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# FOREST RESIDUES in Hemlock-Spruce Forests of the Pacific Northwest and Alaska --

## *A State-of-Knowledge Review with Recommendations for Residue Management*

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## SUMMARY

The forest manager must balance all the interacting and often conflicting factors influencing residue management and decide on the best course of action. He needs to determine optimum volume, size, and arrangement of residues to leave on an area after logging, then to select the harvesting methods and residue management alternatives that best provide these conditions. Cramer (1974) summarized environmental effects of forest residues management for major forest types in the Pacific Northwest, but types of treatment were not listed and only minor attention was given to hemlock-spruce forests. Residue management guidelines have been prepared for Oregon and Washington (Pierovich et al. 1975) but the hemlock-spruce type is not discussed as a separate entity. Alaska is not included in either report. This report provides a detailed look at residue management throughout the north Pacific coastal fog belt, including Oregon, Washington, British Columbia, and Alaska. The approach is a general look at forest residues as part of the ecosystem, then a closer look at dead and decaying material after logging, considering fire hazard and the silvicultural, physical, chemical, and esthetic effects of this material. Residue treatments are described, evaluated, and recommended. The report is intended to provide an improved scientific framework for management decisions.

The coastal environment is more moist than other parts of the Pacific Northwest. Generally, fire danger is low and the need for residue treatment to reduce fire hazard is limited to special situations. Northward into Alaska, increasing summer precipitation relegates fire danger to a subordinate management problem.

Hemlock-spruce residue volumes may range up to 250 tons per acre (560 metric tons per hectare) when an old-growth timber stand is defective and has a high proportion of western redcedar, but volumes may be less than 50 tons per acre (112 metric tons per ha) with more complete utilization of sound young timber. The trend is to less residue volume as defective timber is replaced by vigorous young stands and utilization improves.

Residues often dominate the postlogging environment and are a major factor influencing forest regeneration. Fresh residue intercepts natural seed fall or aerially sown seed and prevents seedling establishment; but later, as it decays and with moisture present, it becomes a suitable seed bed for hemlock and spruce. Advance regeneration, usually hemlock, grows on decaying residue material and almost invariably is intermixed with fresh logging residue. Its fate is determined by residue treatment. When residue treatments expose mineral soil, they influence species composition favoring seral species. These ecological relationships between forest residues and conifer seedlings can be used by forest managers to influence density and species composition of the new timber stand. A common problem in hemlock-spruce is too many seedlings. When advance regeneration is prolific, harvesting plans and residue treatments should be designed to destroy some of the seedlings. Overstocking with postlogging regeneration can be reduced if the logging operation is planned so that fresh slash covers an appropriate portion of suitable seed beds.

In special situations, individual factors carry heavy weight in residue management decisions. For soils with high erosion potential, a protective mantle of organic material should be left. At least the small residue material should be left on nutrient-deficient soils to add to the nutrient capital. Residue should be kept out of stream channels. In Oregon and Washington, broadcast burning of residues in heavy brush areas helps to control the brush and open up the area for planting. Mistletoe-infested seedlings should be classed as residue and destroyed as part of disease control programs. Special attention should be given to residue management in recreation and scenic areas. Large, continuous areas of logging slash should be avoided because of fire hazard. Smoke management plans should be followed. Treatments are needed when residue volume is too great, because the residue will interfere with seedling establishment and intensive management of the new stand.


**KEYWORDS:** Forest residues, western hemlock, Sitka spruce, slash disposal.

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# INTRODUCTION

The unmerchantable organic material remaining after a forest is logged is a challenge to the forest manager. Depending on circumstances, forest residues are a fire hazard endangering the forest, an obstruction to intensive management, a blight on the landscape, a suitable seed bed for tree seedlings or an obstruction to their establishment, a source of essential nutrients, and a protective cover preventing soil erosion. Usually, they are a combination of all these and more. The challenge is for the forest manager to balance all the factors by determining the optimum volume, size, and arrangement of residues that should be left on an area after logging, and by selecting the harvesting methods and residues management alternatives that best provide these conditions. This should be done before harvest cutting because residue treatment begins with transportation planning and selection of the harvesting method and equipment.

Knowledge of the various environmental effects of forest residues and their treatments was summarized for primary forest types of the Pacific Northwest in a compendium (Cramer 1974). That document provides a background for understanding environmental effects of residues, but management practices are not listed. It gives only minor attention to western hemlock-Sitka spruce *(Tsuga heterophylla-Picea sitchensis)* forests. Residue management guidelines have been prepared for Oregon and Washington (Pierovich et al. 1975) but the hemlock-spruce type is not discussed as a separate entity. Neither of these reports include Alaska. This report provides a more detailed look at the coastal forests where the environment is much more moist than in other parts of the Pacific Northwest. Generally, fire danger is low, and an overriding need for disposal of residue to reduce fire hazard, so common farther inland, is limited to special situations. Northward into Alaska, increasing summer precipitation relegates fire danger to a subordinate position in residue management.

Historically, the approach to residue management in hemlock-spruce forests of Oregon and Washington has been to utilize logs that turned a profit, leaving all other logs and organic material to decay on the site. Continuous clearcutting left continuous logging slash. When wildfire started, it spread rapidly. This fire problem led to broadcast burning prescriptions to reduce the hazard and also led to restrictions on clearcut size. After World War 11, many owners adopted the patch-cutting system, in which clearcuts are kept small and green timber left around the perimeter until logging residues are treated or the fire hazard has abated. In British Columbia, there has been a parallel trend to restrict clearcut size and broadcast burn high hazard areas, also a trend to leave uncut strips of green timber as firebreaks. In Alaska, until recently, clearcutting of large areas was the rule. Now clearcut size is restricted, mainly for esthetic reasons. Logging residues are left unburned.

Residue management is fast becoming recognized as an essential part of overall management that affects not only fire hazard but regeneration, site productivity, esthetics, future stand management, and many other factors (Cramer 1974). It should be fully integrated into general management planning.

Several methods for controlling the amount, composition, and distribution of hemlock-spruce logging residues are available. These include selection of yarding methods and equipment, utilization standards, yarding unutilized material (YUM), lopping and scattering of residues, broadcast burning, piling and burning, burning concentrations, and chipping. Armed with these techniques and new ones being developed, forest managers should be able to select the most desirable postlogging condition for a cutover area and to achieve this through careful advance planning and application of residue treatments. This report is intended to provide a background for achieving this goal.

Residue management recommendations made here have the basic objectives of protecting the soil and its nutrient capital, streamflow, and water quality and of providing for establishment of a new forest crop. The land manager must evaluate residue management alternatives, considering economic, esthetic, and recreational objectives, and choose the most appropriate course of action.

## HEMLOCK-SPRUCE FORESTS

Hemlock-spruce forests occupy a 2,000-mile-long (3200-kilometer) coastal strip from northern California to Prince William Sound, Alaska. This north Pacific coastal area provides some of the best forest growing conditions on the North American continent.

Including coastal islands, the hemlock-spruce type is about 130 miles (210 km) wide in Alaska, gradually narrowing southward until in California it becomes restricted to the mouths of coastal streams and low valleys facing the ocean (fig. 1). The climate is characterized by equable temperatures, heavy precipitation, and prolonged cloudiness. Its marine climate is greatly influenced by the warm ocean currents of the north Pacific and the prevailing onshore winds which carry their effects to the lands. In the south, infrequent summer rains are augmented by fog drip in established forests and by decreased evaporation in the frequently foggy and cool climate. The summer drought, so characteristic inland in the Pacific Northwest, is not pronounced in hemlock-spruce forests. But occasional rainless periods of 1 to several weeks may occur, usually in July or August, during which severe fire danger exists. Northward into Alaska, periods of drought are uncommon, but they occur often enough that fire danger cannot be completely discounted in making residue management decisions.

In the southern portion of the range there's a rapid, almost abrupt increase in fire danger inland from the beach. This coincides with reduced summer fog and transition in timber type, usually from hemlock-spruce to hemlock, to hemlock and Douglas-fir (*Pseudotsuga menziesii*), to Douglas-fir. In Alaska, this transition to drier interior conditions is well defined because along most of the Alaskan coast, icefields, glaciers, and low timberlines provide abrupt limits to the hemlock-spruce type. Except for the Kenai Peninsula, the head of Lynn Canal, and some of the larger rivers, a gradual transition in forest type from wet coastal forests to the drier interior forests is lacking.

Residue management recommendations presented here apply to fog belt forests of hemlock-spruce. These forests vary from pure hemlock to pure spruce, including mixtures and occasional pure stands of associated western redcedar, red alder, or Pacific silver fir. Associated species vary by latitude. Toward the south, they include redwood (*Sequoia sempervirens*), Douglas-fir, Port-Orford-cedar (*Chamaecyparis lawsoniana*), and other species. Toward the north and west, Alaska-cedar (*Chamaecyparis nootkatensis*) and mountain hemlock (*Tsuga mertensiana*) become important associates. The hemlock-spruce forest type is the dominant coastal vegetation in all of southeast Alaska, Washington, and Oregon (fig. 1).

Toward.the south, extensive even-aged stands predominate; most have become established following great fires 80 to 100 years ago. Less extensive old-growth, uneven-aged stands are found also, most notably on the Olympic Peninsula

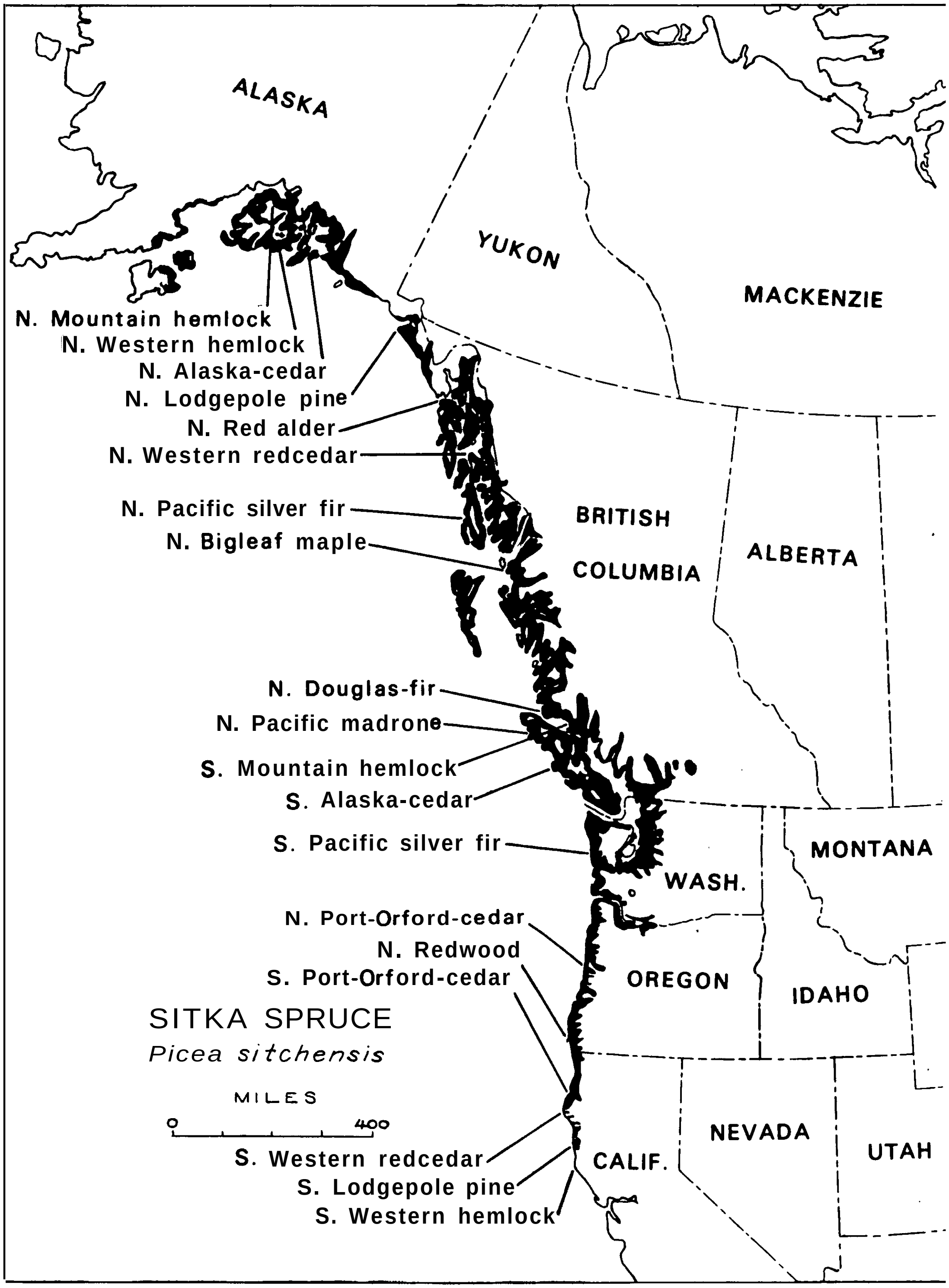


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*Figure 1.--The Pacific coastal strip showing the range of Sitka spruce and, within it, the approximate range of associated tree species. N and S indicate approximate north and south limits of range at sea level.*

of Washington. In Alaska this pattern is reversed, with old-growth, uneven-aged stands predominating but interspersed with even-aged stands, mostly 100 to 250 years of age, which owe their origin to fire or blowdown.

