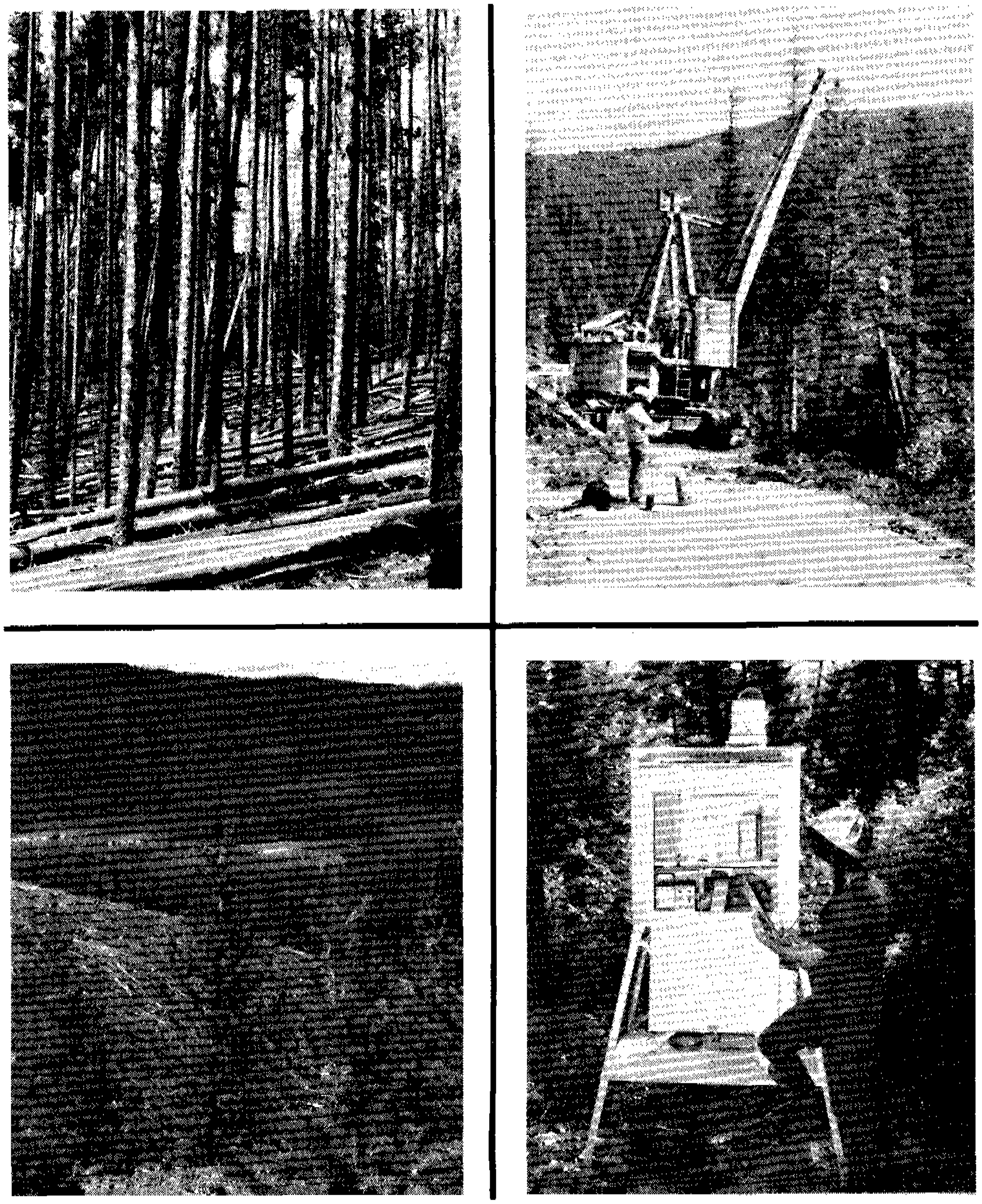
ENVIRONMENTAL CONSEQUENCES OF TIMBER HARVESTING in rocky mountain coniferous forests



Symposium Proceedings, Sept. 11-13, 1979-Missoula, Mont.

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Sponsored by:

Intermountain Forest and
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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
U.S. Department of Agriculture
Forest Service
Ogden, Utah 84401

WELCOME ADDRESS

Welcome to the University of Montana and the School of Forestry. The symposium will examine critically a number of systems that together make up the Rocky Mountain Coniferous Forests. A university setting is the ideal one for such a symposium, and, though biased, I believe the School of Forestry and the environs of Missoula add to that ideal. If we can do something to make your participation more productive, please call on us.

Over half a century ago, Alfred Lotka gave us the ultimate in abstraction of environmental systems. In his book, "Elements of Mathematical Biology," he developed the idea of a system of differential equations to describe environmental systems. He perceived in an all-inclusive way the multitude of interconnected and interacting forces among all living organisms and their environments.

Nicholas Rashevsky, another mathematician with a biological bent, examined a similar system of differential equations and extended the work of Lotka. Rashevsky's analysis of the system of equations led him to conclude that if rates of change in a system are altered to rates abnormal to the system, then it cannot be predicted what the future state of the system will be.

The work to be reported here is largely an effort to find out what the rates of change are in the system we call the Rocky Mountain Coniferous Forest. Also to be reported are the perceived limits on the alteration of normal rates that can be induced without throwing the system into an undesirable state. Viewed from that perspective, the organizational genius of Roland Barger and his committee comes to light. A very productive period lies ahead. I hope your sense of anticipation is as keen as mine.

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FOREWORD

One of the pressing problems confronting forestry today is how to more efficiently harvest and use the timber resource without creating unacceptable environmental impacts on the forest. The manner in which timber is harvested significantly influences almost all aspects of the forest ecosystem--microclimate, nutrient availability, microbiology of the site, insect and disease activity, hydrology, and esthetic quality. The silvicultural prescription, utilization standard, harvesting method, and post-harvest treatment all combine to influence the environmental attributes of the site. Some effects, such as residue concentrations (and reductions), are readily apparent. Less apparent and often unknown are the effects of harvesting activity upon the biological characteristics of the ecosystem.

Timber harvesting is the most significant management tool available to the forest manager. The potential is present to either help or hinder efforts to meet multiple resource protection and management goals. The present concern of land managers, and of researchers evaluating environmental impacts, is to identify timber harvesting alternatives that are compatible with, and can facilitate, responsible management of the forest ecosystem. Research reported in this symposium will provide foresters and others with improved knowledge of how harvesting activities affect the forest ecosystem. It will also provide strengthened guidelines for prescribing harvesting practices to achieve specific land management objectives--objectives relating to esthetics, stand regeneration and development, wildlife, management, hydrology, insect and disease control, fire management, and other management concerns.

Most of the research has been conducted in forest ecosystems common to the lodgepole pine, larch, and Douglas-fir forests of Wyoming and Montana. Investigations of environmental consequences have covered an array of harvesting systems, silivicultural prescriptions, and utilization standards. Emphasis has been directed toward determining the biological consequences of successively more intensive levels of utilization, and alternative post-harvest residue treatments. Although the research has necessarily been site-specific, the results have management implications for coniferous forests in general.

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Carl M. Berntsen

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ABSTRACT

Environmental concern grew out of accelerated timber harvesting in the Rocky Mountains during the early 1960's. Citizen groups concerned about adverse visual impacts were joined by those interested in the preservation of wildlife and wilderness. The forestry environmental movement joined the national environmental movement to work for more stringent congressional legislation and federal regulation. The lack of a comparable level of technical information for decision makers has been costly in terms of dollars and time.

KEYWORDS: Environment, forest management research, coniferous forests, environmental legislation, forest regulation.

In Montana and the Rocky Mountain Region, a strong sense of individual independence and a way of life seem to say: "This is my country. I want something to say about how it is used." A decade ago its "use" accelerated.

In the early 1960's new developments in harvesting and milling technology and increased lumber demands altered the economic picture for marginal timber stands. Lodgepole pine came into its own as a commercial crop, for example, and the opportunity to convert old, deteriorating forests to young, vigorous ones was duly noted. Conversion would prevent additional losses to insects and diseases, and contribute to the public welfare by creating new jobs and suppling lumber for local and national needs.

