case, the site becomes recolonized with fire species and the process begins anew (Haack and Hutto 1973). Thus, we have a natural fire cycle on most mesic sites. The average length of this cycle, up to 400 years, and deviation from the average will vary depending upon site characteristics, climatic conditions, and tree species (Beaufait 1971).

These fires, even though natural, have measurable impacts on the environment. Without extremely intensive management of large forested areas in North America, there is little man can do to prevent these perturbations and their associated impacts.

CLEARCUTTING

Management techniques for the seral fire species usually have been dictated by their regeneration requirements. A mosaic of even-aged stands, each in turn harvested by clearcutting when mature, is the ultimate result of such management.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Wildfire</th>
<th>Clearcutting and debris disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle length</td>
<td>Variable within broad limits.</td>
<td>Set to rotation age.</td>
</tr>
<tr>
<td>Area affected</td>
<td>From small patches to thousands of hectares.</td>
<td>Small and set within relatively narrow limits.</td>
</tr>
<tr>
<td>Season</td>
<td>When driest, usually late summer.</td>
<td>All seasons, with prescribed burning only when controllable.</td>
</tr>
<tr>
<td>Intensity of fire</td>
<td>Intense over long cycles, low intensity at short intervals. May be intense in crowns with low intensity at forest floor.</td>
<td>If used, usually of lower intensity for broadcast debris; or, with piled debris, from extreme in piles to nonexistent between.</td>
</tr>
<tr>
<td>Prior soil condition</td>
<td>Dry surface organic horizon, usually over dry mineral soil. Often results in pronounced heating of mineral soil.</td>
<td>Variable water content, depending on season of cutting; burning usually done over a wet soil mantle; virtually no mineral soil heating, except under burned piles, where it is severe.</td>
</tr>
<tr>
<td>Resulting soil surface</td>
<td>Blackened, and frequently burned to bare mineral soil.</td>
<td>Depends upon debris treatment: 1. Disturbed stand and understory due to harvesting; soil covered with limbs, tops, and culls. 2. Same as (1) but blackened after broadcast burning; mineral soil exposed on 5% to 25% of area. 3. Machine piling of debris bares mineral soil on the 75% of area between piles. Surface organic horizon often scraped away or mixed into mineral soil. Logging roads, landings, and skid trails, often followed by dozer piling of debris cause soil disturbance. Boles removed; limbs and tops remain on ground to decay, to be piled and burned, or to burn in place. Natual, often later thinned; seeded or planted if natural regeneration is unsatisfactory.</td>
</tr>
<tr>
<td>Physical disturbance of mineral soil</td>
<td>No direct disturbance.</td>
<td></td>
</tr>
<tr>
<td>Forest stand</td>
<td>Trees remain standing as live, dying, or dead; often a viable seed crop is in canopy.</td>
<td></td>
</tr>
<tr>
<td>Regeneration</td>
<td>Natural, with seral brush or herbaceous species sometimes preceding conifers by many years.</td>
<td>Natural, often later thinned; seeded or planted if natural regeneration is unsatisfactory.</td>
</tr>
</tbody>
</table>
DEBRIS DISPOSAL

After clearcutting most coniferous stands, especially the overmature old growth common in the western United States and Canada, it becomes necessary to dispose of the logging residue. The quantity varies from 500 metric tons per hectare in coastal Douglas fir (Pseudotsuga menziesii) (Jemison and Lowden 1974), to 250 t/ha in interior larch-fir (Beaufait et al. 1975), to 120 t/ha in old-growth lodgepole pine (Pinus contorta) (Foulger and Harris 1975). Disposal should (1) reduce or eliminate the fire hazard, (2) provide a natural seedbed or at least a surface suitable for planting, (3) open the clearcut interior to access, (4) sanitize the site to reduce insect and disease hazards, and (5) improve esthetic qualities.

Disposal may be accomplished by natural decay processes, by burning the debris in place, by piling (usually with bulldozers) and burning, by mechanical means such as roller-crushing or chipping, or by yarding entire trees and unmerchantable material in the harvesting process and later burning what remains at the landings. Through high utilization it is possible to reduce the debris volume to such small amounts that natural decay becomes a feasible method of disposal (Brown 1974). However, in most instances, burning has been relied upon as an expeditious and economical residue disposal technique after harvesting mature and overmature (old-growth) conifer stands in North America.