These coastal forests are well located for and adapted to providing a variety of important public benefits. They have high esthetic and recreation values. Timber yields also are high, and there are excellent opportunities for increases through intensive management. The forest cover prevents soil erosion in coastal watersheds, protects domestic water supplies and important fish habitats, and provides habitat for wildlife. Demands for all of these 'forest benefits are increasing, and questions of residue management must be examined in this context.

## FOREST RESIDUES--WHAT ARE THEY?

Viewed just after logging, forest residues are the leftovers--the material without enough value to justify its removal. The material is organic, the product of photosynthesis and mineral uptake. Like merchantable logs, its cells contain cellulose, lignin, ash-forming minerals, and extractives. But the pieces are too small or the wrong shape, the chemical components are in the wrong proportion, or the material is in various stages of decay. Trees that are dead and standing, fallen, live culls, trees too small to harvest, and tree tops, bark, branches, leaves, cones, and stumps are included. Stumps are especially prominent when attached to a root system uprooted during a windstorm or rooted out during roadbuilding. Understory brush species are included, especially if they have been knocked to the ground during a logging operation. Some merchantable logs may have been missed by the loggers.

Forest residues are "residues" only in a utilization sense and cause public concern only for a short period during a forest rotation. This period begins with timber harvesting, which removes merchantable material. It ends as residues decay and are incorporated into the soil, as tree seedlings grow and hide them from view, or as the canopy of a thinned stand closes. Large logs left as residues, especially western redcedar and Alaska-cedar, extend the decay period and may impede intensive management of the new stand.

Viewed from a long-term perspective, residues are an essential part of the forest ecosystem. Man disturbs the ecosystem by harvest cutting, much as nature disturbs it by fire or wind damage. This changes the energy flows, food chains, and the structure; but the ecosystem remains and builds anew, again tending toward the characteristic hemlock-spruce forest. The long term as well as immediate effects should be evaluated in residue management decisions.

Residue treatments may have detrimental as well as beneficial consequences. For example, burning, which has been practiced widely in southern parts of the hemlock-spruce type, reduces the nutrient capital; creates smoke, reducing visibility; and creates the risk of fire escaping control and damaging adjacent property. Treatment alternatives must be carefully considered and the best course of action determined. In some situations, no treatment at all may be best. This will be increasingly true as residue volumes continue to be reduced by improved standards of utilization.

Here, we look generally at forest residues as part of the ecosystem, then more closely at dead and decaying material after logging, considering the fire hazard and the silvicultural, physical, chemical, and esthetic effects of this material. Residue treatments are described, evaluated, and recommended. We hope this report will provide an improved scientific framework for management decisions. With the recent emphasis on environmental quality and improved utilization, questions of residue management are timely.

## *VOLUME AND ARRANGEMENT*

Several factors lead to high residue accumulation in hemlock-spruce ecosystems, including high basic productivity of the species (Fujimori 1971, Dimock 1958), infrequent wildfires, a preponderance of decadent old-growth stands with high percentages of defect, and the cool climate and high rainfall resulting in mor humus and accumulation of organic debris on the forest floor (Gregory 1960). Southward, high productivity is the main cause of residue accumulation while lack of wildfire, old-growth stands, and mor humus are more important in residue accumulation in the cooler northern parts of the range.

The volume and arrangement of residues vary widely depending on the age and size of the timber harvested, its volume per acre and percent of defect, the volume in undersize trees and unwanted species, topography, logging method, utilization standards, contract requirements, market conditions at the time of logging, and even the attitude of the logger who harvested the timber. The variation in tree size, characteristic of climax or near-climax stands, contributes to residue volume because felling of large trees tends to break up small ones and heavy equipment needed to get out the large logs tends to break small logs. In Alaska, where logs are rafted to the utilization plant, small logs and chunks may be left in the woods because they will escape from rafts and be lost.

Residue volume generally increases with stand age and successional development (Howard 1973). Vigorous young stands may be essentially free from defect with tops, limbs, and stumps making up almost all residue volume. Occasional stem sections bucked out due to felling breakage or forked tops are present. There may be some undersize trees, standing or down. But there are very few cull logs that in old-growth stands add so much to residue (fig. 2). There is little understory vegetation. Most young stands are harvested in the southern parts of the hemlock-spruce type where demand for logs is high and economic conditions permit taking logs to a smaller top diameter and shorter length than farther north. Residue exceeding 4 inches (10 centimeters) in diameter, 4 feet (1.2 meters) long, and 10 percent chippable measured on six industrial forest clearcut areas averaged 1,332 cubic feet per acre (93.2 $m^3$/hectare).[1/] With a conversion factor of 25 pounds per cubic foot (400 kilograms/$m^3$) (bone dry) (Grantham et al. 1974), this is equal to 16.6 tons per acre (37.3 metric tons/ha). This did not include decayed material less than 10 percent chippable, stumps, understory vegetation, and fine material from branches and leaves. Branches and leaves were estimated by Fujimori (1971) at 18.6 tons per acre (41.7 metric tons/ha) in a dense 19- to 32-year-old stand.

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1/ Melvin E. Metcalf, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, personal communication, March 17, 1971.

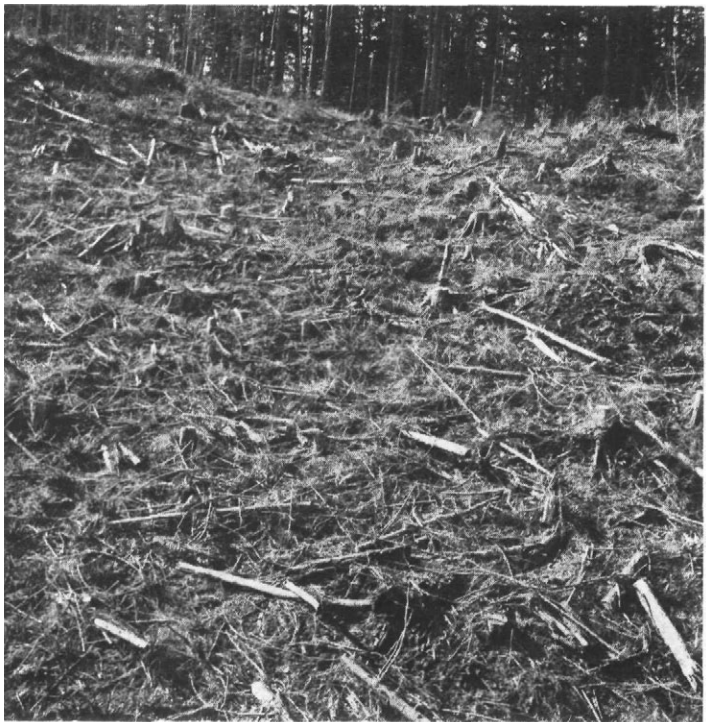

*Figure 2.--Logging slash remaining after clearcut logging of 125-year-old hemlock-spruce with little defect. Broadcast burning is not planned. Oregon coast, 1973.*

Highest residue volumes remain after harvest of old-growth western redcedar (fig. 3). For example, clearcutting of one stand containing much western redcedar on the Olympic Peninsula left a gross volume of 18,604 cubic feet per acre (1302 $m^3$/ha) of residues over 4 inches (10 cm) in diameter. The weight was estimated at 227 tons per acre (509 metric tons/ha). Twenty to 40 tons per acre (48 to 90 metric tons/ha) should be added for the fine material (Dell and Ward 1971). Cedar stands generally have high residue volumes because most remaining stands are decadent old growth. Also, cedar tends to split or shatter during felling operations. There has been little demand for cedar chips and little market for low quality logs (Howard 1973).

Timber volumes are lower in Alaska because of lower site quality, but stands that are logged tend to be older and therefore more defective than in Oregon and Washington. Total volume of chippable wood remaining as residue may equal that in the Pacific Northwest. On 19 clearcutting units sampled in 1971,[2/] 1,329 cubic feet per acre (93 $m^3$/ha) of chippable material remained after yarding, a volume equivalent to 20 percent of the net merchantable cubic volume.

In Alaska, stands favored for harvest cutting have been the better, overmature, even-aged stands containing a high percentage of spruce. Such stands are less defective than uneven-aged climax stands, and the timber is more uniform in size. As logging shifts to more uneven-aged, near-climax stands, there is potential for greater residue volume (fig. 4). Offsetting this, as the value of wood increases and utilization standards improve, more small and low quality material will be removed from the woods (see footnote 2).

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[2/] Personal communication with Richard L. Davis, U.S. Forest Service, Region 10, Juneau, Alaska.

*Figure 3.—Logging slash remaining after clearcut logging of an old-growth hemlock-spruce stand with a high proportion of western redcedar. Cedar shake bolts have been salvaged. Olympic Peninsula, Washington.*

*Figure 4.—Residue after harvesting of a near-climax hemlock-spruce stand, Thomas Bay, Alaska, 1972.*

Utilization standards in hemlock-spruce forests have varied with economic conditions, but there has been general improvement over the years with smaller and more defective logs becoming merchantable. Early day loggers seldom took top logs less than 30 inches (76 cm) in diameter. Today, 6 inches (15 cm) is common and a 4-inch (10-cm) top is the rule on some ownerships. The percent of sound wood that a log must contain before it is taken has dropped dramatically. There is a market in Oregon for utility logs which have a sound chippable content of at least 50 percent of the gross scale. Thus, there has been a downward trend in logging residue volumes. Also contributing to this trend in Oregon and Washington is the increasing proportion of the annual harvest in young stands with little defect. Residues are being reduced still further by periodic thinnings which remove defective trees and reduce levels of growing stock. This downward trend in volumes of residue has alleviated some detrimental effects of residues such as fire hazard and physical obstruction to planting and thinning. It also has reduced beneficial effects; residues protect the soil from erosion and serve as a source of nutrients for growth of the new stand.

The arrangement of forest residues after logging is greatly influenced by the logging method. High-lead yarding leaves numerous narrow skid roads radiating out from the landing like the spokes of a wheel. Disturbance increases toward the landing as skid roads run together and more logs are yarded along each section of road. Slash tends to be pulled into the landing with the logs, and invariably, a deep pile remains there after yarding is finished. Skid roads are narrow and have slash left in depressions. They do not form adequate firelines.

Tractor yarding tends to divide logging slash into sections bounded by tractor roads which often are quite adequate as firelines. This facilitates control of wildfire but requires extra effort in setting fire for a prescribed broadcast burn.

Grapple yarding, in which at least one end of a log is lifted free of the ground, causes less disturbance and usually leaves a more uniform distribution of slash than high-lead or tractor yarding. Skyline yarding in which logs are soon lifted free of the ground causes still less disturbance, leaving a quite uniform slash distribution (Ruth 1967). Helicopter yarding which essentially lifts logs directly upward causes the least disturbance, and logging slash generally remains where it landed as the trees were felled and limbed.

Numerous red alder stands within the hemlock-spruce type present a special residue management problem. The most common management objective is to convert alder forest to hemlock-spruce or hemlock-fir, usually by clearcutting and planting. At rotation age, alder stands have much less biomass than conifer stands (Worthington et al. 1960), and residue volumes are correspondingly less. But alder characteristically has a rich understory of shrubs and herbs (Franklin and Pechanec 1968) which becomes part of the residue. The resulting tangle of logging slash and brush obstructs travel and interferes with planting operations. The brush overtops and suppresses hemlock and spruce seedlings.

## ECOLOGICAL EFFECTS OF FOREST RESIDUES

### EFFECTS OF SEEDLING ESTABLISHMENT

Harvest cuttings and the resulting accumulation of residue should be designed to leave an environment suitable for establishing a new timber stand. Residues often dominate the site and therefore are a major factor in seedling establishment.

Residues can be suitable seed beds for establishment of both hemlock and spruce, but their suitability depends on the stage of decay and moisture and temperature conditions. Fresh logging residues are unsatisfactory seed beds (fig. 5); but after decay is well advanced, the radicle from a germinating seed can penetrate the surface, and the decaying wood provides adequate nutrition for seedling survival and growth. Litter covering the surface further improves the seed bed and may speed decay of the underlying wood. In contrast to hemlock and spruce, Douglas-fir and red alder seldom become established on rotten wood.