Most people welcomed the changed social and economic outlook. The lumber industry, encouraged by these signs, built timber processing plants at locations adjacent to national forests, the main source of timber in the Rockies. Thousands of acres of lodgepole pine and spruce were clearcut--much of it in large, conspicuous units.

By the mid-1960's the apparently unforeseen impacts of timber harvesting reached the public and fostered organized opposition (USDA Forest Service 1975). The opposition believed that continued harvesting in the high-altitude forests would have serious effects on soil, water, wildlife, and landscape values. These concerns took on special currency with the rapidly increasing public attention to environmental quality in the late 1960's.

The Rockies are nationally famous for magnificent landscapes and rich resources of water and wildlife. Many citizens consider these the essentials of a quality environment. For some, even minor change is degradation, and timber harvest produces more than minor change. Consequently, harvesting in the Rockies suddenly moved into national significance within the context of environmental quality.

THE ENVIRONMENTAL MOVEMENT

This scenario has been repeated again and again in hamlets, cities, states, and over issues involving the atmosphere, the sea, the land, and even the depths of the earth. Environmental issues include the air we breathe, the food we eat, the clothes we wear, the landscapes we see, the animals we seldom see, and even things we imagine. And we wonder: "Why has this wave of environmental concern swept over our country?"

Indeed, why would the Supreme Court decide to stop construction of a $120 million dam to save an endangered but useless little fish? Why would hundreds of thousands of citizens protest the slaughter of whales and seals they had never seen? Why would a provincial judge force road builders to spend millions of dollars to save a pond used by a few dozen endangered geese every winter?

Jacques Costeau (1978) replied to these, his own questions, with: "The answer is simple. Today the public is realizing that there is an urgent need for an environmental code of ethics." Whether this is all there is to it, I am not sure. But the respect that the general public has for Costeau certainly lends credibility to the environmental movement.

Quite possibly the element of the environment that first gave rise to public concern about forest management was that of adverse visual effects. Few people in the 1950's and 1960's understood the environmental movement, and fewer knew what ecology and silviculture meant. But untidyness was something most of us had been conditioned to recognize as undesirable. Adverse visual impacts became a rallying point, one to which other elements of environmental quality became attached--some with substance, others as whims of imagination.

And the environmental movement kept growing. The concern with forestry grew too. Timber harvesting began sharing the spotlight with preservationist goals and objectives. Forestry, like other environmental issues, developed a following that inevitably found its way to Congress, frequently through a congressman from a district where environmental degradation had occurred. The legislation and regulation that followed is unprecedented in its impact on social, industrial, and political activities.

The environmental movement is now a Juggernaut. Built into its power structure is a whole new regulatory agency that must prove it can regulate; vast sums of industry investment that must be recoverable; a whole new profession of environmental law, with a more than ample following of agressive attorneys.

For all parties there is a significant economic and social cost to the resolution of environmental disputes through prolonged litigation. Enormous sums of public and private money are spent in lobbying, legal fees, and the escalated costs of development or construction after long, court-imposed delays.

Equally damaging to society is the growing polarization between those who support environmental caution and those who see a fundamental conflict between environmentalist goals and the economic and social needs of our society. In the construction, mining, and timber industries, where the impact of environmental programs has been considerable, labor and industry leaders tend to regard the environmental movement as a "no-growth" policy, detrimental to business and society. Environmentalists, in turn, see their opponents as short-sighted, intransigent, and self-centered (Train 1978). Such polarization is subsequently reflected in Congress, and results in frequent stalemates and sometimes questionable decisions.

CONGRESS AND ENVIRONMENTAL DECISIONS

Congress responds primarily to pressures--social, political, and industrial pressures. Most members of the House and Senate admit that they are subject to pressure tactics. But Congress is desperate to find ways to improve decisionmaking.

Recently a two-day forum was held on Capitol Hill, sponsored by the American Association for the Advancement of Science (AAAS) in cooperation with the Joint Senate and House Committee on Science and Technology. The subject was "Risk/Benefit Analysis in Decisionmaking." Invitations were extended to scientists and science-related individuals and organizations. The morning meeting of each day was a congressional hearing. Three or more Congressmen or Senators would introduce a subject, and three scientists would respond with prepared statements. Then followed an audience-participation discussion. The afternoon meetings were similar, but less tied to the legislative format.

After 29 presentations and hours of debate and discussion, no profound conclusions were reached. A glimpse of the dilemma that exists as a part of decisionmaking in Congress is revealed by an opening remark by one Senator: "I have never seen a problem, no matter how complex, which, when looked at in the right way, is not even more complex than originally thought to be."

One three-scientist panel produced these remarks:

> Scientist, policy and management research: "Richer is better." (Meaning the safety and health of a population is directly correlated with the financial wellbeing of that population.)
>
> Professor, political science and former newspaperman: "The press has not done its job adequately in covering science legislation or science-related events. The press' self-appointed authority in technical matters frequently leads to misinforming the Congress and public as well."
>
> Professor, law: "There is no zero risk, and risk/benefit decisions should not be made by scientists, but by the responsible member(s) of Congress."

> Scientist, audience: "The Three-Mile Island and DC-10 accidents were crises causing the public to be more concerned about the ineptness of 'management' than about danger to human life."

And so it went, a disjointed dialogue with a slender thread of understanding between members of Congress and scientists. Congress is desperately groping for technical information to help make legislative decisions, while knowing that, in the end, the decisions will be heavily influenced by political pressures. The scientists were offering the best information on hand, and they too knew that the decisions will be heavily swayed by pressure tactics.

The issue of risk/benefit was summed up by John Giggons, Director of the Office of Technology Assessment: "There are no scientific formulas to measure risk--only judgement values. For example, on opposite sides of Long Island Sound are two sites for nuclear reactors. On one side the reactor is operational, on the other the reactor was not built--different judgement values on the same scientific information by different communities."

LEGISLATION AND MANAGEMENT CONFLICT

However frustrating it may be for Congress to make the "best" decisions, it has not prevented the passage of masses of environmental-related legislation directly or indirectly related to forestry. A working group report to the President's Interagency Task Force on Environmental Data and Monitoring Programs (USDC 1979) states that over 70 legislative acts have had an impact on land and natural resources. The working group on Natural Resources and Land Use of this task force concluded that no cohesive Federal land and natural resource policy exists today. Federal policy among 25 agencies is highly fragmented, with diverse goals and missions.

A few of the environment-related legislative acts within the past 10 years are:

.1969	Natural Environmental Policy Act
.1970	Geothermal Steam Act
.1971	Wild Horses and Burros Act
.1972	Federal Water Pollution Control Act
.1972	Coastal Zone Management Act
.1973	Endangered Species Act
.1974	Forest and Rangeland Renewable Resources Planning Act
.1976	Federal Land Policy and Management Act
.1976	Safe Drinking Water Act
.1976	Resource Conservation and Recovery Act
.1977	Clean Water Act
.1977	Surface Mining Control and Reclamation Act
.1977	Soil and Water Resources Conservation Act

The conflicts over the management of Federal land create problems and issues that permeate the land and natural resource management field. One important aspect is the multiple-use policy (enacted in 1964), which involves striking a balance between conflicting or competing land uses. Whether mineral and timber needs outweigh the nation's needs to preserve recreation and wilderness is an issue involving many Federal agencies, and one that does not have clear policy guidance.

Other conflicts between agencies cited in the report in the program area of forestry include:

- .Inconsistency of management purpose and extent of water reservation on public lands.
- .Duplication of authority.
- .Limitation on BLM clearcutting guidance.
- .Lack of strong private forest development.
- .Conflict over RARE II.

Similar lists of conflicts were developed by the working group for 14 other program areas such as water, air, and minerals.

MEDIATION

\s competition increases for our limited natural resources, so will the need for orderly responses to environmental conflicts. Industry and government can marshal substantial resources in support of projects embroiled in litigation. But environmentalists have effectively countered these by mobilizing broad public support and by calling on a pool of sophisticated attorneys from the new public-interest law firms.