Broadcast burning perhaps is the best imitator of the natural fire cycle in these forests. It causes little disruption of the mineral soil; it has relatively uniform intensity over the entire area; it consumes some of the organic layer on the mineral soil surface; it blackens the entire area; and coarse debris is left scattered over the clearcut. However, it is difficult to control and can be effectively applied only during a relatively short season each year. Logging debris can be piled during a much longer season. This is usually done as part of the logging operation. The piles of stump, culm logs, limbs, and tops can be burned when snow is on the ground or when the forest is wet—when fire control is no problem. The piling operation is costly, but some of the costs are offset by negligible burning costs.

Mechanical methods of crushing the slash, as with large rollers, or reducing it to small particles with chippers are applied at the time of logging or at any time later when saturated soils or deep snowpacks do not prevent these practices. Mechanical disposal is limited to suitable terrain. These methods are being used increasingly in North America as stronger restrictions are placed on the use of fire. However, we must consider that these are energy-intensive means of residue disposal that often may not be economically or morally justified in an energy-deficient world.

EFFECTS

Except through closely controlled research, it is difficult or impossible to separate the effects of forest harvesting from the effects of debris disposal. Fortunately, for practical purposes, these effects need not be considered separately because the combined product, the total harvest impact, is our real concern.

Logging

Logging directly removes some nutrients from the site. In the environment being considered, the nutrients removed in the form of wood and bark through conventional harvesting are a minor part of the available plant nutrients and a very small fraction of the total nutrients on most sites. Stone (1973) summarized this loss to be from 1 to 10 kg/ha/yr for each of the major elements. Solution loss for forested lands is streamflow. It is often this great or greater. Whole tree utilization and extremely short rotations may increase this loss from two- to fivefold.

Many logging systems set up conditions that result in potential soil and water impacts from other causes. For example, soil is often burned and severely disturbed, thus exposing it to erosional forces (Rice et al. 1972). Durney (1967) concluded that increases in erosion rates may be expected following road construction and logging. The nature and severity of this erosion will depend upon the type of harvesting operation, design and location of roads and skid trails, and inherent characteristics of the individual area. Roads and skid trails are usually the primary sources of sediment from logged areas (Packer 1967b); however, their proper design, location, and drainage will markedly alleviate this problem (Packer 1967c).

Stream temperatures are raised by clearcutting vegetation that shades the water (Mehean 1970; Levno and Rothacher 1967; Swift and Messner 1971). Raised water temperatures and increased solar radiation will affect the aquatic environment and are particularly important in streams containing trout or other salmonid fishes (Gibbons and Salo 1973). Leaving an uncut buffer strip will moderate these changes (Swift and Baker 1973).

Increased streamflow volume following forest removal is well documented and is reviewed by Hibbert (1967). In the 39 studies reviewed, first-year response to complete forest reduction varied from 34 to 450 mm increased streamflow. This increase declines as the forest regrows. Both the amount of increase and the rate of decline are site specific, dependent upon several climatic, edaphic, and biological factors.

Destruction of vegetation by clearcutting temporarily halts the annual cycling of plant nutrients. The chemical nature of the nutrients will be altered and the quantities held in each compartment of the system will change. This often leads to additional nutrient loss by leaching or solution in overland flow (Cole and Good 1965; Likens et al. 1970).

A third indirect impact is that of altered microclimate. Insolation at the forest floor is markedly increased by clearcutting. The forest, which absorbed 60% to 90% of solar radiation (Reifsnider and Lull 1965), is now virtually gone. Also, there is much reduced and soils remain wetter throughout the growing season (Johnston et al. 1969; Johnston 1975). The altered microclimate, both above and below ground, affects the development of vegetation. It can change microbial populations in the litter and in the soil. Decay processes may be accelerated (Stone 1973). The amount and availability of nutrients, particularly nitrogen, will be changed. Some nutrients will be leached if in excess of amounts that can be held in the soil or immediately taken up by new vegetation (Bormann et al. 1974; DeByle 1976; Stone 1973).

Fresh logging debris on the soil surface has immediate direct effects. It shades the soil, thus partially protecting it from the increased insolation. This retards evaporation and keeps the microclimate at the soil surface cooler and more stable than a bare site. The debris begins losing soluble components with the first soaking rain and continues to do so throughout the decomposition process. Some elements, such as potassium and sodium, are readily leached from the fine material without microbial action. Others, such as calcium, require some breakdown of the organic structure before being transferred back to the soil. Some organic compounds, phenols for example (Hart and DeByle 1975), are also leached from debris and either passed downward through the soil or lost in surface runoff waters. For the first few years after clearcutting, while the site is sparsely
colonized with new vegetation, these processes result in net chemical additions to the soil that are greater than those that would occur through annual additions from the mature standing forest.