Logging residues intercept natural seed fall or aerially sown seed. They cover mineral soil seed beds, obstruct the movement of planting crews, and make impractical maintenance of a specified spacing of planted trees. Slash accumulations contribute to the clumped tree distribution often apparent in young hemlock-spruce stands. Slash-caused openings tend to seed in eventually, but the delay retards stand development, causing variation in height and age in the new stand.

Moisture and temperature are particularly important. In the southern portion of the range, organic material often dries before the root from a germinating seed can penetrate to adequate moisture, and organic seed beds may develop lethal surface temperatures more often than mineral soil. Exposed rotten wood or duff generally is unsatisfactory for seedling establishment (Minore 1972). A few

*Figure 5.--Fifteen years after clearcutting on an exposed ridgetop, this decaying log remained nonstocked while spruce seedlings became established on the soil surface nearby, Cascade Head Experimental Forest, Oregon.*

sunny days during the germination period can cause heavy seedling mortality.[3/] Consequently, most natural regeneration on southern clearcuts is on mineral soil (fig. 5). There are exceptions, as when the organic seed bed is well shaded or the weather remains wet or at least cloudy during germination and initial seedling establishment. Over time, seedlings do become established on organic seed beds. For example, Morris (1958a, 1970) reported on nine paired plots in a long term study on coastal Oregon clearcuts where natural regeneration became established on both mineral soil and organic surfaces. However, production may be lost waiting for suitable weather conditions and for fresh residues to decay.

On northern clearcuts where cloudy weather and drizzle are more common during the germination periods, organic seed beds usually retain adequate moisture for seedling establishment. Most seedlings become established on organic seed beds. Partial shade provided by moderate amounts of logging slash has been shown to improve early survival of spruce and hemlock on mineral soil during an abnormally dry summer in Alaska (Harris 1967).

Under a forest canopy, the environment is cool and moist and rotten wood is a more satisfactory seed bed than in the open. Western hemlock and, to a lesser extent, Sitka spruce commonly become established here. Under coastal Oregon stands where there is less than 40 percent full sunlight, seedlings usually are larger and more abundant on rotten logs than on the duff-covered forest floor (fig. 6). When sunlight is over 40 percent, seedling occurrence is about the

*Figure 6.--Natural hemlock regeneration on a rotten log under a 125-year-old hemlock-spruce stand. Cascade Head Experimental Forest, Oregon.*

[3/] Robert Harvey Ruth. Differential effect of solar radiation on seedling establishment under a forest stand. Ph.D. thesis, Oregon State University, Corvallis, 176 p., illus., 1967.

same on these two seed beds (Minore 1972). Sitka spruce also will become established on decaying residue material if the overstory is moderate or less in density. Colonnades of Sitka spruce growing on decaying logs are a familiar sight in coastal forests.

Decayed wood is a suitable planting medium for Sitka spruce and also for Douglas-fir seedlings in coastal Oregon. Berntsen (1960) planted 200 seedlings on north and south slopes of a.clearcut area where decayed wood was sufficiently deep that roots did not initially contact mineral soil. Other seedlings were planted on nearby mineral soil. Survival after four growing seasons was approximately the same in both planting mediums for both species and on both aspects (table 1).

Height growth of Sitka spruce was significantly better on rotten wood, but Douglas-fir grew about the same as on mineral soil. There was 14 inches (360 millimeters) of rainfall during the first growing season after establishment, probably contributing to the good survival.

Forest residue seed beds sometimes are an advantage to hemlock and spruce regeneration because few competing plants are able to grow on them. When only occasional seedlings are found in brush areas, almost invariably they are growing on rotten wood. Berntsen (1955) examined a clearcut area in coastal Oregon 6 years after logging and found rotten wood seed beds 97 percent stocked compared with 83 percent for mineral soil. The difference was attributed to competing vegetation which thrived on mineral soil and tended to crowd out tree seedlings. The shrubs and herbs did not do well on rotten wood, and tree seedlings essentially were free to grow there. Plots completely covered with a layer of limbs and logging debris were 67 percent stocked. Stocking was 62 percent on plots dominated by brush and herbaceous vegetation.

Table 1.--*Survival and total height of Sitka spruce and Douglas-fir 4 years after planting on decayed wood and on mineral-soil microsites*

| Species and aspect | Survival | | Total height | |
|---|---|---|---|---|
| | Mineral soil | Decayed wood | Mineral soil | Decayed wood |
| | ---- *Percent* ---- | | --- *Inches* (cm) --- | |
| Sitka spruce: | | | | |
| Northerly | 98 | 98 | 29 (74) | 43* (109) |
| Southerly | a4 | 80 | 36 (91) | 47* (119) |
| Douglas-fir: | | | | |
| Northerly | 90 | 90 | 25 (64) | 25 (64) |
| Southerly | 66 | 62 | 32 (81) | 29 (74) |

* Difference significant at 95-percent level.

Hemlock and spruce seedlings often invade openings dominated by other vegetation by becoming established on top of logs that have fallen into the opening from an adjacent timber stand./

There are several incidental ways in which forest residues affect tree seedlings. Bark may slough off a log or stump and cover nearby seedlings. Some seedlings become established under logs or large limbs, only to have the leader grow up into them and be damaged or grow around them causing a deformity. Sometimes the residues settle to the ground and crush seedlings. Other seedlings are damaged as their leaders sway in the wind and rub against residue materials. Residues tend to creep downslope under the weight of a heavy snowpack, destroying small seedlings in their path.

Residues also limit access to tree seedlings by cattle and big game, thereby reducing browsing damage. On the other hand, they provide shelter for the small mammals that damage seedlings.

Where frost damage is a problem, forest residues intercept outgoing longwave radiation and tend to slow nighttime cooling. They also slow cold air drainage. The net effect is variable.

In Alaska, Harris and Farr (1974) noted that on alluvial streamside sites subject to flooding, Sitka spruce and western hemlock seedlings become established alongside stumps or atop decayed logs or debris, thus avoiding the intermittent high water.

The foregoing relationships between hemlock-spruce forest residues and tree seedlings can be used to influence seedling establishment. Historically, even large cl'earcuts have seeded in well; so there is little risk of general regeneration failure. The major concerns are to speed seedling establishment, improve spacing, and control species composition. Residue management affects all of these.

Thinning of near-rotation-age stands and the slow opening of the canopy as stands become overmature normally result in establishment of hemlock and some spruce seedlings in the understory (Farr and Harris 1971). Most seedlings become established on decaying residue material. Usually there are too many. If the seedlings are free of mistletoe, overstory removal should be designed to destroy some seedlings but to leave enough well-spaced seedlings for full stocking. Techniques for doing this are not well developed, and research and experience are needed. But to the extent that it can be done, planting will be avoided and costs of precommercial thinning reduced.

Regeneration time can be shortened by planting rather than waiting for natural regeneration. Depending on volume, some residue disposal may be needed to uncover planting sites and facilitate movement of the planting crew. The objective should be to distribute residues to expose properly spaced planting sites. The remainder of the area should be left slash-covered to restrict unwanted natural regeneration which, in this case, would only result in costly precommercial thinning at a later date.

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4/ Eric Duncan Davidson. Synecology features of a natural headland prairie on the Oregon coast. M.S. thesis, Oregon State University, Corvallis, 79 p., 1967.

Much progress toward desired slash distribution can be accomplished by selecting an appropriate yarding system. If the timber stand is young and has little defect, minimum ground disturbance--as with helicopter, balloon, or skyline yarding--may expose sufficient planting sites. With more residue volume, more disturbance, as with grapple yarding, may be appropriate. High-lead would provide still more. Yarding of unutilized material to the landing will further reduce the volume of residues left on the area. This reduction can be controlled if dimensions of material to be removed are specified. Its removal will increase disturbance of the area and expose more mineral soil for planting. In the southern hemlock-spruce range, additional exposure may be obtained by broadcast burning.

Residue treatments greatly affect species composition of the new timber stand. Advance regeneration runs strongly to hemlock, so minimizing disturbance of the site favors this species. Increased disturbance destroys hemlock seedlings and exposes mineral soil. The opportunity for spruce on bare soil is better than for hemlock. It is more of a pioneer species. Exposing mineral soil also favors Douglas-fir if a seed source is available--also red alder, frequently causing it to become a major competitor on sites where conifers are preferred.

## SOIL AND STREAM EFFECTS

Logging residues cause soil loss and stream sedimentation when they accumulate in stream channels and trigger debris-mud flows, This problem is most common in high rainfall areas and in steep "V-notch" ravines (Swanston 1974, Bishop and Stevens 1964). Accumulation of tops, branches, and other logging residues in stream channels may form dams that obstruct waterflow and sometimes cause shifting of the streambed. During high water, these dams can wash out, initiating a debris-mud flow that collects downstream debris and soil as it goes and scours the channel clean for considerable distances (fig. 7).

This process occurs where no harvest cuttings have been made--when natural residues such as snags and windthrown trees accumulate. On logging areas, accumulation of branches, logs, and other residues in streams may accelerate the process. Where debris-mud flows occur, stream gradient usually is too steep for use by fish populations; however, debris and sediment may be carried downstream to lower gradient sections used by fish.

When streams have a resident fish population or serve as spawning streams, the occasional introduction of natural residues causing pools and riffles tends to improve local fish habitat (Brown 1974) but, if extensive, may obstruct fish movement. The introduction of logging residues may also disrupt the natural habitat and reduce rearing space (fig. 8). When debris dams wash out, gravel beds may be scoured, covered, or otherwise destroyed as spawning areas (Bishop and Shapley 1963, Narver 1971), and new dams may form downstream. Residues, particularly bark, chips, twigs, and needles, may become intermixed with spawning gravel and impede waterflow carrying oxygen to fish eggs. The oxygen demand as this fine organic material decays may deplete oxygen supplies (Gordon and Martens 1969, Servizi et al. 1970, Ponce 1974, Reed and Elliott 1972, Lantz 1971). Accumulation of such residue in stream gravel can also decrease living space for stream invertebrates which are used as food by fish (McCrimmon 1954) (fig. 9).

*Figure 7.—Debris-mudflow from a steep ravine, Maybeso Valley, Prince of Wales Island, Alaska:* A, *Debris-choked stream channel before flushing;* B, *debris deposit on gentle topography.*

*Figure 8.—Forest residues may choke streams and hinder or block migration of fish. Tributary to Fish Bay, Chichagof Island, Alaska. (Photo, courtesy Alaska Department of Fish and Game.)*

*Figure 9.—Small residues such as bark and wood chips, twigs, and needles damage fish habitat in spawning and rearing streams. Seal Bay, Chichagof Island, Alaska. (Photo, courtesy Alaska Department of Fish and Game.)*

On flat areas, residues may plug stream channels, raise the water table in the soil, and destroy the adjacent forest crop.

Harvest cuttings must be conducted in a way that will keep residues out of streams. Protection can best be provided by falling and yarding timber away from streams, with immediate clearing of debris if necessary (fig. 10). If residues do get into stream channels, they should be removed promptly with minimum disturbance and placed above high water level. Care must be taken so that stream clearing does not break down streambanks and damage them (fig. 11) (Lantz 1971, Reed and Elliott 1972). Logs should not be skidded in or across streams. Detailed rules for stream protection have been written by individual States and are backed by State law (Oregon revised statutes 527.610 to 527.990 (Oregon State Legislature 1971); Washington 1974 Second Substitute House Bill 637 (Washington State Legislature 1974); British Columbia Forest Service;[5] Oregon Forest Protection Association 1972; Washington Department of Natural Resources 1974; Alaska statutes 16.05.870-900, 16.10.010-040 as revised through 1974; Alaska Department of Environmental Conservation 1973).