Yet, for all parties involved, a significant economic and social cost must be paid for the resolution of environmental conflict through protracted disputes. The question has been raised by many: "Is environmental mediation a solution?" What is mediation? It can be defined as a voluntary process in which those involved in a dispute jointly explore and reconcile their differences, employing a mediator who has no authority to impose a settlement.[1]

This passive exercise and other techniques have been tried, but no serious national effort has been made to bring a greater use of mediation to environmental disputes.

A RATIONALE

The forestry profession finds it difficult to understand why environmental groups and the general public do not give our mission of growing trees at least equal billing with cutting trees. Growing trees is slow and unspectacular compared to the action associated with felling, logging, road building, and hauling. And perhaps that partially explains the imbalance between credit and criticism. But it would be unwarranted to conclude that the public and concerned groups are not interested in growing trees. Perhaps the passive nature of forest replacement is seen as a "cure," and "no comment" should be accepted as endorsement of doing what is expected of the profession, whereas tree cutting may be perceived as being on the side of "injury" requiring remedial action or prevention.

Timber harvesting, as a part of the overall environmental movement, is now caught up in directives, regulations, laws, and the will of society. These controls are so firm that all forest land planning must now give serious consideration to the possible adverse consequences of any management activity. Are we wise enough to use our science and technology for real rather than apparent progress? If we are, the future of forestry seems unlimited.

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[1] The Office of Environmental Mediation of the University of Washington's Institute for Environmental Studies.

I believe that the future of forestry is unlimited, because I not only find a growing sense of the environmental ethic among foresters, but an additional sensitivity being molded into the technical qualifications that seem to characterize our professional work force. Our university, industry, and government leaders have in no small way contributed to the motivation and substance of this change.

CONCLUSION

The environmental ethic is not new. Foresters have always been practicing ecologists. Many foresters were well acquainted with concepts of ecology long before that word entered popular usage. Most of us know the common definition of ecology, but the derivation of the word gives it an even greater meaning: OIKOS meaning home or house, and LOGOS, meaning to study. Ecology is the study of "the house we live in." John Muir expanded that concept and beautifully implanted it in our minds with these words: "In such places standing alone on the mountain top it is easy to realize that whatever special nest we make--leaves and moss like marmots and birds--or tents or piled stone--we all dwell in a house of one room--the world with its starry firmament for its roof."

The balance of nature as well as its beauty is indeed remarkable, but nature is not benign. Though it creates magnificently, it often destroys whimsically and sometimes disastrously. And so, though we may study nature objectively, man cannot be totally objective about it on a personal level (Seaborg 1970). Man must to some extent tamper with this balance of nature within ecological limits. The study of "the house we live in" has helped us understand nature, and along with technological advances, has made it accessible, usable, and enjoyed by a large segment of our population.

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THE FOREST RESIDUES UTILIZATION PROGRAM IN BRIEF

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ABSTRACT

Since 1974, the Intermountain Experiment Station has directed a coordinated program of research, the Forest Residues Utilization R&D Program, toward investigating alternative timber harvesting practices that may facilitate more intensive, environmentally compatible, timber utilization. The evaluation of biological and resource management consequences of alternative harvesting practices has been a major component of the Program. Most of the research has been conducted in forest ecosystems common to the lodgepole pine, larch, and Douglas-fir forests of Wyoming and Montana. Investigations of environmental consequences have covered an array of harvesting systems, silvicultural prescriptions, and utilization standards. Emphasis has been directed toward determining the biological consequences of successively more intensive levels of utilization, and alternative post-harvesting residue treatments. Although the research has necessarily been site-specific, the results have management implications for coniferous forests in general.

KEYWORDS: forest-residues, wood-utilization, timber-harvesting, forest-practices

FOREST RESIDUES -- PROBLEM AND OPPORTUNITY

A major problem confronting forestry is how to more efficiently harvest and utilize timber without creating unacceptable impacts on the forest environment. There are two immediate and related needs. The first need is to improve the recovery and utilization of the total wood resource, leaving less material as residue. National projections predict substantial increases in demand for wood and wood-fiber-based products, expecially softwood housing construction materials. Environmental considerations also favor extending (or at least maintaining) the use of wood, a renewable resource that can be processed with less energy and less attendant pollution than alternative materials. Harvesting practices that facilitate more complete utilization of the available wood resource in the northern Rocky Mountain States can contribute significantly to meeting this demand.

The second and concurrent need is to reduce the adverse esthetic and environmental impacts of timber harvesting, associated road construction, and other on-site activities. Present utilization standards and logging practices leave large amounts of residue--small trees, cull and broken logs, tops, and dead timber--on the ground following harvesting operations. Road right-of-way clearing and thinning operations result in additional volumes of unused wood. These residues can contribute to the forest's nutrient reservoir, reduce erosion, protect seedlings, and provide wildlife cover. In the quantities that frequently occur, however, they create a fire hazard, inhibit regeneration, detract from area esthetic values, and represent waste of a scarce fiber resource. Harvesting and transportation practices that improve the economic feasibility of using more of this material can remedy a major source of undesirable impacts on the area.

Since 1974, the Intermountain Experiment Station has directed a coordinated program of research, the Forest Residues Utilization R&D Program, toward investigating alternative timber harvesting practices that may facilitate more intensive, environmentally compatible, timber utilization. Major objectives of this Program have been

(1) To develop resource information--present and predicted--defining the location, quantity, and physical characteristics of material considered residue, as a means of strengthening utilization opportunities;

(2) To evaluate harvesting and transportation systems that can improve the technical and economic feasibility of recovering and using more of the total wood resource;

(3) To evaluate the biological and environmental effects of residue reduction, and the influence of residue reduction on post-harvest forest management needs and activities.

The principal subject of this report and of the "Environmental Consequences..." symposium, is the third area of research--evaluating the biological and management consequences of alternative timber harvesting and utilization practices.

INFLUENCES OF TIMBER HARVESTING ON FOREST ECOSYSTEMS

The effects of timber harvesting and utilization upon the ecosystems are in fact the aggregate effects of several sub-activities (fig. 1). These include,

--the silvicultural prescription, which defines the proportion of the stand that will be cut, and the nature of any residual stand;

--the utilization standards specified, which largely determine the amount and type of material that will be left on the ground;

--the harvesting method and system or systems specified, which determines yarding or skidding practices, associated disturbance of the site, and to some extent road requirements;

--the post-harvest residue treatment, which determines the final character and arrangement of material on the ground, and frequently specifies some type of on-site burning activity.

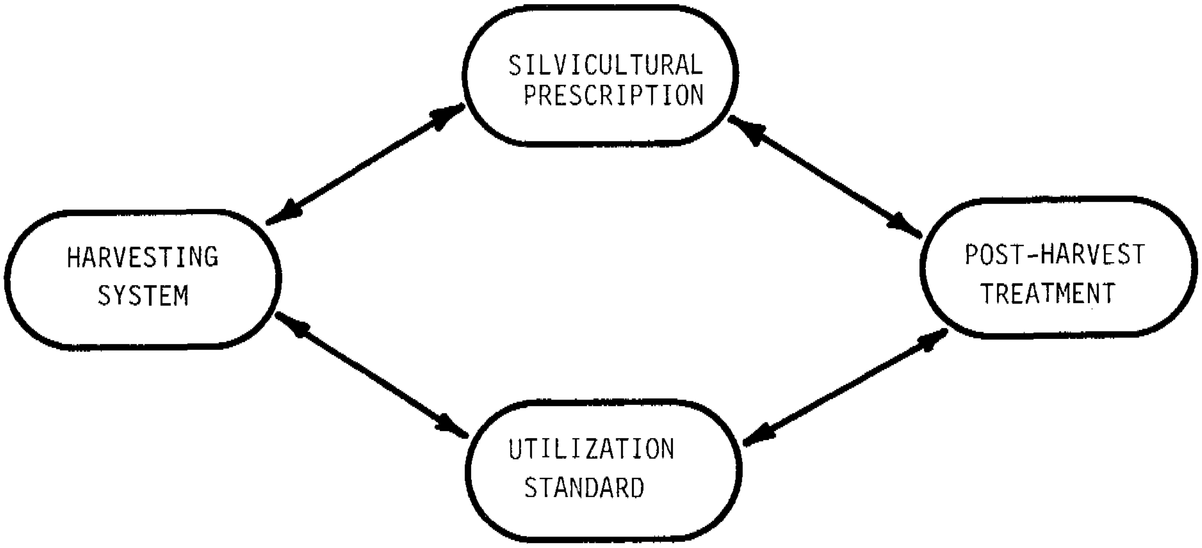

Figure 1.--The effects of timber harvesting on forest ecosystems are the combined effects of four components of the total harvesting process.