The same type of additions occurs below ground, too. Roots of the severed vegetation decay and their elements are returned to the soil. At first this process is rapid, as fine roots decay; later it slows as the larger, less uniformly distributed roots of the cut trees decay.

Debris Disposal

Each method of debris disposal has its own set of potential impacts on soil and water. Generally, all methods accelerate the return of chemical elements to the forest floor. Mechanical means of disposal are used where burning is unnecessary or not practicable. Mechanical disposal produces a layer of soil and litter that is free from inorganic and organic debris. This material can be pushed or bulldozed.

After clearingcutting and broadcast burning there may be a surge of nutrients lost in runoff during the first posttreatment year (Bollen 1974; DeByle and Packer 1972). Fredriksen (1971) found that the rate of nutrient loss increases threefold during this surge. Nutrient losses rapidly returned to preharvest levels during subsequent years.

Fire, clearcutting, and debris disposal are too frequently simplified by overlooking the varying controls on these processes. They and the trees that occupy them do not fit the previous argument. They and the trees that occupy them (cedar [Thuja], hemlock [Tsuga], and some spruces) have evolved with periodic fire disturbance. Use of prescribed fire on these sites is more likely to cause marked impacts on the ecosystem. Similarly, clearcutting may be a foreign agent on such sites, unless the natural system has been periodically disturbed by extensive blowdowns, or catastrophic disease or insect outbreaks.

The more closely we follow nature in our management of the forest, the less will be his long-term impact on the system. Intense wildfire or clearcutting does not always have the environmental catastrophic results that some people claim. As scientists and resource managers, we must take an objective view of these forest perturbations.

Some coniferous forest sites have burned very infrequently or not at all. They do not fit the previous argument. They and the trees that occupy them (cedar [Thuja], hemlock [Tsuga], and some spruces) have evolved with periodic fire disturbance. Use of prescribed fire on these sites is more likely to cause marked impacts on the ecosystem. Similarly, clearcutting may be a foreign agent on such sites, unless the natural system has been periodically disturbed by extensive blowdowns, or catastrophic disease or insect outbreaks.

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result in the least stable with respect to their ability to absorb the impacts of fire, logging, and debris disposal without a significant loss of soil or nutrients and possible site quality changes.

<table>
<thead>
<tr>
<th>Most stable sites</th>
<th>Least stable sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level terrain.</td>
<td>Steep, long slopes.</td>
</tr>
<tr>
<td>Deep soils.</td>
<td>Shallow soils over impervious bedrock.</td>
</tr>
<tr>
<td>Well-drained soils.</td>
<td>Saturated soils, high ground water table.</td>
</tr>
<tr>
<td>Soils with high clay content.</td>
<td>Sands and gravels.</td>
</tr>
<tr>
<td>Little or no surplus precipitation.</td>
<td>Large precipitation surplus.</td>
</tr>
<tr>
<td>Favorable growing season for rapid revegetation of site.</td>
<td>Short, cold, dry, or otherwise unfavorable growing season.</td>
</tr>
<tr>
<td>Seral forest type on site.</td>
<td>Climax forest type on site.</td>
</tr>
<tr>
<td>Site has history of periodic destructive wildfires blowdown, or other catastrophic tree removal.</td>
<td>A site with no history of fire, blowdown, or catastrophic forest destruction.</td>
</tr>
<tr>
<td>Present vegetation regenerates readily after fire or blowdown.</td>
<td>Catastrophic destruction of forest removes propagules; new species must invade site.</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

In recent years much concern has been expressed about the environmental effects of forest fire and clearcutting. Particular interest and effort has been directed at the effects on soils and on water quality. Past research has shown effects that range from virtually undetectable to those that could drastically alter site or water quality. The range in results is due to several interacting factors of climate, soils, geology, topography, vegetation type, fire intensity, and site history. Care should be used in applying research results; all factors must be recognized and understood.

More research is needed to achieve full understanding of these controlling factors that they affect the impacts upon the environment after forest perturbation. We also need to integrate our present knowledge into a working model that allows the forest manager to make a reasonable prediction of impacts from fire, clearcutting, blowdown, or other drastic forest disturbances.

**LITERATURE CITED**


Brown, James K., 1974: Reducing fire potential in lodgepole pine by increasing timber utilization. USDA Forest Service Research Note INT-181, 6 pp. Intermountain Forest and Range Experiment Station, Ogden, Utah.


Johnston, Robert S., 1975: Soil water depletion by lodgepole pine on glacial till. USDA Forest Service Research Note INT-199, 8 pp. Intermountain Forest and Range Experiment Station, Ogden, Utah.