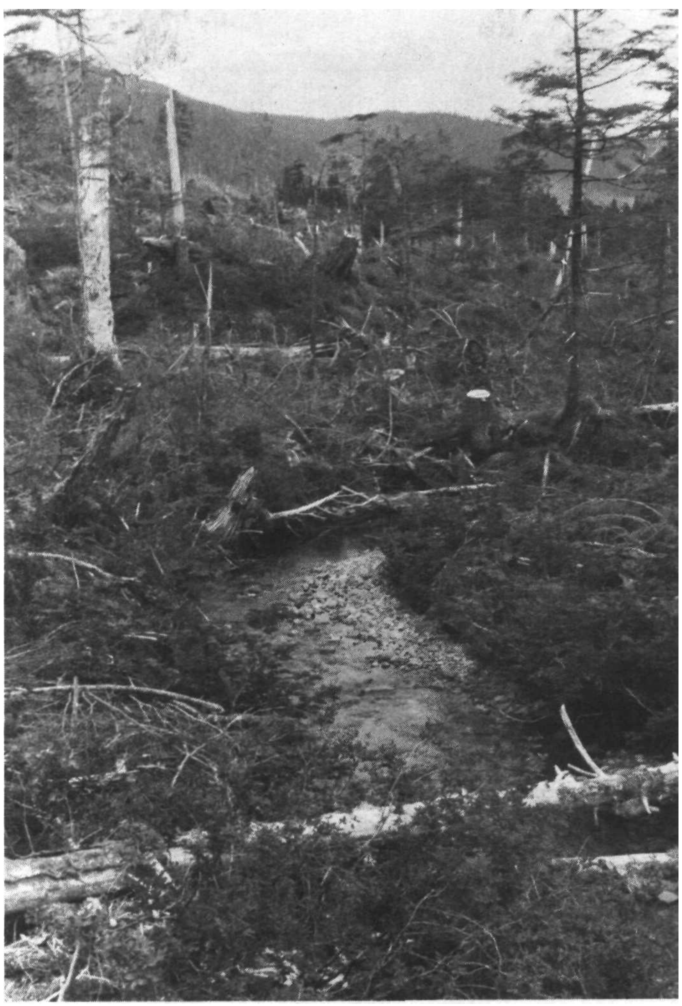

*Figure 10.--Fish habitat may be protected by falling and yarding timber away from the stream, followed by hand clearing if necessary. Tributary to Luck Lake, Prince of Wales Island, Alaska. (Photo, courtesy Alaska Department of Fish and Game.)*

[5] British Columbia Forest Service. Interim provincial guidelines relating to prescribed burning in site rehabilitation. File No. 09565, 5 p. July 1974. Victoria.

*Figure 11.--Debris removal by heavy equipment damaged stream banks in this tributary to Shelikof Creek, Kruzof Island, Alaska. (Photo, courtesy Alaska Department of Fish and Game.)*

Forest residues serve as a storehouse for an important part of the nutrient capital of a hemlock-spruce ecosystem. Depending on the residue volume and fertility of the mineral soil, they contain variable proportions of the total nutrient supply. The proportion is higher in Alaska where residues decompose slowly, lower in the southern portion of the range where they decompose rapidly. On nutrient-deficient forest soils and soils low in clays or organic material, the nutrient capital stored in forest residues, especially in the forest floor, is needed for tree nutrition. Only large residues should be removed from these areas, and the forest floor should not be reduced by burning.

The surface of the mineral soil needs to be protected from the impact of raindrops and other disturbance. Usually the litter layer of needles and small twigs on the forest floor is sufficient, but some of this may be scraped away during logging. Depending on the degree of aggregation in the surface soil, exposed soil particles may be dislodged by the splash of raindrops and plug pore openings. This reduces infiltration rate and increases the possibility of surface runoff. Surface water picks up still more soil particles which seal off additional pore spaces, and erosion may result. Forest residues can serve as a substitute mantle protecting the soil. The need usually occurs on steep slopes where disturbance is difficult to avoid and the potential for erosion is great. But coastal soils vary widely in erodibility. Soil exposure which may be inconsequential with some may be disastrous with others. Soils developed on recently stabilized sand dunes particularly are subject to erosion if exposed. Part or all of the residues on such areas should be left to protect the soil. Together with shrubs and herbs, they hold back downhill movement of soil during winter storms or during rare periods when dry ravel may occur. Lopping and scattering of residues and special fire protection measures on such areas are preferred alternatives to broadcast burning.

Residues affect the physical properties of underlying soils. As they decay, the organic compounds in the surface soil often cause aggregation of fine soil particles and this usually improves the water infiltration rate (Rothacher and Lopushinsky 1974). Shade afforded by residues reduces evaporation from the soil surface. Operation of machinery over the surface will, under adverse moisture conditions, compact the soil and reduce infiltration rate, permeability, and gaseous exchange (Froehlich 1973). Thus, machine piling of residues to reduce fire hazard or for seedling establishment may have adverse effects as well.

## EFFECTS OF RESIDUES ON ESTHETICS

Forest residues have important effects on esthetics of hemlock-spruce clearcuts, effects that increase with residue volume and as more people come in contact with cutover land. Volume-related effects will decrease as logging shifts to second-growth stands. However, in Alaska, logging of old growth will continue for decades; and residue volumes may even increase as logging shifts to more decadent stands.

Although public reaction to timber harvesting usually focuses more on the loss of tree cover than on logging debris, the presence of large amounts of residue is considered by many people as evidence of forest devastation (Wagar 1974) and a waste of wood fiber.

With recreational use of coastal forests mostly water oriented, distant views of cutover areas are particularly important. Color and general appearance are major factors. During the first year after clearcutting, logging debris, stumps, and the organic duff layer are brown, contrasting with the green of surrounding timber. From the first to fourth year, green plants cover the ground. Stumps, logs, and tops bleach to gray. The green plants blend with surrounding timber, and the major contrast is between adjacent ground vegetation and the gray of the residues. From 5 to 8 years after clearcutting, residues become covered by ground vegetation and major contrasts disappear. A new hemlock-spruce forest canopy usually closes over the area 15 to 20 years after clearcutting.

Direct contact with forest residue is of greatest concern in areas of high public use, usually near roads and campgrounds where berrypicking and hunting are important. Berrypicking is increasing in importance in Alaska. Clearcuts are suitable for berrying as shrubs develop in the increased sunlight, until they are overtopped by the new forest canopy. Clearcuts also are suitable for deer and bear hunting during this period.

Snags are a special component of forest residue, especially important in old-growth forests. The esthetic value of snags is debatable. A few snags left in the proper setting can be esthetically pleasing, whereas many snags located throughput a cutting unit may not be (fig. 12). Snags often have value as nesting sites for wildlife but may also interfere with timber management activities. Conflicts over the disposition of snags may develop, based on concern for various resources.

At present, snags are felled on most National Forest cutting units. However, in some cases retention of a certain number per acre has been required for use by wildlife. Blanket rules governing snag disposition on all cutover areas are not desirable. Ideally, a compromise for snag retention on each cutting unit should be worked out by landscape, wildlife, and timber management specialists.

*Figure 12.--Eight years after logging, most residues are hidden by conifers but snags remain in view. The esthetic value of snags varies by their numbers and distribution and by the individual tastes of viewers, Maybeso Valley, Alaska.*

The adverse esthetic effects of logging residue may be reduced in various ways; by rearranging or reducing the amount of residue left after logging, by separating the public from timber harvest operations, and perhaps by education to show why residues are created and some of their positive benefits. Some combination of the following would improve esthetic effects of logging residue in the hemlock-spruce type.

1. Improved utilization. Improved utilization would directly eliminate much of the problem, especially that of large residues.

2. Cleaner foreground areas along travel routes. The condition of the foreground has a great effect on one's interpretation of the view of an entire cutover unit. Also, the greatest public use of cutover areas is adjacent to roads. Removal of large residues from along travel zones would substantially reduce adverse esthetic reactions. YUM might have application for cleanup of foreground. In more remote situations, piled unmerchantable material could be burned.

3. Layout of cutting units. Whenever possible, cutting units should be designed to provide screening from public view. Leaving strips along roadways or waterways and placing cutting units to take advantage of topography would

help reduce adverse esthetic effects. When necessary to cut timber along travel routes, small cutting units would be less objectionable than large ones and would attract less close attention to residues.

4. Residue treatment. Broadcast burning or piling and burning substantially reduces the amount of residue and greatly improves access. Blackening of remaining debris causes it to blend in better with the surrounding soil surface, thereby reducing its visibility. But clearcuts revegetate quickly, providing a contrast between the green foliage and black residue.

5. Education. The public needs to be better informed about residue management. They will be better prepared for the reality of woods operations if they know the roles played by forest residues in nutrient cycling and forest regeneration and understand the economics of forest utilization.

Residues created by precommercial and commercial thinning and shelterwood cutting also have esthetic effects but less so than those following clearcutting. Volumes are less,,sizes smaller, and much of the residue is screened from view by the residual stand. Residues from precommercial thinning substantially reduce travel through an area until thinned stems have settled to the ground; then the area has a parklike appearance more pleasing than that of an unthinned stand.

## EFFECT OF RESIDUES ON INTENSIVE TIMBER MANAGEMENT

Forest residues on a logged area are a physical obstruction to intensive management of the new stand. Cull logs, stumps, and piles of debris get in the way of men and equipment during thinning and other cultural operations; some large residues persist until the next harvest cut. Obstructions make stand treatments more costly and may cause them to be deferred or rejected. The yield potential of the site, therefore, may not be fully realized. This problem is most acute after logging of defective old growth or stands with a high proportion of cedar (fig. 3).

The impact of residues,on intensive management of the new stand should be estimated and considered in prescribing residue treatments to be applied after harvest cutting of existing stands.

## EFFECT OF RESIDUES ON FIRE DANGER

Fire danger from accumulation and exposure of forest residues is of definitt concern in the hemlock-spruce type, although less so than in drier forest types. The greater concern is in the southern part of the range where several major conflagrations have occurred (Munger 1944). Throughout the range, however, there always is danger of wildfire starting in forest residues.

Three major components of fire danger are fuel, weather conditions, and risk of ignition. Fuels usually are present in hemlock-spruce areas, often in great excess. Risk of ignition, always present to some degree, varies from very high in high-use areas of coastal Oregon and Washington to very low in remote areas of Alaska. Lightning hazard generally is low in coastal areas. The wet coastal climate is the major factor keeping down fire danger. Periods of dry weather are relatively rare in coastal Alaska. They increase southward until, at the southern end of the range, moist conditions in summer are maintained mainly by fog that moves in off the Pacific Ocean most evenings. Fire danger increases greatly when wind patterns associated with a continental high pressure area produce strong offshore winds, replacing nearly saturated marine air with dry continental air. Most wildfires have occurred in the southern part of the range, and most residue management treatments to reduce the fire hazard have been applied there.

Without residue treatment, fire hazard in hemlock-spruce areas decreases gradually as needles drop off, fine materials decay or become compacted by winter snows, and growth of forest regeneration, brush, or hardwoods provide shade that keeps the residues moist.

In case of wildfire, unburned logging residues may offer so many obstacles that building a fireline through them in the face of spreading fire is impracticable. In this situation, a common procedure is to drop back to an area offering less resistance--a truck or tractor road, stream, preestablished fireline, or an area of'recently treated residue. Resistance to control increases with depth of duff and rotten wood, also with rank growth of tree seedlings, brush, and herbs, but decreases with gradual decay of logging residue--the net result varying with locality.

## DECAY OF LOGGING RESIDUES

Organic residues decay slowly, the rate depending primarily on presence of inoculum, moisture, temperature, and the decay resistance of the wood. These factors are affected in turn by degree of shading, cloudiness, slope, aspect, soil type, topographic situation, bark retention, and whether the slash has been burned. Temperature generally becomes limiting in the winter, the limitation increasing northward. Moisture generally becomes limiting in the summer, this limitation increasing southward.

The following account of decay of logging slash is from the Quatsino Region, British Columbia (MacBean 1941).

| Years since logging | Stage of decay |
|---|---|
| 1 - 3 | Needles dry out and have mostly fallen. Fine twigs become brittle but still adhere to the branches. |
| 4 - 6 | Twigs flatten out. |
| 7 - 9 | Twigs less than 0.25-inch (0.64-cm) diameter have fallen. Small branches can be easily broken. |
| 10 - 12 | Slash well flattened, material less than 0.5-inch (1.3-cm) has fallen. Small logs become well rotted. |
| 13 - 15 | All small material decomposed. Small branches 2-3 inches (5-8 cm) in diameter still intact. Decay in logs well advanced. |

Roff and Eades (1959) studied annual progress of decay in hemlock and spruce residue down to 6 inches (15 cm) in diameter and 8 feet (2.4 m) long in British Columbia and found that incipient decay occupied 20 percent of the total volume 1 year after logging. Advanced decay, where wood exhibited partial or complete disintegration of structure, was less than 10 percent. After 2 years, decay was proceeding at a high rate. Bark on logs hastened decay of hemlock only slightly, but bark definitely hastened decay in Sitka spruce. The proportion of brown and white rots increases annually in both western hemlock and Sitka spruce, with brown rots more prominent in hemlock, white rots in spruce. Growth of ground cover did not produce effective shade until the fourth year after logging. Decay was well advanced by this time, so shade was not an important factor in promoting it. Childs (1939) identified some 30 wood-destroying fungi attacking western hemlock, Sitka spruce, and associated Douglas-fir and Pacific silver fir.

Rate of heartwood decay varies among species, with western hemlock and Pacific silver fir most susceptible, followed by Sitka spruce and Douglas-fir; the cedars are most resistant. Large logs decay more slowly than small ones and butt logs more slowly than top logs. Lopped and scattered slash generally deteriorates faster than piled or windrowed slash (Aho 1974). Where relogging is planned for salvaging merchantable residues, it should be done promptly to avoid extensive losses from decay.