In addition to these four, a fifth activity--road construction--is frequently required to accomplish timber harvesting. New road construction on the sale area can contribute substantially to visual and physical effects.

With the possible exception of fire, timber harvesting is the most drastic treatment that can be imposed on forested land. The manner in which timber is harvested significantly influences almost all aspects of the ecosystem--microclimate, nutrient availability, microbiological activity, insect and disease activity, hydrology, and other such basic attributes. The potential is present to either help or hinder efforts to meet multiple resource protection and management goals.

Concern about the environmental effects of timber harvesting is not new. Some of the earliest research in the Forest Service, for example, was directed toward determining effects of timber harvesting upon yields or quality of other resources. In recent years, however, there has been a remarkable growth in environmental awareness, especially by the public at large. With this awareness and interest has come a renewed concern about the impacts of any forest-based activity upon the environment. Timber harvesting and associated road construction have been a particular source of concern, because of the inherent potential for environmental deterioration, including soil loss, water pollution, visual degradation, and loss or reduction of future productive capacity. Recent legislation dealing with public land management has included explicit requirements to evaluate and consider the probable effects of any management activity upon other resources and the ecosystems.

The need to recognize and avoid unacceptable environmental impacts of harvesting is one reason for current emphasis upon research that will better define and quantify effects. A second, and perhaps more basic, reason is the fact that properly prescribed timber harvesting can be the most effective tool the public land manager has to manage forested lands for a variety of resources and uses. In the Rocky Mountain area especially, timber is rarely if ever harvested from public lands simply to obtain wood fiber. Principal management objectives for the site are more likely to relate to insect and disease control, wildlife habitat, recreation potential, or watershed potential. Typical planning guidelines for the central and northern Rocky Mountain Forests emphasize key values relating to recreation, scenic beauty, wildlife, and other non-timber resources, toward which management of public forest lands will be directed. To make effective use of timber harvesting as a management tool, however, the land manager must be able to predict both short-term and long-range environmental consequences of specified harvesting prescriptions.

THE RESEARCH APPROACH

To meet specified objectives, Program research has necessarily involved a wide variety of subject matter and associated disciplines. The core Program staff has included researchers with skills in engineering, wood technology, economics, meteorology, microbiology, entomology, and biometrics. Other Station research work units in such subject areas as silviculture, fire management, economics, hydrology, and wildlife habitat have participated extensively in studies of biological and management impacts. Other major participants in Program biological research have included researchers in other Forest Service units and researchers at a number of Universities. Participating organizations especially worthy of note because of their extensive involvement include

--the Center for Mycology Research, USFS Forest Products Laboratory, Madison, Wis.

--faculty and staff researchers, School of Forestry, University of Montana, Missoula, Mont.

--faculty and staff researchers, School of Forestry, Michigan Technological University, Houghton, Mich.

Early Program planning was developed around three basic concepts: recognition that wood utilization objectives and practices must extend from, and be compatible with, broad forest management objectives; belief that the best approach to residue utilization is through more efficient initial harvesting practices, rather than salvage operations; and recognition that residue reduction has significant and direct effects upon the forest ecosystem and subsequent management activities. The typical procedure followed in planning and implementing Program research is illustrated in figure 2. First consideration is given to defining the total forest resource management objectives for a particular timber stand and site situation. Treatment specifications are then developed for tree removal and/or other stand or site character modifications (usually an array of possible alternatives) that may meet management objectives. Harvesting systems, utilization levels, and post-harvest treatments that can achieve the selected treatment effects are applied. Finally, technical and economic feasibility is evaluated, and the environmental and management consequences of tested alternatives are determined. A central concern, of course, is to apply and test harvesting alternatives that have the capability of recovering much of the wood material commonly left on-site as residue. For comparative purposes, the effects of various levels of intensive utilization are compared to observed effects of conventional sawlog utilization and post-harvest residue disposal practices.

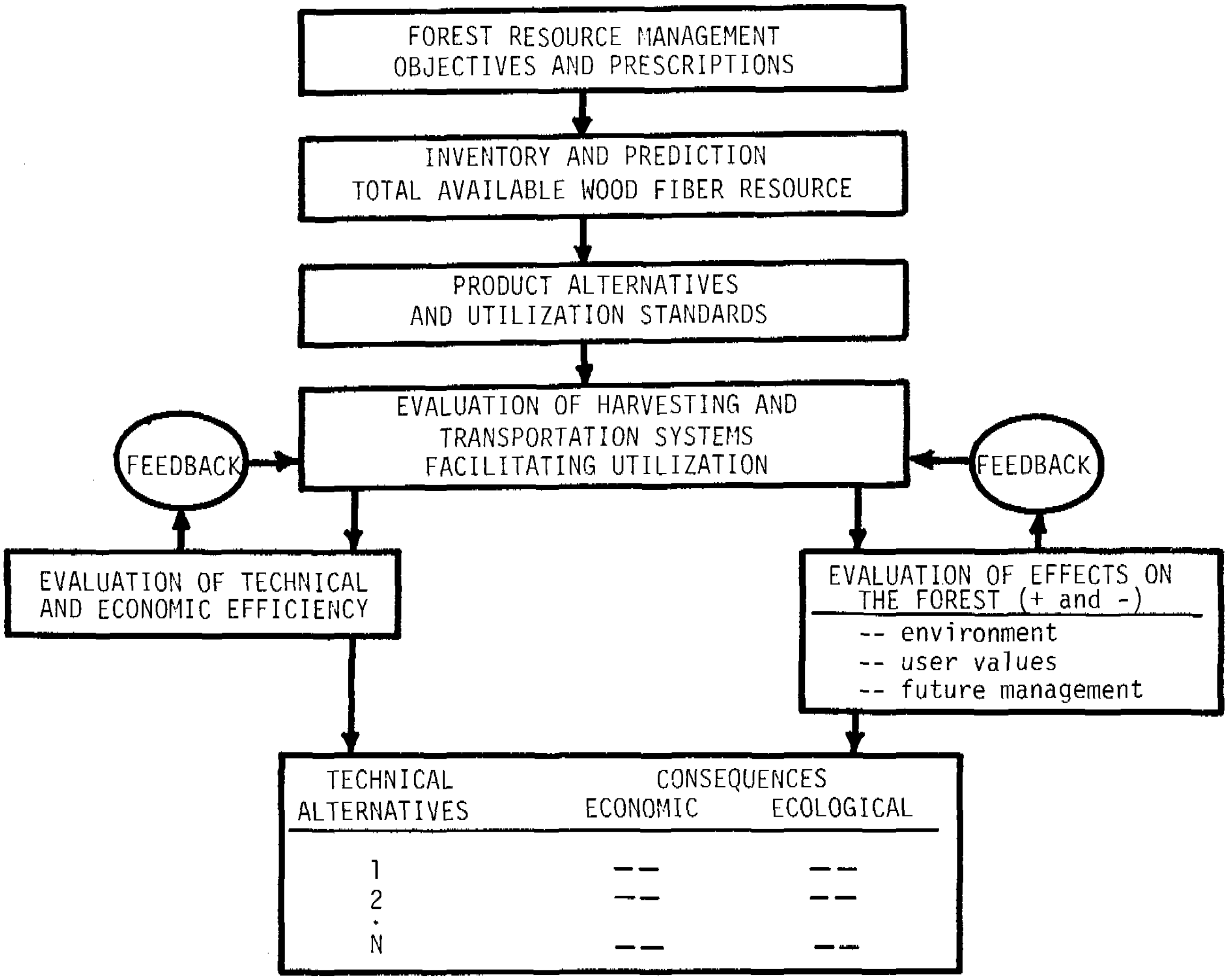

Figure 2.--The Program has emphasized developing and testing harvesting and utilization alternatives that are compatible with, and facilitate, total forest resource management on the site.