Although some of the slash-inhabiting fungi also attack living trees, their presence in logging residues may not greatly increase the risk of infecting the residual stand. Inoculum is already present from other sources in the forest, and rate of infection is governed mostly by occurrence of entry courts in living trees rather than absence of inoculum (Childs 1939, Aho 1974). Root rots such as *Fomes annosus* survive as saprophytes in stumps and roots after a tree is harvested and may spread. to living trees through root contact (Nelson and Harvey 1974).

## INSECTS IN FOREST RESIDUES

Hemlock-spruce forest residues provide food, shelter, and reproductive sites for many insect species. Some are forest pests, but most are beneficial in that they fragment the forest litter and facilitate its decomposition. Hemlock and spruce residues rarely contribute to a buildup of insect populations that attack living trees. Forest residues harbor ambrosia beetles which readily attack felled and bucked timber and trees felled by the wind or other damaging agents. They cause little or no damage to pulp timber but often seriously degrade saw logs or veneer logs. Ambrosia beetles and other insects provide entry courts for disease organisms which, in turn, speed decay of forest residues (Mitchell and Sartwell 1974).

In Alaska, a localized outbreak of Sitka spruce beetle (*Dendroctonus obesus)* occurred in 1941; it lasted several years. Origin of the infestation was thought to have begun in windthrown timber or in overmature live trees during an abnormally dry period.[6] Although it could be possible for this insect to build up in logging slash, experience has not shown this to be a serious problem.

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6/ Report by R. L. Furniss and Ivan H. Jones, December 5, 1946. On file at Forestry Sciences Laboratory, Juneau, Alaska.

# TREATING HEMLOCK-SPRUCE LOGGING RESIDUES

The most common method of handling hemlock-spruce logging residues is to leave them untreated; that is, to utilize as much material as practicable and leave the remainder to decay where it falls. This is least costly in current expense, but it may cost more in the long run. For example, in areas of appreciable fire danger, failure to treat residues can contribute to serious losses from wildfire. Other treatment alternatives are described below.

## BROADCAST BURNING

Broadcast burning, or the controlled use of fire over an entire cutting unit, historically has been the most common method of treating residue in the southern portion of the hemlock-spruce range. Burning is less expensive than mechanical treatments and does not require heavy equipment that may expose and compact the soil. Use of fire is diminishing, although it still is a recognized residue management tool. Pressures are mounting for its elimination because of the adverse esthetic effects of smoke. Also, blackening of the burned area is distasteful to many persons. There are situations, however, in which danger of wildfire may reach levels where hazard reduction by burning is the best alternative. It is still a treatment alternative that warrants careful consideration by forest managers.

### Effects of Burning on Fire Danger

The net effect of residue disposal by broadcast burning is a sharp reduction in fire hazard. Many clearcut areas in Oregon and Washington have been burned for this purpose. Most needles, twigs, and material up to 3 inches (8 cm) in diameter are consumed in a prescribed burn with most larger material consumed only in part (fig. 13) (Martin and Brackebusch 1974). Prescribed fires are set only under conditions where benefits are judged to outweigh detrimental effects. For example, spring burning, when soil moisture and moisture in large residues are high, consumes only the fine, flashy fuels, leaving the duff layers and large logs and chunks mostly intact. In general, prescribed fires burn much cooler and destroy less organic material than does wildfire.

*Figure 13.--Broadcast burning consumed almost all residue material up to about 3 inches (8 cm) in diameter, leaving only the remains of larger logs as a continuing fire hazard, Siuslaw National Forest, Oregon. Divisions on stake indicate 1 foot (30 cm).*

Most broadcast burning has been in Oregon and Washington where summer drought is more severe than farther north. But even here, burning is less common than in adjacent Douglas-fir forests farther inland. There summer drought is more common, wood is more resinous, and advance regeneration is less likely to be present. Needles drop from spruce and hemlock slash more readily than from Douglas-fir, reducing the rate of spread the first season. The rapid growth of brush and hardwoods in fog belt areas soon shades the slash and keeps it moist.

Prescribed fire can become wildfire. The risk is low in coastal forests, particularly where the residue area is surrounded by green timber, but it does happen and the risk must be evaluated when residue treatment is considered. Where fire danger is high, the greater risk may be to leave forest residues untreated.

### Effects on Conifer Regeneration

Residue treatments by burning have important effects on the timing, amount, and species composition of natural regeneration. Broadcast burning destroys most advance regeneration and, unless the area is planted or seeded,, delays seedling establishment until after the next seed crop. This may be several years, and many burned areas are planted to avoid risking this delay.

Gockerell (1966) measured average height of natural regeneration on burned and unburned clearcuts near Forks, Washington. Five years after logging and burning, weighted average height of hemlock, spruce, Pacific silver fir, and western redcedar seedlings on burned areas was 1.9 feet (0.6 m) compared with 3.7 feet (1.1 m) on unburned areas. Harris (1966) recorded similar results in Alaska where, seven growing seasons after burning, height of hemlock seedlings on a burned area averaged 3.7 feet (1.1 m) compared with 8,2 feet (2.5 m) on an unburned area. Broadcast burning obviously delays seedling establishment. On the other hand, if planting is planned, burning opens up the area and facilitates the planting operation. Residues are an obstruction to planting on both burned and unburned areas but are much more of a problem without burning. Planting is more costly on unburned areas because access is more difficult, and small slash and duff must be removed from most planting spots.

Since burning destroys most advance regeneration, burned areas initially have fewer seedlings than do unburned areas. But where burning exposes additional seed beds, the potential for subsequent regeneration may be greater than without burning. Hetherington (1965) recorded a 20-percent increase in suitable seed beds on burned hemlock plots on Vancouver Island and, after the third growing season, a 50-percent increase in the number of postlogging seedlings. In coastal Washington, Gockerell (1966) observed postlogging regeneration that had become established over a 4-year period on burned and unburned areas. In 2 of the years, more seedlings became established on unburned areas, in 1 year more came in on the burned, and in 1 year both regenerated about the same. Berntsen (1955) compared burned and unburned areas in the hemlock-spruce type on the Oregon coast. Through the fifth growing season, there was more established postlogging regeneration on unburned plots which, however, received SO percent more seed. During the sixth season, the burned plots forged ahead and, by the end of that season, had 25 percent more established seedlings. Burning had delayed regeneration but had reduced logging residues to expose additional seed beds and had retarded competing vegetation. After a light broadcast burn in southeast Alaska which consumed small material but only blackened the duff layer, Harris (1966) found more postlogging regeneration on unburned plots but greater milacre stocking on burned plots and, therefore, better seedling distribution.

These variable results probably stem from interactions between seedlings, seed beds, and weather conditions. Where burning exposes mineral soil, the seed bed tends to remain cooler and apparently retains more moisture than an organic seed bed. Germinating seedlings have a better chance of surviving spring and summer insolation. A blackened organic seed bed exposed to the sun gets very hot and dry and becomes inhospitable to germinating seedlings. These conditions vary from south to north and are further influenced by the intensity of the prescribed burn. In the south where exposed organic seed beds are slow to regenerate, a burn should expose enough mineral soil for adequate stocking, leaving enough blackened organic material to avoid overstocking.

Harris (1966) found spruce seedling establishment was better and hemlock poorer on a burned area compared with an unburned area, indicating that burning might be used to increase the proportion of spruce. This is consistent with the role of Sitka spruce as a more seral tree species than western hemlock and characteristically ahead of hemlock in primary and secondary succession. Where a seed source is available, red alder and Douglas-fir also are favored by burning. Burning favors spruce by killing most advance regeneration, which almost invariably is hemlock.

The decision of whether to burn and at what intensity depends first on fire danger. In special cases, fire danger may be high enough that the greater danger is to leave the area unburned and risk wildfire which may burn not only the logging residues and established regeneration but surrounding areas as well. Second, the decision of whether to burn depends on the amount of advance regeneration--whether it's mistletoe free and undamaged--and the policy of the landowner regarding planting and species composition. These factors must be considered along with others mentioned in following sections. The effect of a burning treatment can be increased or decreased if appropriate fuel moisture conditions for the burning operation are specified.

A decision to utilize advance regeneration is also a decision that logging residues will be intermixed with the tree seedlings with the difficulties of residue treatment this involves. Increasing trials of the shelterwood system in southern hemlock-spruce forests emphasize the importance of this problem. With shelterwood cutting, the problem varies with rate of removal of the mature stand. Clearcutting with protection of advance regeneration leaves all the logging residue at one time. On the other hand, a shelterwood cutting with a seed cut and one or more removal cuts leaves logging residues over a span of several years with time for some decay to take place between cuts. A residue treatment decision should be made before each cut.

In coastal forests of Oregon and Washington, Douglas-fir often is a component of existing stands and is preferred as a replacement for Sitka spruce in the next rotation because of fir's higher stumpage value and because of the spruce weevil problem. In this situation, broadcast burning destroys much of the hemlock advance regeneration and opens up the area for planting. Generally, the fir is planted without waiting for natural seedings. The fir seed source may be inadequate; it may be a poor seed year; and generally, planting is needed to give seedlings a head start on competing vegetation. A decision to plant Douglas-fir is itself an argument for burning because the burn sets back the competing vegetation and cleans up the area for the planting crews. Some hemlock advance regeneration often survives the fire, and additional hemlock and spruce usually seed in to create a mixed stand.

## Effects on Competing Vegetation

Besides its effect on tree seedlings and seed beds, burning facilitates subsequent establishment of tree seedlings by reducing vegetative competition for light, water, and nutrients. In Oregon and Washington, burning may be prescribed almost solely for vegetative control, the reduction in logging residues being only an incidental result. Many old-growth stands have low volumes per acre, heavy underbrush, and only scattered regeneration in the understory. Clearcutting without burning perpetuates the brush which, in turn, prevents establishment of new seedlings. Advance regeneration, much of which is destroyed during the harvesting operation, may be inadequate to stock the site.

## Effects on the Soil

Effects of removing forest residues from the soil surface by burning depend on the kind of soil, intensity and duration of the fire, topography, weather conditions, and many other factors. There is considerable literature on burning effects; but of the little that pertains directly to the moist hemlock-spruce situation, most concerns the southern portion of the range.

Research by Morris (1970) in coastal Oregon showed that actual exposure of mineral soil due to controlled broadcast burning is quite limited. Intensity of burn on the surfaces of coastal plots was:

| Classification | Percent of plot area |
|---|---|
| Light burn--duff, crumbled rotten wood, or other woody debris partly burned but not down to mineral soil; or where these were absent before the fire, logs not deeply charred | 75.2 |
| Moderate burn--the foregoing materials consumed or logs deeply charred but mineral soil under the ash not changed in color | 14.2 |
| Severe burn--top layer or mineral soil changed in color, usually to reddish; next one-half inch often blackened from organic matter charred by heat conducted through the top layer | 0.1 |
| Unburned | 10.5 |
| Total | 100.0 |

Most of the surface was left with a charred but protective mat of organic material to receive the initial impact of raindrops (fig. 14). Morris' study was in the drier portion of the hemlock-spruce range. In more moist situations farther north, burning is less likely to consume protective forest floor material. Fahnestock[7/] examined a 110-acre (44.5-ha) wildfire area on Chichagof Island, Alaska, and found no areas of hard-burned soil. Rapid influx of herbaceous and shrubby vegetation and establishment of tree seedlings provides additional protection throughout the hemlock-spruce type.

[7/] George R. Fahnestock. 1970 forest residues. Memorandum to the files, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, August 12, 1970.

*Figure 14.--Broadcast burning generally leaves a charred mat of organic material which receives the initial impact of raindrops and protects the underlying soil from erosion. July, after a spring burn, Oregon coast.*

Austin and Baisinger (1955) pooled data from moderately burned and hard-burned areas and concluded that burning substantially reduced the organic matter content and moisture-holding capacity of the top half inch (1.3 cm) of soil. Effects were much less in the 2-inch (5-cm) layer and insignificant in the 6- to 12-inch (15-cm to 30-cm) layer. Tarrant (1956) also compared physical properties of soil from unburned, lightly burned, and severely burned areas. Soils under lightly burned slash had less macroscopic pore volume, more microscopic pore volume, about the same percolation rate in sandy clay loam, and greater percolation rate in pumiceous sandy loam. Total pore volume and bulk density were about the same. Severe burning had more detrimental effects on soil; but with only 0.1 percent of the soil in this category, the total effect is insignificant. Hydrophobic properties of soils may be increased by burning, thereby reducing the infiltration rate (DeBano et al. 1970). Light burning apparently will have little or no effect on the long-term geologic process of soil formation (Moore and Norris 1974).

In general, the main physical effect of broadcast burning on hemlock-spruce forest soils in the southern part of the range is increased exposure of mineral soil. This improves the regeneration potential, also the potential for erosion. But a prescribed burn normally exposes only a small portion of the soil, most of the effect being limited to the forest floor material itself (Morris 1970). The effect can be controlled by proper timing of the burn. Generally, increased erosion due to burning of residues is limited to special topographic and soil situations. Erosion potential usually is highest on steep slopes but may be high on gentle slopes with erodible soils. Soils developed on recently stabilized sand dunes particularly are subject to erosion if the subsoil is exposed.