Much of the research investigating environmental effects has been conducted as closely integrated study series on specific harvesting sites. Sites were selected to represent dominant timber types, physiography, and stand conditions in the northern Rocky Mountains. Most of the research reported in this document was conducted on four primary field study sites. The four sites, and the harvesting, utilization, and site treatment practices applied, are described below.

The Coram Study Site

The Coram study site is located on Coram Experimental Forest, on the Hungry Horse District of the Flathead National Forest. The site typifies old-growth western larch/Douglas-fir stands on steep slopes. Elevations range from 3,900 to 5,300 feet (1188 to 1615 m), and annual precipitation is in the 25 to 35 inch (64 to 89 cm) range. Western larch and Douglas-fir are the predominant tree species, although sub-alpine fir, Engelmann spruce, western hemlock, and birch also occurred in intermixture on the harvested units. Management objectives for the site (and for similar sites in the northern Rocky Mountains) include:

--protecting esthetic values;

--timely regeneration and stand development;

--maintaining species diversity, especially in retaining western larch in the stand;

--avoiding high road densities;

--avoiding adverse biological impacts on the forest ecosystem.

Steep slopes and operating constraints dictated the use of either aerial or cable yarding systems, capable of relatively long reach (1,000 - 1,200 feet) (305 - 365 m) and at least partial suspension of logs being yarded. In the case of the Coram study site skyline yarding systems were used--a running skyline systems where both up- and down-hill yarding was required, and a live skyline where uphill yarding alone was adequate.

Treatments imposed on the study site were developed to test the feasibility of practicing intensive wood utilization under the management objectives and operating constraints represented. Since the biological effects of timber harvesting are the combined influence of silvicultural prescription, utilization standard, and any post-harvest site treatment, combinations of the three were tested. Silvicultural prescriptions or methods included in the field tests were

(1) clearcutting--harvesting all trees included as merchantable under the designated utilization standard;

(2) shelterwood cutting--harvesting approximately 50 percent of the merchantable volume, leaving a designated overstory to help establish a new stand.

(3) group selection cutting--clearcutting all trees designated as merchantable under the utilization standard, from irregular, randomly spaced 1- to 2-acre (.40 to .80 ha) plots.

Four levels of utilization were practiced under each of the three silvicultural prescriptions (table 1). Utilization treatments represented successively more intensive utilization practices, ranging from conventional sawlog utilization to near-complete utilization of all stems.

Table 1.--Timber utilization treatments and post-harvest site treatments tested under each of the three silvicultural methods employed, Coram study site.

Utilization Standard	Material Removed	Post-Harvest Treatment	Treatment Designation
Conventional sawlog	Green and recently dead logs, to 5-1/2" (14 cm) top; 1/3 or more sound.	Remaining understory slashed; broadcast burned.	2
Close log utilization, trees 7" (17.8 cm) d.b.h.+ (sawtimber trees)	Green logs, to 3" x 8' (7.6 cm x 2.4 m); dead and down logs, to 3" x 8' (7.6 cm x 2.4 m), if sound enough to yard.	Understory protected and retained; left as is.	4
Close tree utilization, trees 5" (12.7 cm) d.b.h.+	Green logs, to 3" x 8' (7.6 cm x 2.4 m); dead and down logs to 3" x 8' (7.6 cm x 2.4 m), if sound.	Remaining understory slashed; broadcast burned.	1
Close fiber utilization, all trees	Green 1"-5" (2.5 - 12.7 cm) d.b.h. material tree length, in bundles; green trees 5"[1] (12.7 cm) d.b.h., tree length; dead and down, to 3" x 8' (7.6 cm x 2.4 m), if sound enough to yard.	Remaining understory slashed; left as is.	3

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[1] Trees 1"-5" (2.5 - 12.7 cm) d.b.h. cut and pre-bundled prior to logging activity on the site.

Six sale area blocks were logged (fig. 3), two under each basic silvicultural system. Each block was subdivided into four treatment areas upon which the four levels of utilization were applied. Blocks were laid out to take advantage of existing and new system roads, and purposely included both up- and down-hill yarding. Back-to-back yarding with the running skyline system allowed laying out the larger units up to 2,000 feet (609 m) in slope length (blocks 11 and 21). Utilization treatment areas designated for post-harvest broadcast burning were burned the season following logging.

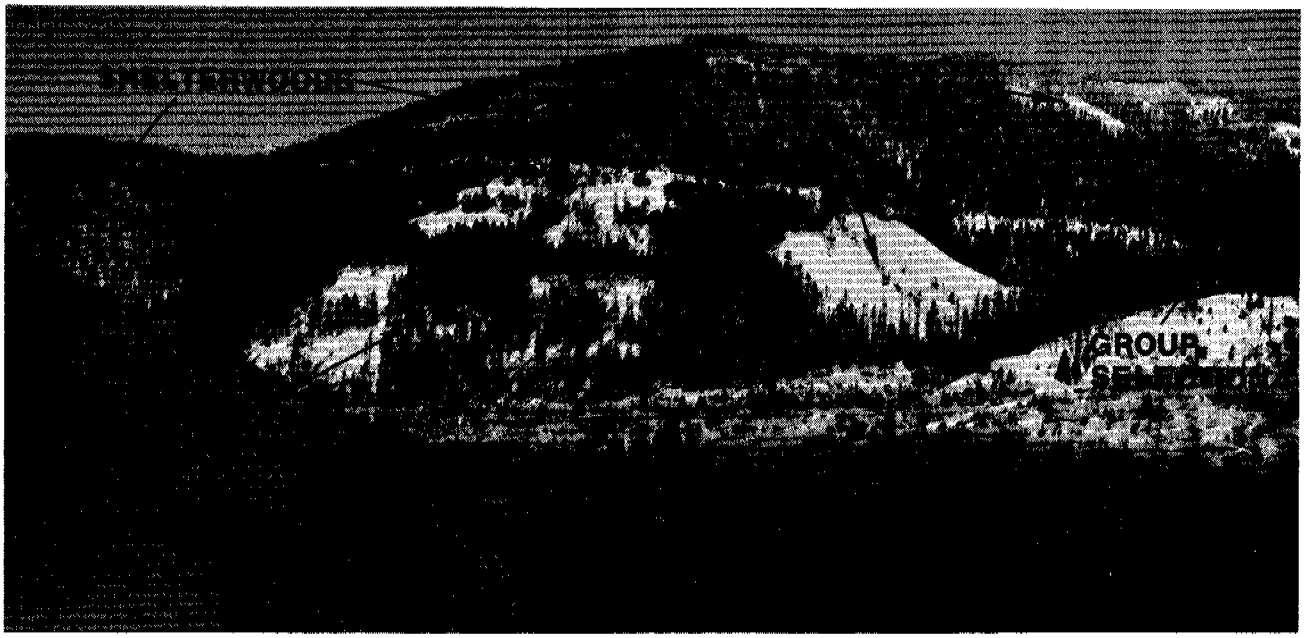


Figure 3.--Sale area units harvested to meet prescribed levels of utilization, on the Coram study site, included shelterwood, clearcut, and group selection silvicultural prescriptions.

The Lubrecht Study Site

The Lubrecht study site is located on Lubrecht Experimental Forest, a State-owned and administered area belonging to the University of Montana. The area is essentially dry site Douglas-fir, with a significant intermixture of ponderosa pine and western larch, on gentle terrain. The area has a cutting history of selective removal of older, larger timber in the late 1800's-early 1900's. The remaining mixed species and mixed age class stand is broadly representative of a major segment of the commercial forest land in the region. In addition, the stand occurs on one of the more productive Douglas-fir habitat types *(Pseudotsuga menziesii/Vaccinium caespitosum)*, and represents an operating situation and management opportunity in which intensive utilization is likely to occur first. The mixed size and age classes provide an opportunity for a range of silvicultural and utilization options.

Major management objectives for timbered lands represented by the site include:

--reducing probability of catastrophic insect and disease damage;

--achieving acceptable stand regeneration and development and retaining species diversity;

--in partial cuts, improving the residual stand through selective thinning;

--protecting esthetic, recreation, and wildlife values;

--avoiding adverse biological impacts on the forest ecosystem.

Harvesting treatments to be tested were developed to include combinations of silvicultural practices, utilization levels, and post-harvest site treatments that could be considered management alternatives. Silvicultural prescriptions applied to harvest units included

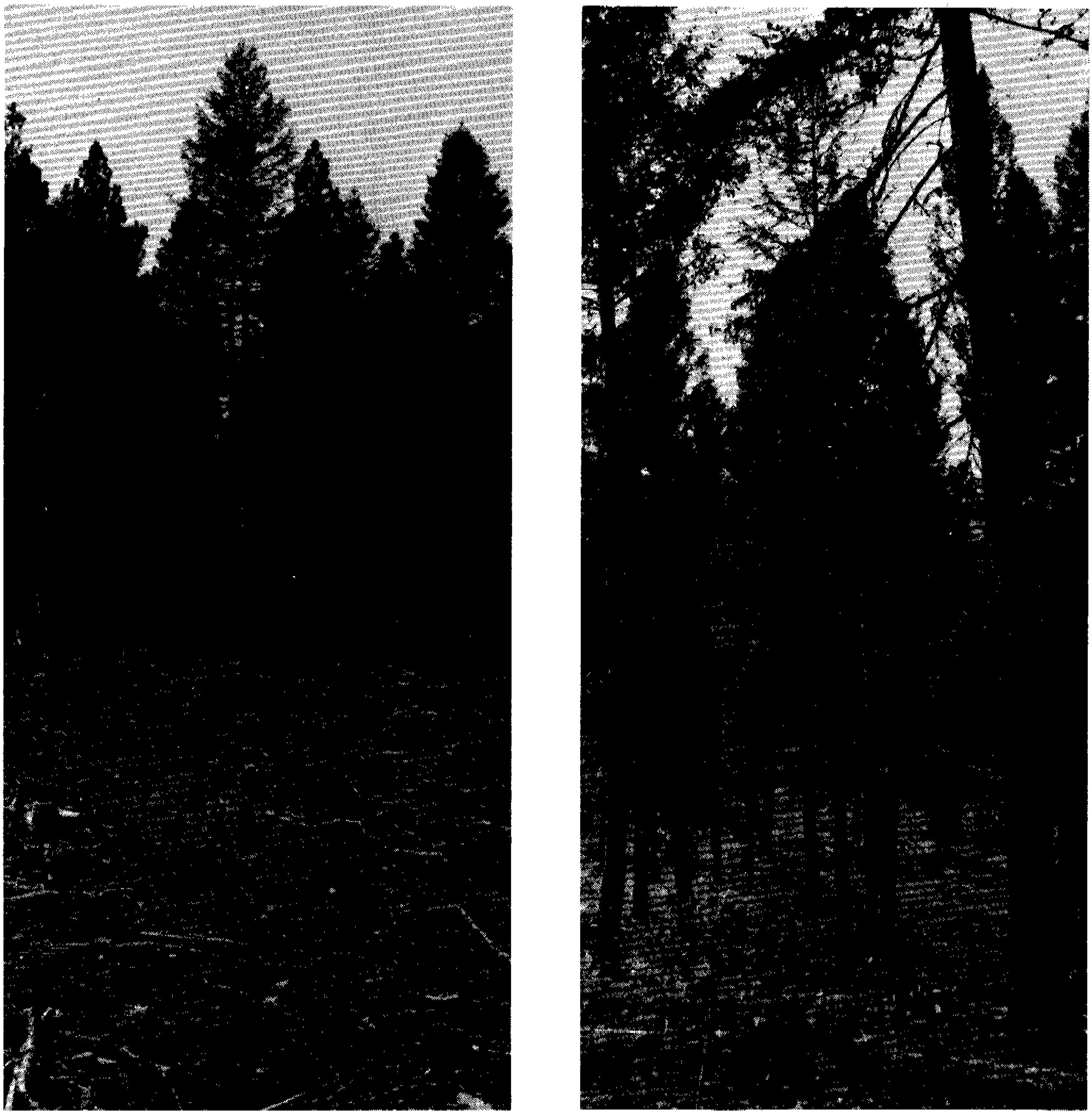
(1) Selection cutting--harvesting approximately half of the merchantable volume, leaving a designated overstory of small saw timber and pole stems. Dense sapling and pole stands were selectively thinned. The treatment represents current common practice in such stands.

(2) Understory removal--removal of approximately half of the merchantable volume (and up to 2/3 of total cubic volume), leaving a designated overstory of the better sawtimber and large pole stems.

(3) Overstory removal--removal of all sawtimber trees and thinning pole stands, leaving the seedling-sapling-small pole stems as a residual stand.

(4) Clearcutting--harvesting all trees designated as merchantable under the specified utilization standard. All other trees on the unit were slashed and treated as prescribed.

Four cutting units totaling approximately 60 acres (24 ha) were harvested, one under each of the described silvicultural prescriptions (fig. 4). Three of the units--those designated for clearcut, overstory removal, and understory removal--were further sub-divided into three treatment areas for application of varying utilization and site treatment practices. Utilization standards tested included conventional sawlog utilization and near-complete fiber utilization (table 2); post-harvest treatments included broadcast burning (fig. 5) and leaving residues scattered on the site.



Clearcut

Understory Removal

Figure 4.--Experimentally harvested units on the Lubrecht study site included clearcut, overstory removal, and understory removal silvicultural prescriptions, under which intensive levels of utilization were practiced. Intensive utilization treatments in the clearcut and understory removal units are illustrated.

Table 2.--Timber utilization treatments and post-harvest site treatments tested under specified silvicultural prescriptions, Lubrecht study site.

Silvicultural Prescription	Unit	Utilization Standard[1]	Post-harvest Treatment
Selection	1.1.3	Conventional	Machine pile and burn
Understory Removal	2.1.1	Conventional	None
	2.1.2	Conventional	Broadcast burn
	2.2.1	Close	None
Overstory Removal	3.1.1	Conventional	None
	3.1.2	Conventional	Broadcast burn
	3.2.1	Close	None
Clearcut	4.1.1	Conventional	None
	4.1.2	Conventional	Broadcast burn
	4.2.1	Close	None

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[1] Utilization standards applied to trees designated for cutting were:

Conventional utilization -- removal of green and recently dead logs from sawtimber trees 9" (23 cm) and larger d.b.h.; utilization to 5" (13 cm) top, and 1/3 or more sound.

Close utilization -- removal of all green and dead sawlog material if sound enough to skid; removal of all submerchantable trees 1" (2.5 cm) and larger in d.b.h., tree length (hand bunched prior to skidding).

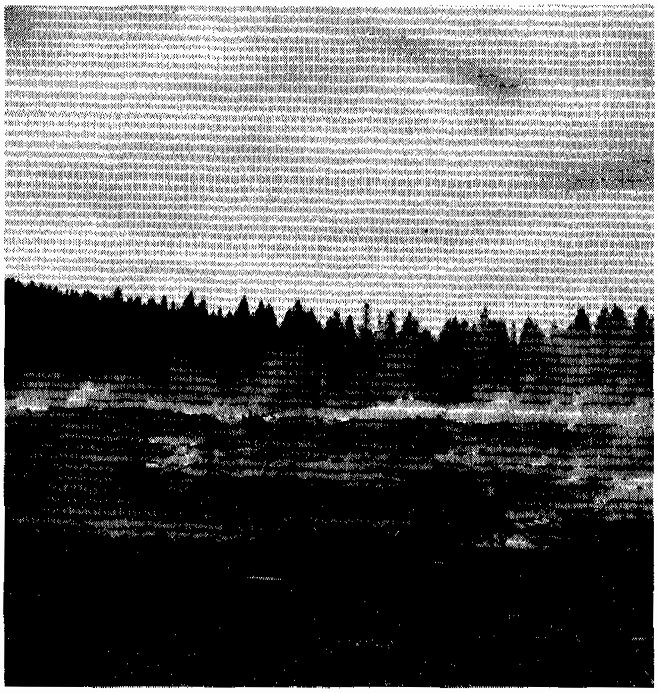


Figure 5.--Conventional residue disposal treatments, illustrated by the broadcast residue burning treatment on the Lubrecht study site (pictured), were included on each study site to provide a basis for direct comparison with residue reduction through intensive utilization.