Burning also affects soil flora and fauna, but specific effects in hemlock-spruce forests are little known. Indications from other areas are that burning causes no major qualitative changes in composition, and capacity for rapid recovery is great (Jorgensen and Hodges 1970, Metz and Farrier 1971).

Effects on Tree Nutrition

Forest residues serve as a storehouse for an important part of the nutrient capital on many hemlock-spruce sites. Depending on the residue volume and the fertility of the underlying mineral soil, they contain variable proportions of the total nutrient supply. The proportion is high in podzol soil areas in the north with their thick accumulations of mor humus, lower in the south where the residues decay more rapidly and are incorporated into the soil. Part of the nutrient capital is hauled out of the forest as logs, but the nutrient-rich leaves and twigs (Cole et al. 1967) are scattered about as part of the forest residue.

A major effect of burning on nutrition is on timing of nutrient availability for tree growth. Nutrients are released during combustion and, except for nitrogen, most are left in the ash. Subsequent rains leach these nutrients into the soil where, in part, they become available for uptake by plants. Thus, nutrients, accumulated over a period of many years, are made quickly available. This quick availability is at the expense of slow release of nutrients through the decay process. Which schedule is more favorable to tree nutrition is not well known. The burst of nutrients from the ash often contributes to a lush growth of herbs and brush, which compete with tree seedlings for light and moisture and accumulate some of the nutrient capital in their tissues. These nutrients need to be recycled and again made available for uptake as trees become dominant in the ecosystem and their nutritional demands increase.

Research in other forest types has shown that some of the nutrient capital in forest residues is lost from the site during and after burning. In particular, much of the nitrogen is volatilized during combustion and lost into the atmosphere. This reduces the total amount of nitrogen. On the other hand, nitrogen concentration of the residual material may be increased. Nitrogen-fixing activity in the soil tends to be accelerated, so that after a few years the surface soil may have as much nitrogen as an area that was not burned[8/] (Wells 1971, Jorgensen and Wells 1971, DeBell and Ralston 1970, Knight 1966). Losses of other elements during burning are less. Although some ash is carried away on convection currents during the fire (Knight 1966, Allen 1964; also see footnote 8), the greater potential for loss is for nutrients in the ash to be leached or eroded away before they can be utilized by plants. Leaching tends to be more rapid in coarse, sandy soils than in fine soils. Nitrogen also may be lost from a site by leaching, with this loss increasing following burning (Fredriksen 1971).

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8/ Charles C. Grier. Effects of fire on movement and distribution of elements within a forest ecosystem. Ph. D. thesis, University of Washington, Seattle, 167 p., 1972.

Calcium and other salts included in the leachate make the soil more alkaline, a condition often more favorable to competing vegetation than to conifers. This alkalinity is short lived, however (Austin and Baisinger 1955, Tarrant 1956). Coastal soils with an average pH of 7.1 immediately after burning averaged a near-normal pH of 4.6 4 years later. This compares with nearby unburned soils where the pH ranged from 4.3 to 4.5 during the same period.

In Alaska, little information is available concerning the effects of burning on tree nutrition. Stephens (1969) found that organic matter rather than clay is the source of almost all the cation-exchange capacity of soils in coastal Alaska. Thus, a reduction in organic matter by burning could have adverse long-term effects on tree growth. On the other hand, Stephens et al. (1969) found that stands which originated after wildfire did not differ significantly in growth rate from stands originating after logging. In general, wildfire tends to be less severe farther north, with severely burned areas rare. On immature soils such as alluvium, glacial outwash, or till, care should be taken to preserve the surface organic layer as a source of nutrient capital and to reduce erosion.

The main nutritional effects of burning hemlock-spruce logging residues seem to be increased availability of base elements and short-term losses of nitrogen. Burning never adds to the nutrient capital of an ecosystem. It volatilizes nitrogen and creates the potential for loss of other nutrients. More research is needed on relationships between residue treatment and tree nutrition.

## Effects on Esthetic Values

Controlled burning generally improves the appearance of a logged area by removing the tangle of logging slash and other residue, but it changes the appearance by making it black. The net effect varies from area to area and according to the feelings of the individual viewer. In either case, the appearance improves when green vegetation grows tall enough to cover the residues. Burning improves access to the extent that logging slash is consumed in the fire.

Most people do not like to see burning in progress. The production of smoke, blackening of the surface, apparent waste of fiber, and potential for uncontrolled spread are all negative esthetic factors. The important beneficial aspects of controlled burning are less obvious.

## Effects on Streams

Clearcutting a forest crop increases exposure of the surface of a stream to direct rays of the sun. Depending mainly on aspect, width of stream, and disturbance of streamside vegetation, this may increase water temperature. In Alaska, maximum stream temperatures during July and August increased 9° F (5° C) after clearcutting (Meehan et al. 1969). Broadcast burning of streamside vegetation might further increase temperature. Clearcutting and burning also may result in cooler stream temperature or freezing during winter, thereby altering the development of fish eggs and alevins and affecting the time of fry emergence and entry into saltwater. The availability of terrestrial insects to fish also may be altered when streamside vegetation is burned.

Water temperature in small streams may increase dramatically during residue burning. A severe case occurred in Needle Branch on the Oregon coast, a V-shaped valley with steep slopes. Stream temperature rose from 55" F (13" C) to

82° F (28° C) during slash burning. This increase was enough that many juvenile coho salmon, cutthroat trout, and sculpin died during the burn. The population of cutthroat trout was severely affected, but the other fish population levels returned to normal within 2 years (Hall and Lantz 1969).

Above the high-water mark, burning of residues may affect water quality if the fire is hot enough to consume surface organic material. Additional mineral soil is exposed, and soil trapped behind residues may be released. Soil movement usually is slow, and effects may not be noted for some time if at all. Generally, erosion from prescribed burning is not a serious problem in coastal areas because burning does not greatly increase the percentage of exposed soil (Morris 1970). Also, encroaching vegetation may again stabilize the soil before it reaches a stream. In special situations, however, burning may contribute to stream sedimentation; and this possibility should be evaluated when residue management plans are developed.

Burning may reduce the infiltration rate of water into the soil (Austin and Baisinger 1955), and this tends temporarily to increase peak flows. To the extent that live vegetation is damaged or killed by fire, transpiration is reduced, leaving more water available for streamflow. To the extent that riparian vegetation is destroyed, diurnal variation in streamflow temporarily is reduced or stopped.

## Effects on Air Pollution

Effects of prescribed fire on air quality are summarized by Hall (1972). He concludes that, "In general, the only penalty inflicted upon the environment by prescribed burning is a small and temporary decrease in visibility." Burning forest residue does not produce the sulfur oxides common to combustion of coal and oil. Production of nitrogen oxides is rare. Carbon monoxide and carbon dioxide concentrations were measured near the perimeter of an experimental burn of Douglas-fir residue in western Washington, and high concentrations at the site decreased rapidly to normal in both horizontal and vertical directions (Fritschen et al. 1970, Murphy et al. 1970a, 1970b). Hydrocarbons produced by burning residues are similar to or identical with natural products always present in the environment. Only small traces of low-molecular-weight, photochemically active compounds are produced (Hall 1972).

Close to a prescribed fire, dense smoke may be unpleasant from the standpoint of odor and lung or eye irritation. Locally, it can obstruct visibility to the point of causing traffic hazard. But mainly, smoke and haze obstruct distant views, thereby decreasing visibility and enjoyment of the outdoors. Strong objections to prescribed burning arise when the smoke drifts into urban areas where intensive efforts have been made to eliminate visible air pollution. This risk is reduced by burning in accordance with a smoke management system (Cramer and Graham 1971).

The decision for the land manager often is whether to reduce fire hazard by prescribed burning when smoke problems will be minimum, or to leave the hazard, hoping it never will burn. Leaving it runs the risk of wildfire with much greater smoke emission and the possibility that smoke will drift over urban areas. Prescribed fires can be set when airflow will facilitate smoke dispersal and carry it away from urban areas, when a hot convection column will carry smoke aloft, and when fuel is dry enough to burn with little smoke (Cramer and Graham 1971). The latter is difficult in hemlock-spruce compared with drier inland forests. Prolonged smoldering of slash piles after the main fire produces a lot of smoke which, without strong convection currents, tends to flow at ground level. Soil mixed in the slash aggravates this problem.

## YARDING UNUTILIZED MATERIAL

YUM is a contract requirement on some public timber sales in Oregon and Washington. The requirement is that, in addition to removal of merchantable logs, all other logs above specified dimensions, regardless of defect, be yarded to the landing. YUM leads to improved utilization because, once logs are at the landing, more may profitably be hauled to a utilization plant. The dimensions usually specified are 8 inches (20 cm) or larger on the large end and 10 feet (3 m) or more in length; but these may be adjusted to any size. Thus, YUM may be used not only to improve utilization but to control the amount and size of residues left on a harvested area. This procedure normally removes the larger residues leaving only smaller pieces which tend to be broken up during yarding. Ecological effects are similar to yarding additional merchantable logs. There is added damage to advance regeneration, more exposure of mineral soil, and more removal of nutrient capital. The area is opened up for planting, and physical obstructions to thinning and other cultural treatments to the next crop are reduced. As with yarding merchantable logs, effects on the site vary widely depending on logging methods and equipment used. When YUM reduces fire hazard to the point that burning is avoided, its effects are substituted for those of fire.

Even though some of the defective material becomes merchantable after it is yarded to the landing and removed from the site, huge piles of unusable material remain (fig. 15). If they are left unburned, the area covered is at least temporarily taken out of production and the piles are in the way of managing the new stand. If burning is planned, it usually is delayed until late in the season when surrounding residues are wet from fall rains and danger of spread is minimal. Air pollution problems are much less then. The fire usually burns hot, and the underlying soil may receive a "hard burn" according to the definition of Morris (1970). This is of limited consequence because of the small area involved. Good survival and growth of planted seedlings have been noted on such areas.

*Figure 15.--A pile of hemlock-spruce forest residues yarded to the landing.*

YUM has not been required in Alaska or British Columbia, partly because small material tends to be lost from log rafts. It does offer an opportunity for control of the volume of residues in an environment in which treatment by burning often is not a viable alternative.

YUM may find little application in hemlock-spruce forests. The cost is high, sometimes over $400 per acre ($988 per ha) (Dowdle 1974); the need to reduce fire hazard is generally low; and adequate seed beds are usually available. But like other treatment alternatives, advantages and disadvantages should be carefully evaluated prior to harvest cutting. A positive cost-benefit ratio seems most likely where large volumes of cedar are present. As more and more residues become merchantable and are yarded as merchantable material, there will be less need to remove remaining unutilized material.

## PILE AND BURN

Tractor piling of logging residues on clearcuts is sometimes done in Oregon and Washington, usually limited to areas of high public use or extreme fire hazard. Residues are pushed into rounded piles or long windrows, the latter being most common with high residue volumes. Tractor piling should be confined to gentle slopes where exposure of mineral soil will not cause erosion and should be limited to compaction-resistant soils.

Piled residues usually are burned during periods of moist weather when fire is unlikely to spread. The piles may be left unburned but then become an obstacle to intensive management of the next timber crop. The practice would be destructive to most soils in Alaska and is not recommended for use there.

## BROWN AND BURN

Brown and burn or preburn spray is a combination herbicide-fire treatment, particularly useful where brush and herbaceous vegetation shade logging residues and obstruct seedling establishment--a common problem on hemlock-spruce clearcuts. The herbicide serves as a desiccant by killing live foliage which then dries in the sun. The leaves shrink and curl, letting sunlight through to the residues below. Both the killed foliage and the drying residue provide fuel for the fire to run across the area. The objective is to set back competing vegetation and open up the area for planting; hazard reduction is a secondary benefit. In this situation, it is impractical to depend on natural regeneration because brush and herbaceous plants come back too quickly. Rather, large, vigorous planting stock should be used; and even then, additional treatment may be needed to prevent overtopping.

Almost any effective and approved herbicide may be used as a preburn spray. It need not be selective to protect conifer seedlings, because presumably none are present. Dinitro is often used (Hurley and Taylor 1974). Another common formulation is 3 pounds acid equivalent of 2,4,5-T in an oil-water emulsion containing three-fourths gallon of diesel oil, plus water to make 10 gallons per acre (3.36 kg 2,4,5-T with 6.8 liters oil to make 93.5 liters per hectare).[9]

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[9] Ronald E. Stewart. Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon, personal communication.

## OTHER RESIDUE TREATMENTS

Few other residue management treatments have been used following clear-cutting of hemlock-spruce forests. Next to broadcast burning, the most common treatment is to burn only heavy slash concentrations (fig. 16). The heaviest concentrations are at the landings. Others occur where the timber was particularly defective or where slash has accumulated in depressions. Burning usually is accomplished during the first fall rains when concentrated piles will burn but adjacent areas will not.