Gentle slopes and easy access to cutting units made possible the use of ground skidding harvesting systems. All units were logged using crawler tractors to accomplish skidding. On areas designated for intensive utilization, smaller trees (1" to 6" in diameter) (2.5 to 15 cm) were bunched by hand prior to skidding, and were skidded tree-length. Units designated for broadcast burning were burned the season following harvesting.

The Teton Study Site

The Teton study site is located on the Gros Ventre District, Bridger-Teton National Forest, southwest of Dubois, Wyo. The site is typical of higher elevation old-growth lodgepole pine in the central and northern Rocky Mountains. The area is a gently rolling plateau at about 9,000 feet (2,743 m) elevation, in the *Abies lasiocarpa/Vaccinium scoparium* habitat type. The stands are essentially pure, overmature lodgepole pine, interspersed with natural open meadows. Stand volumes are heavy for lodgepole pine, averaging in excess of 9,000 ft^3 per acre (254 m^3) in stems 3 inches (7.6 cm) d.b.h. and larger. As a result of endemic insect activity, mistletoe, and other causes of mortality, standing and down dead material makes up approximately one-third of this volume.

Management objectives for old-growth lodgepole pine sites include

--timely regeneration and development of a new stand;

--avoiding or reducing possible insect and disease impacts, both on adjacent stands and the new stand;

--protecting or enhancing esthetic and wildlife habitat values;

--Avoiding adverse biological impacts on site quality.

Historically, the lodgepole pine timber type has been considered most important for wildlife habitat, high elevation watersheds, and other such non-timber uses. More recently, however, the emphasis has shifted to recovery of available wood to meet a growing demand for softwood products.

Harvesting activity in old-growth lodgepole pine often results in large volumes of residue because of the decadent nature of the stands. Consequently, harvesting alternatives that can achieve more intensive recovery and utilization of the total fiber resource are particularly important to successful management of the site. Intensive utilization can solve a difficult residue disposal problem, reduce adverse public reaction to harvesting, and facilitate planting and other site-management activities. The ultimate value of intensive utilization as a management tool, however, depends upon the aggregate influence upon nutrient availability, microclimate, beneficial soil microorganisms, soil moisture, and other site quality factors.

Silvicultural alternatives in old-growth lodgepole pine are generally limited to clearcutting in some fashion, since a manageable residual stand does not exist. Treatments applied to the study site specified clearcutting, and included two levels of utilization and four post-harvest site treatment alternatives (table 3). The intensive or "near complete" utilization treatment was intended to evaluate a harvesting alternative in which virtually all wood fiber on the site is used, either as sawlog material or as chips for pulp or particleboard. In the absence of a chip market, the possibility of chipping residue and returning it to the site (in lieu of other disposal methods) still exists. Spreading chips back on the site, one of the specified post-harvest treatments, allows evaluation of the biological consequences of this option.

Table 3.--Timber utilization treatments and post-harvest site treatments evaluated in old-growth lodgepole pine, Teton study site.

Utilization Standard	Material Removed	Post-harvest Treatment
Conventional	Green and recently dead sawlogs, to 6" (15 cm) top; 1/3 or more sound.	A. Broadcast burn B. Windrow and burn
Near Complete	All green and dead material, tree length, including down dead pieces 6 feet (1.8 m) and longer.	A. Leave as-is (bare) B. Re-spread chipped residue as mulch.

Four cutting units, each approximately 20 acres (8.1 ha), were harvested (fig. 6). Two were logged to conventional utilization standards, using common chainsaw felling, bucking, and sawlog skidding. Residue volumes following harvesting on these units amounted to over 4,300 ft^3 per acre (121 m^3). The two remaining units were logged to a near-complete utilization standard, using a feller-buncher, tree-length skidding with rubber-tired grapple skidders, and segregating merchantable logs at the deck. All material not meeting minimum specifications for sawlogs was chipped, using a portable whole-tree chipper at the site.

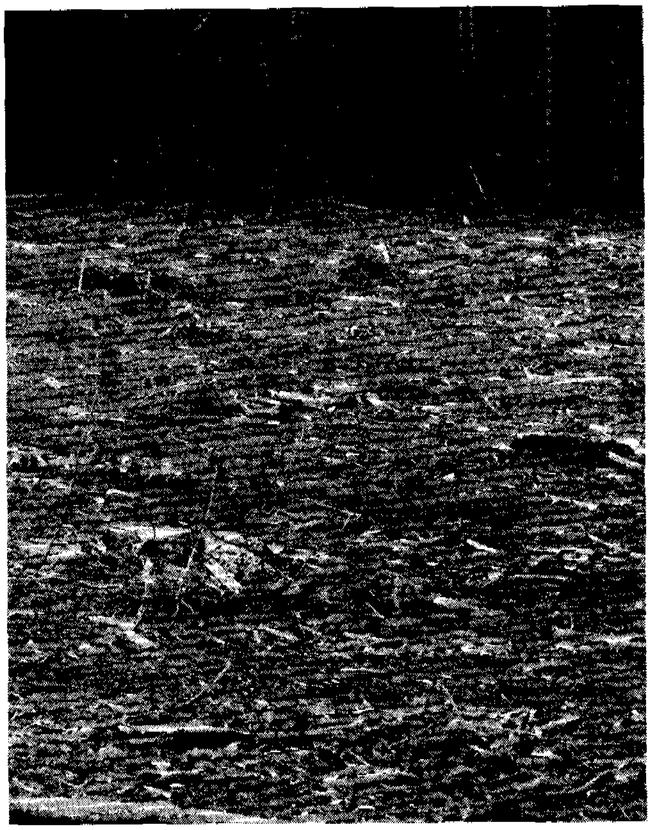


Figure 6.--Harvesting treatments carried out in old-growth lodgepole pine on the Teton study site included intensive utilization of virtually all wood fiber. An intensive utilization subtreatment area is shown immediately following harvesting operations.

Each of the four cutting units was sub-divided to accommodate specified post-harvest site treatments. Residue piling, burning, and chip spreading was accomplished two years after harvesting was completed.

The Solo-Hemlock Study Site

The Solo-Hemlock study site is located on the Priest Lake District, Idaho Panhandle National Forest, approximately 25 miles (40 km) northwest of Priest River. The site represents the cedar-hemlock forest type common across northern Idaho and parts of western Montana. Western red cedar, western hemlock, and grand fir make up most of the stand, with western hemlock predominant. The site is on gentle terrain at an elevation of about 4,000 feet (1220 m), and receives in excess of 50 inches (127 cm) of precipitation annually. Stand volumes are typically high. Merchantable sawtimber volume removed from the study site was approximately 40 Mbd.ft. per acre (560 m^3/ha), and inventory of an adjacent control area found 13,000 cubic feet per acre (909 m^3/ha) of standing volume in all stems. Because the species present are particularly subject to internal rot, volumes of residue remaining on site following harvesting are usually high. Post-harvest residue volumes of 5,000 - 7,000 cubic feet per acre (350 - 490 m^3/ha) are not unusual.

Management objectives in old-growth cedar-hemlock stands are strongly oriented toward timber production. Major considerations include

--reducing or treating the typically heavy volumes of residue to facilitate planting nursery stock;

--obtaining early regeneration and development of a new stand;

--avoiding adverse biological impacts on site quality and productivity;

--avoiding or reducing insect and disease impacts.

Silvicultural alternatives depend upon the composition and condition of the stand, and upon management objectives. Clearcutting is the most feasible alternative in older stands in which a manageable residual stand does not exist. Large volumes of residue that remain following logging are a significant management problem. Consequently, intensive utilization alternatives are of particular interest, and can help solve the residue treatment problem as well as recover additional usable wood fiber.