*Figure 16.—Spot burning of residue concentrations, Oregon coast.* A, *Before;* B, *after.*

Chipping residues and distributing the chips over the soil surface is a frequent suggestion, This would help protect the soil; but on steep slopes where protection is needed most, equipment for doing the job probably would damage the site more than leaving the residues untreated. Chipping is becoming increasingly common along roadsides. Unwanted vegetation and limbs trimmed from roadside trees are chipped, and the chips are blown into small piles. This improves driving safety and the esthetic appearance of the roadside.

A layer of chips on the soil surface affects the nutrient status at the site by increasing the surface area of the residues, thus speeding decay. This tends to tie up nitrogen in decay organisms and may temporarily limit tree growth (Cochran 1968). Not enough chipping has been done to fully evaluate the fire hazard of chips on the soil surface, although chips have been found to be a definite hazard along railroad rights-of-way (Jemison and Lowden 1974).

## CONVERTING RED ALDER TO CONIFERS

In Oregon and Washington, red alder stands often are converted to conifers by a combination of logging, felling tall residues, broadcast burning, planting, and chemical brush control. The conversion usually is made on conifer sites previously logged or burned by wildfire, then abandoned without further treatment. Red alder and brush often invade and dominate such areas. Usually there are some conifers, growing singly or in small clumps. The usual management objective is to convert back to conifers because hemlock, spruce, and Douglas-fir all have greater stumpage value than alder and, with rotation ages currently used, greater productivity.

The procedure generally is to log all merchantable alder and conifers, in the process knocking down as many unmerchantable trees as possible. Remaining trees are felled. Then the area is broadcast burned to clean it up for planting and further set back brush and other vegetation (fig. 17). Planting is accomplished as soon as practicable after burning with large and vigorous planting stock that has a better chance of keeping ahead of sprouting brush. If planted seedlings later become overtopped, approved selective herbicide sprays are used. Red alder frequently seeds in again and also must be controlled.

Mechanical eradication of the alder and brush is an alternative approach (Gratkowski et al. 1973). Tractors equipped with brush blades may be used on gentle slopes where residues are pushed into windrows and later burned. On steep slopes, cable systems may be used to drag weighted drums, chains, or other tools through the alder and brush in preparation for burning. These mechanical eradication techniques are effective but quite expensive, and there is danger of causing soil compaction and erosion.

Large acreages of high-site forest land in coastal areas are now dominated by red alder and brush. Substantial gains in timber growth will come as this land is put back into full production.

## TREATMENT OF THINNING RESIDUES

Residues from hemlock-spruce thinnings generally have been left untreated. Fire danger under the shade of a residual stand has not been great, even though most thinnings have been in the drier portion of the hemlock-spruce range. Residues sometimes are lopped and scattered to put them in contact with the soil where moisture will speed decay. Lopping and scattering often is prescribed along road rights-of-way where the risk of fire is high and esthetic values are particularly important.

*Figure 17.--A stand of red alder encroached on this conifer site which is now being converted back to conifers by logging, slashing, broadcast burning, and planting. The alder stand with occasional conifers can be seen in the background. Tillamook County, Oregon.*

In shelterwood cutting, residues sometimes are piled in the larger openings and burned. This clears the area for seedling establishment and reduces fire hazard. Hand piling usually is preferred over machine piling because tractors are limited to gentle slopes; and they may compact the soil, damage established regeneration and surface roots of the residual stand, and expose mineral soil to erosion.

Precommercial thinning in hemlock-spruce is standard practice on many public and private ownerships in Oregon, Washington, and British Columbia. Both powersaws and chemicals are used, with saws most common. These thinnings leave a high fire hazard, particularly while foliage remains on the crowns. The small limbs and foliage are light, carry fire rapidly, and are only partially shaded from the sun. With chemical thinning, the trees remain standing; this slows decay because the wood dries out too much during dry weather to support fungal growth. Limbs usually decay and fall off first; then the roots decay, and the main stem topples over. With powersaw thinning, some trees remain upright but most fall over and remain suspended above the ground on their limbs. The main stems are not heavy enough to crash to the ground. The resulting tangle of stems and branches strongly discourages foot travel (fig. **18**). It takes 5 to 10 years for the main stems to settle to the soil surface unless borne down by a heavy snowpack. Thereafter, decay accelerates rapidly. Extra fire protection usually is provided for the years it takes these thinning residues to decay or be covered with understory vegetation.

Residues from precommercial thinning generally are left untreated. Broadcast burning is impractical because of intermingled crop trees. Piling and burning would be difficult because the slash is too light and springy to form compact piles. Cut trees are pulled out of roadways and roadside ditches, and sometimes these are chipped. Slash on the general area usually is left to decay over time.

*Figure 18.--Residue from thinning of dense, 19-year-old hemlock-spruce stand, Maybeso Valley, Alaska. An average of 6,300 trees per acre (15,565 per ha) averaging 1.6 inches (4 cm) in diameter were cut, leaving crop trees spaced 16 by 16 feet (4.9 by 4.9 m).*

# CURRENT PRACTICE

Residue management is in transition in the hemlock-spruce type as well as generally in the Pacific Northwest. Improvement in utilization, gradual over the years, recently has been more rapid--both in harvest of smaller sizes and better utilization of defective material. Greatest reductions in residue volumes have been near utilization plants where transportation costs are low. Others come from careful felling and bucking to reduce breakage, cutting lower stumps, taking shorter chunks, utilizing to a smaller top diameter, handling logs more carefully, and using defective logs.

Increased utilization of timber sometimes is accomplished by prelogging small trees that might be broken if felled and yarded with the main crop. Relogging--logging the area again, usually with smaller equipment than the main harvesting operation--also may be used to improve utilization. Relogging is common when periods of high log prices make profitable removal of more logs from the area. Areas with western redcedar slash often are salvage logged for shake bolts.

Soil is recognized as the basic resource, with increased attention given to short- and long-term effects of residues on soil stability and nutrition. Timber harvesting and road construction are planned to keep residues out of streams. 'If residues fall into streams, they should be removed and placed above high-water level.

Fire regulations in each State and most timber sale contracts on public land require felling of snags and Unmerchantable trees on clearcut areas. The main objective is to reduce fire hazard. The need for snag felling, particularly in the wetter parts of the hemlock-spruce type, needs further study.

The appearance of the forest is given special consideration, with most public and some private landowners designing clearcut boundaries to blend into the landscape and present a more pleasing appearance than would a rectangular clearcut. Forest residues are often screened from view until they have been overtopped with tree seedlings or other vegetation.

Additional practices vary from south to north and are best discussed by locality.

## OREGON AND WASHINGTON

Treatment of logging residues differs among forest landowners in Oregon and Washington. Those who have heavy slash accumulations, summer drought conditions above average for the type, or a high proportion of western redcedar slash tend to favor burning. Others require WM, then wait until late fall and burn the large concentrations at the landing. Still others forgo the added yarding cost for the unmerchantable material and burn the heavier concentrations at the landings and out on the harvested area. Others leave the slash untreated.

Public land managers often are faced with increased fire risk due to heavy public use, and this tips the scale in favor of burning. Private landowners more often restrict use of their property during periods of extreme fire danger, thus reducing the risk of wildfire. Some of them strongly oppose burning of any kind. Often they have a nearby utilization plant and are able to remove quite small material from the area, thereby reducing residue volume.

Arrangement of cutting units is an important factor influencing residue management decisions. When a clearcut area is surrounded by green timber, as in the patch-cutting system, wildfire normally can be confined to the vicinity of the clearcut area because the surrounding hemlock-spruce timber stand usually remains damp enough to slow wildfire, facilitating its control. General fire hazard, therefore, is not greatly increased by the presence of slash. If, on the other hand, a new slash area will be an extension of an existing one, danger of spreading wildfire will be increased materially. Cutting units often are selected to avoid creating large continuous areas of logging slash.

The principle of avoiding large areas of continuous slash applies also to precommercial thinning areas. Usually they are broken up into small enough units that wildfire soon will hit a fuel break where it can be controlled.

Broadcast burning in coastal forests may be done in the spring, summer, or autumn, most being done in the autumn during the drying period after rain. Then the logging slash and duff exposed on a clearcut may be dry enough to carry the fire while the residues under surrounding timber tend to remain too wet to burn. The larger fuels on the cutover usually are still dry inside from the summer drought and tend to be consumed more than during a spring burn. Also, in autumn there is less risk of dry weather following the fire than would be the case in the spring. Often there is the prospect of rain within a few days, thus minimizing risk of holdover fires.

Burning in spring is less common than in summer because many areas remain too wet to burn. Where burning can be accomplished, the fire consumes mostly fine material. Some recent increases in spring burning have resulted from smoke management restrictions delaying autumn burning, so the treatment is applied the following spring. Smoke management restrictions also have provided some emphasis for summer burning which, until recently, has been restricted mostly to wet areas with red alder residues. There are only limited periods when the westerly flow of air stops long enough to avoid smoke being carried inland over population centers, and these are more common in the summer. Spring and summer burns should be thoroughly mopped up to prevent fire escape during subsequent dry weather.

Fuel moisture is one of the most important factors in the timing of slash burning. If fuels are too wet, time will be wasted in getting the fire to burn and smoke will be increased. The resulting reduction in fire hazard may be inadequate, increasing the risk of a reburn. If fuels are too dry, the fire may burn too hot, damage the site, and spread to other areas.

Fuel-moisture indicator sticks may be used to indicate when burning conditions are favorable (Morris 1953, 1958a, 1958b, 1966). Ideal timing of a burn must be tempered with air quality requirements, and burning must be restricted to days when smoke will not be carried over population centers or recreational areas. Burning may be delayed until a later date, or until another year. However, rapid growth of vegetation on most coastal sites precludes burning after a year's delay unless a preburn spray is applied.

Firelines are constructed around most slash areas in advance of burning. Water often is made available for the more dangerous parts of the perimeter, and organic materials immediately outside the fireline are wetted down before ignition. Ignition often is started along the upper perimeter of the area, and a strip is burned out. As this fire dies down, the burned strip becomes, in effect, a widened fireline. Fire then is set progressively downhill to the lower edge of the unit. There are many variations, depending on wind, topography, and other local conditions. The various techniques used for burning are described in detail by Brown and Davis (1973).

In general, fast and hot combustion of the fuel causes the least smoke emission and contributes to better dispersal by upper winds. Improved ignition systems have been developed for the rapid ignition required (Schimke et al. 1969).

Foresters in Oregon and Washington pioneered burning and related residue treatments for conversion of conifer sites currently dominated by red alder. This practice is increasingly common in these two States.

Generally in the Oregon and Washington hemlock-spruce, the trend is away from broadcast burning--to not burn at all or to restrict burning to the landing area and perhaps a few heavy slash concentrations. Major contributing factors are the moist climate, presence of advance regeneration, better utilization, more harvest cuttings in young stands that have little defect, and smoke management restrictions. There are, however, heavily decayed old-growth stands or open stands with dense brush understories where burning still appears to be a necessary treatment.

Residues management guidelines for public lands and for private lands for Oregon and Washington have been compiled by Pierovich et al. (1975).

## BRITISH COLUMBIA

Residue management on all public and private forest land in British Columbia is prescribed by the British Columbia Forest Service after inspection of harvested areas (British Columbia Lumberman 1971). The B. C. Forest Service has prepared a guide to broadcast burning of logging slash where this treatment is prescribed (British Columbia Forest Service 1969). Currently, some areas are broadcast burned, some are left unburned, and on some only the residue concentrations are burned. It is the responsibility of the operator to carry out the prescribed treatment. The area must be released by the Forest Service before adjacent timber may be logged. The prescription may require special measures to protect the soil, established seedlings, adjacent timber, or other property (British Columbia Lumberman 1969). Snag felling is required as part of the hazard reduction program. Timber operators may elect to burn additional areas to improve access for planting or expose more mineral soil seed bed. Part of the road network is maintained after slash abatement to provide ready access in case of wildfire.

There has been a general reduction in fire danger in British Columbia in recent years, mostly due to better utilization. Contributing factors include conversion from steam to gas or diesel power, from rail to truck haul, and from lumber only to a lumber-plus-pulp economy. Snag felling has been made compulsory. Logging operations are closed during critical fire weather, better weather forecasts are available, and training and equipment for firefighting are better (British Columbia Lumberman 1969). Beginning January 1, 1966, the British Columbia Forest Service initiated a "Close Utilization Policy" providing a financial incentive for better utilization. In coastal forests, wood volume between 9.1-inch (23-cm) d.b.h. to a 6-inch (15-cm) top and 13.1-inch (33-cm) d.b.h. to an 8-inch (20-cm) top was sold for 55 cents per 100 cubic feet (2.8 $m^3$). These changes and increasing public pressure against smoke in the atmosphere are resulting in a trend away from residue management by burning. The consensus of Canadian Forest Industries in 1971 was that about 30 percent of slash areas should be burned, although at that time the B.C. Forest Service was requiring about 50 percent (British Columbia Lumberman 1971).

### ALASKA

In coastal Alaska, some 99 percent of commercial forest land is administered by the U.S. Forest Service or State of Alaska, the remainder being in small private ownerships. Logging residues on all forest lands are left essentially untreated.

Fire danger is usually low because of the cool, moist climate; and experience since pulp logging began in 1953 has shown the risk of wildfire in slash is not great enough to require treatment to reduce the hazard. Present Forest Service regulations limit the size of clearcuts to 160 acres (65 ha). This disperses the slash hazard and reduces the probability of large fires.

Operators are required to maintain fire equipment on logging operations at all times and, during occasional brief summer dry periods, may be required to alter working hours or suspend operations. Snag felling is required on National Forest lands.

Most of the timber logged in coastal Alaska is overmature, and defect is often high. This results in large accumulations of residue. Public concern is largely over esthetics and the apparent waste of raw material. Forest managers are also concerned over the obstruction caused by large residue to future management of young stands. Utilization standards continue to improve, and more defective material is used for pulp. There may be some limited need for burning in the future, but the present trend toward better utilization and no burning appears likely to continue for some time.

## *CONCLUSIONS AND RECOMMENDATIONS*

Forest residue is receiving increased attention from land managers, and there is increasing interest by the general public. These are favorable trends which surely will continue. The result will be increasingly better residue management decisions. Decisions for treating residue or leaving it untreated should be based not only on short-term effects during the logging slash period but also on long-term effects on the ecosystem and the next rotation. A major objective is to maintain a viable forest ecosystem that will produce the desired balance of goods and services. The potential long-term productivity of a site must be maintained or improved, including the air and ground water resource, the fish and wildlife habitat, and the natural beauty of the area. There must be an adequate cover of organic material to protect the mineral soil from surface erosion.

Residue management decisions are made best as part of overall management planning and by consultation with experts in several fields. Single-purpose treatments usually should be avoided. Pierovich and Smith (1973) developed a framework for determination of the optimal residue treatment which essentially portrays the thought processes that might be followed in making a decision. Their model can be used for analyzing alternatives on relative scales, or it can be translated into operational forms for handling large masses of data in a computer. Jemison and Lowden (1974) point out that different areas have a different mix of important environmental factors, and different landowners have different land-use objectives. They suggest establishing environmental goals for each area requiring a residue treatment decision, then listing the desirable and undesirable effects of each treatment alternative. Alternatives are evaluated in light of their costs and benefits before treatment decisions are made.

Blanket rules often do not apply. The same residue volume may be an essential part of the ecosystem in one area and require almost complete disposal in another, An independent decision should be made for each.

A caution to keep in mind in Oregon and Washington is a tendency to extend Douglas-fir silviculture, including residue management, westward into the more moist coastal strip. This tendency should be avoided and the hemlock-spruce type recognized as a separate entity with different residue management problems.

A basic solution to the residue problem is improved utilization--improvement to the point that residue treatment for hazard reduction is unnecessary. Much progress has been made--logs are now being removed down to a 6-inch (15-cm) and often smaller top diameter.

An increasing percent of total harvest is in 'young age classes with little defect. Extension of road systems permits salvage logging over increasingly larger areas; so fewer residues accumulate. The trend toward less residue volume is likely to continue as increasing demand for wood fiber permits utilization of smaller and more defective material. Whole-tree chipping is a rapidly increasing practice in small timber (Wallace 1974). .Pulping the complete tree including limbs and stump, complete use of logging residues as fuel, and chemical extraction are definite possibilities (Lowe 1973, Grantham et al. 1974, Schofield 1960). For the near term, the costs of handling and processing residues in comparison with long-established sources of fiber will limit utilization. However, in the final analysis, utilization probably will be limited, not by economics but by the need to maintain the nutrient capital and soil stability of the site. Additional research to determine minimum residue.levels is needed. In the interim, we feel that leaving the duff plus the needles, twigs, and branches from the logging residue should be adequate on most sites (fig. 19).

The forest manager and, in many cases, also the concerned government forester should decide, in advance of logging, the most desirable postlogging environment for each area to be harvested. The harvesting operation and any followup residue treatments should be designed to provide this environment. It is important that decisions be made and treatments, if any, applied promptly. Hemlock-spruce ecosystems change rapidly and a treatment planned for one season may not be appropriate if delayed until the next.

Usually, first consideration is the fire hazard--is slash burning or other treatment needed to reduce the hazard? Will added protection suffice? Is any action needed at all? Generally in southern areas, experienced and efficient fire control organizations have crews on standby in the hemlock-spruce or adjacent Douglas-fir type. Here, greatest reductions in damage from wildfire probably will come not from increasing the protection organization 'but from reducing the fire hazard. Particularly important is the development of fuel breaks to provide strategic and safe places where firelines can be quickly established.

*Figure 19.--Leaving the duff of the forest floor plus leaves, twigs, and branches of the logging residue should maintain adequate nutrient levels on most sites. Divisions on stake indicate 1 foot (30 cm).*

Strong arguments for burning develop when there are large residue accumulations, an expectation of dry weather, and accompanying risk of ignition--the high fire danger situation. This is most common in the southern portion of the range. A prescription for burning based largely on residue accumulations probably will be a one-time prescription, because large fuel accumulations will be unlikely in the future.

Strong arguments against burning develop in the opposite situation where fire danger is low. The obvious example is Alaska where harvested areas rarely dry out enough to burn. Residue volumes, however, are high and will continue high until the old-growth timber is harvested and the residues there have time to decay and become incorporated into the soil. In Oregon and Washington, advocates of nonburning often are managing healthy young stands in areas where economic conditions facilitate good utilization. They may be able to exclude the public during periods of high fire danger. They often plan to utilize advance regeneration present on harvested areas.

These arguments for and against burning eventually may be resolved in favor of nonburning as improved techniques and economic conditions permit improved utilization of small logs and defective material. Forest land managers should strive for utilization that will avoid the need for the costly, sometimes risky, residue treatments now essential on some harvested areas.

The ecological relationships between residues and seedling establishment should be used to control seedling density and species composition of the new timber stand. Fresh residues are poor seed beds. Residue management should leave them distributed so as to provide the desired number of mineral soil seed beds or planting sites, covering all others to prevent overstocking. Where advance regeneration is prolific and intermixed with. logging residues, treatments, should destroy enough seedlings to reduce stocking to the desired level. Where Douglas-fir is desired, treatments should expose mineral soil planting sites or seed beds. Shade provided by residues can aid seedling establishment during dry summers.

There are several situations where individual factors carry heavy weight in making residue management decisions:

1. Protect the soil resource. Soils with high erosion potential need to'be protected by a mantle of forest floor material or logging residues. Broadcast burning and tractor piling of slash should be avoided in such areas. Yarding of logs and, where appropriate, YUM should be accomplished by lifting logs free of the ground. Lopping and scattering of residues and special fire protection measures are preferred alternatives to treatments that would expose mineral soil.

2. Protect the nutrient capital. On nutrient-deficient forest soils and soils low in clays or organic matter, the nutrient capital stored in forest residues, particularly the forest floor, is needed for tree nutrition. Only large residues should be removed from these areas, and the forest floor should not be reduced by burning. The desired volume and arrangement of residues to be left on the site should be identified and the harvesting operation and residue treatments planned accordingly. More information is needed on how much organic material should be left. In the interim, we feel that leaving the duff plus needles, twigs, and branches from the logging residue should be adequate for most sites.

3. Protect the stream channels. Timber should not be felled across streams used for fish spawning or rearing. Residues that are imbedded in stream channels or streambanks and are not blocking fish migration or causing channel erosion should be left undisturbed. Residues that may be picked up by high water and cause downstream damage and those that occupy fish rearing space should be carefully removed from stream channels, preferably during the low-water period, and placed above high-water mark or otherwise disposed of. Cleaning should be done by hand where necessary to reduce damage to streambanks. Riparian vegetation should be left to shade the stream surface and serve as a barrier for surface movement of soil toward the stream. Stream cleaning should be done under supervision of an experienced fisheries biologist.

4. Protect intermixed seedlings. When desirable tree seedlings are intermixed with logging residues, broadcast burning should be avoided. Alternative treatments include piling and burning, lopping and scattering, YUM, and providing extra fire protection. Often it will be possible to destroy numerous trees and still leave a full stocking of well-distributed seedlings. If stocking is incomplete, site preparation should be incorporated into the residue treatment with the objective of preparing appropriate seed beds for natural or artificial regeneration.

5. Control vegetative competition. Some stands in Oregon and Washington have a heavy brush understory which, after harvest cutting, remains intermixed with logging residues. Broadcast burning may be appropriate here to control brush,

reduce fire hazard, and open up the area for seedling establishment. An approved preburn herbicide spray may be needed. Burning should be followed by prompt plantation establishment and followup treatments with approved herbicides as needed to keep seedlings ahead of sprouting brush plants.

6. Control dwarf mistletoe. Mistletoe-infested seedlings should be classed as forest residues and destroyed by broadcast burning or other methods as part of disease control programs.

7. Maintain recreation and scenic areas. Special attention should be given to residue management in recreation and scenic areas. When accumulation of residues is unavoidable, prompt action, within cost limitations, should be taken to improve the appearance of the area. Particularly important are areas close to public travel. Residues which are obviously man caused and do not blend with the landscape should be disposed of. If chipping is used, chips should be distributed well, avoiding piles that will be apparent to the public and take a long time to decay. If burning is used, charred remains such as partly consumed logs, burn piles, and scorched trees should be avoided.

8. Avoid continuous areas of logging residues. Creating large areas of continuous logging residues unnecessarily increases fire hazard and should be avoided. This problem is confined mostly to the southern portion of the hemlock-spruce range. Precommercial and commercial thinnings also should be planned to avoid large, continuous slash. If thinning is done in the fall, needles will have fallen off the branches before the next fire season.

9. Change the timber type. If seral species such as Douglas-fir are desired, residue treatment by burning often is indicated. Burning is less expensive than most other treatments. It will destroy much of the advance regeneration of shade-tolerant species and open up the area for seeding and planting, or natural seed fall of desired species. Concurrently, it will reduce the fire hazard.

10. Follow smoke management plans. When residue concentrations are near smoke-sensitive areas and there is a history of wildfire, residue reduction by prescribed burning often is a better alternative than accepting the risks of wildfire. Burning should be accomplished when smoke will flow away from the sensitive area or be carried far aloft by strong convection currents. Local smoke management plans should be followed. A fast, hot fire followed by prompt mopup is desirable.

11. Treat large residue volumes. Residue treatments are needed when residue volume is so great that it will interfere with seedling establishment and intensive management of the new stand. Intensive management programs are more advanced in the southern portion of the range and this is where residues are more likely to be a serious fire hazard. The most appropriate treatments are broadcast burning and YUM. Treatments should be designed to leave an adequate number of partially shaded mineral soil seed beds available for natural regeneration, seeding, or planting.

In general, the trend away from broadcast burning is likely to continue. Unlike Douglas-fir and pine, hemlock and spruce have not depended on fire for their perpetuation, and fire or similar disturbance need not be an integral part of their ecology. Fire should not be eliminated but should be retained as a management alternative and used when the benefits outweigh the detriments.

Additional research is needed to expand the scientific base for residue management. Research needs for the Pacific Northwest are listed in detail by Cramer (1974); here we emphasize only thr'ee needs of particular import in hemlock-spruce.

Long-term nutritional aspects of residues need further study. Economics of forest utilization may soon make profitable the removal of organic material better left on the site as part of the nutrient capital. This point already may have been reached in some hemlock-spruce areas. We need to know what is needed to nurture the new crop. May some of it be removed and replaced by fertilization? In short, what are the trade offs between utilization of organic material and site productivity? In southern hemlock-spruce areas, the alternative of fire and its short- and long-term effects also enter this picture.

Esthetic aspects of residue management also need study. Hemlock-spruce forests receive high recreation use. Most of this is water oriented with people congregating on the beaches or in the estuaries, or traveling by boat along sheltered waterways. The general public, then, sees most harvest cuttings from a distance. How residue management affects the appearance of an area and public reaction to it needs to be determined and considered in decisionmaking.

Protection and improvement of fish habitat are particularly important in coastal forests, and more knowledge is needed on effects of residues and residue treatments. Brush and other live residues are a problem on many areas. Often they can be controlled with herbicides, but we need herbicides that do not contaminate the aquatic environment.

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Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key--out of the reach **of** children and animals--and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

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If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

**Do** not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

**NOTE:** Some States have restrictions **on** the use **of** certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

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