A conventional sawlog harvesting operation, under a clearcut silvicultural prescription, had been completed on the site just prior to initiating research. A ground skidding logging system, using crawler tractors, had been employed. Three treatment subunits were selected for research purposes. Post-harvest treatments specified for the selected subunits included simulating intensive utilization by removal of essentially all residue; leaving residue on the site untreated; and broadcast burning residue (the standard management practice) (table 4).

Table 4.--Timber utilization treatments and post-harvest site treatments evaluated in the cedar-hemlock forest type, Solo-Hemlock study site.

Unit	Utilization Standard	Non-merchantable volume				Post-harvest Treatment
		Removed		Left on-site		
		ft³/a.	m³/ha	ft³/a.	m³/ha	
1	Simulated intensive utilization	4,500	315	485	34	None
2	Standard sawlog utilization	--	--	6,241	436	None
3	Standard sawlog utilization	--	--	7,105	497	Broadcast burn

Due to the volume and character of residue on the unit designated for simulated intensive utilization, removal by skidding was not considered feasible. Instead, residue was removed by blading off the area with a crawler tractor. The resulting level of removal was somewhat more intensive than would normally be accomplished through yarding or skidding, and represents an extremely "clean" treatment. The intensive utilization treatment is intended to evaluate the biological consequences of applying a harvesting alternative in which virtually all wood fiber on the site is recovered and used.

POST-TREATMENT EVALUATION

Research investigations following harvesting and residue treatments on study sites involved a number of biological disciplines, and were designed to evaluate the early post-harvest biological and management consequences of the respective treatments. The array of studies on a particular site varied with the resources, people, and opportunities available. The most intensively instrumented and studied sites were the Coram (larch-Douglas-fir) and Teton (lodgepole pine) sites; the least intensively evaluated site was the Solo-Hemlock (cedar-hemlock) site.

In general, the research conducted on the more intensively studied sites included

--responses to treatment in such areas as biomass, meteorology, nutrient status, hydrology, and microbiology;

--consequences relating to insect activity, site productivity, stand regeneration and development, understory vegetation, esthetics, wildlife habitat, and fuels management;

--implications for resource protection and management on the site.

A concerted effort was made to coordinate the variety of sampling and instrumentation tasks required to obtain data on studied sites. On the Coram site, for example, a grid of monumented sampling points was established in each subtreatment unit. At each point (or at a subsample of points, depending upon the requirements of the particular study) the necessary installations or reference plots were established. A typical sampling point (fig. 7) might include insect traps, access tubes for neutron probe measurement of soil water, a set of soil water sampling tubes, seed traps, and vegetation measurement sub-plots. Large numbers of soil, water, and vegetation samples were collected in the field and subsequently analyzed in the laboratory.

Field data and the data generated in lab analyses were identified and placed in computerized storage in such a manner that later cross-referencing could be accomplished. A researcher investigating regeneration success, for example, can retrieve data describing microclimatic conditions, nutrient availability. soil moisture, and other site characteristics for specific sub-treatments and sample points within the subtreatment.

INTERPRETING RESULTS

Defining the environmental consequences of timber harvesting can be approached from either of two points of view. One approach is to subjectively observe the vegetative responses and biological events that occur on a site following treatment, and infer treatment effects from those observations. A second approach is to develop a basic body of knowledge about how specific treatments affect the physical, chemical, and biological character and function of the ecosystem. From that knowledge, hypotheses that link treatment to response can be developed and tested. Program research has subscribed to the second approach for three reasons:

--Basic ecosystem effects such as changes in microbiological activity, nutrient levels, and microclimatic conditions occur almost immediately following treatment, and can be measured and quantified within a short post-treatment time period.

--Developing cause-and-effect relationships between initial ecosystem responses to treatment and subsequent biological behavior provides a better basis for extrapolating to other sites, and for predicting the probable effects of new or untried treatments.

--Understanding basic cause-and-effect relationships provides a basis for developing harvesting treatment guidelines and specifications to meet site management objectives and ameliorate adverse consequences.

There exists a recognized progression of effects in response to harvesting and residue reduction, beginning with basic environmental responses and ultimately leading to implications for resource management. Program research is heavily

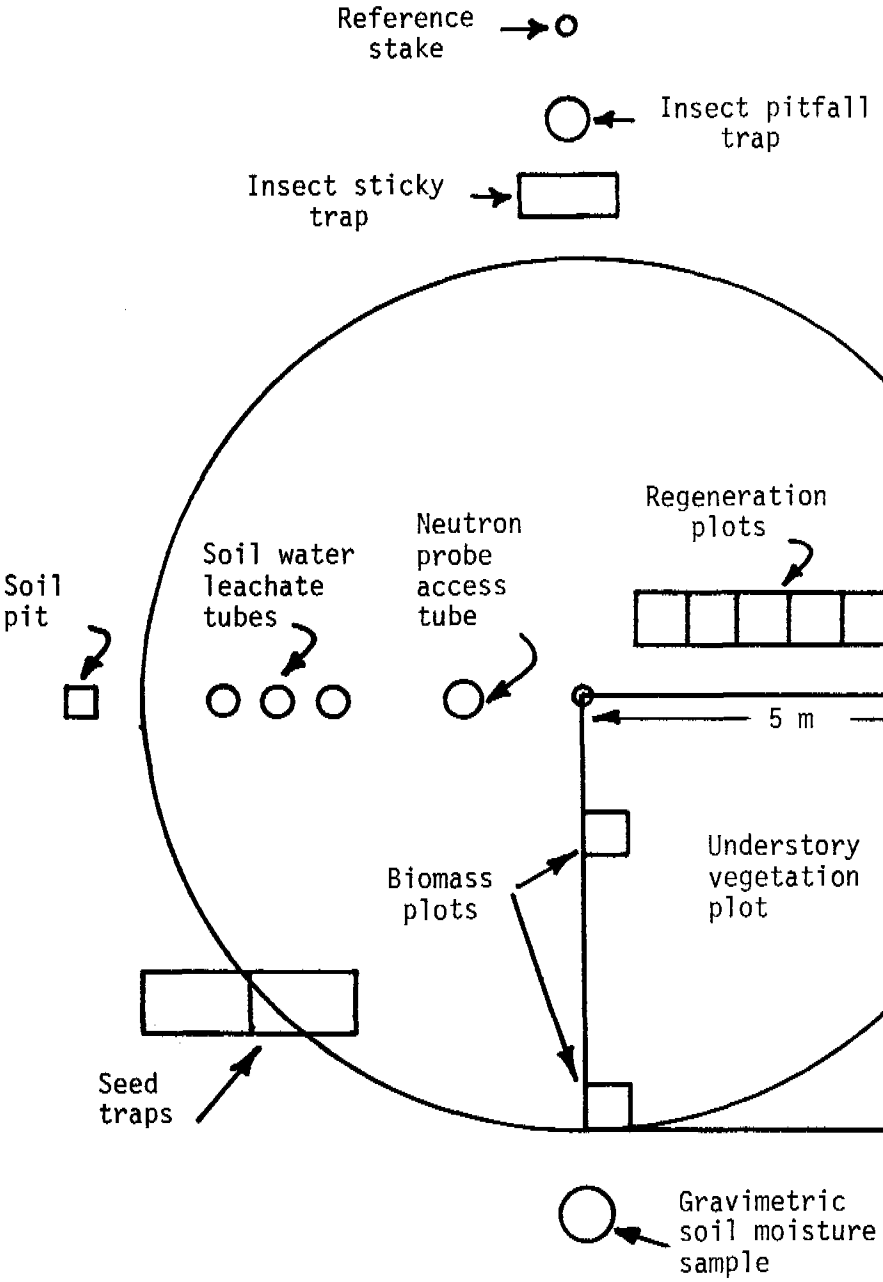


Figure 7.--The layout of a typical sampling point on the Coram study site illustrates the manner in which the sampling needs of a number of individual researchers and disciplines were coordinated on the ground.

oriented toward the basic response end of the spectrum for the reasons just discussed, but includes research in all aspects of the progressive process. Research being reported here can be broadly classified as addressing

- --<u>First-order responses</u>: basic environmental responses relating to soils, water, microbiology, meteorology, nutrients, and other basic site attributes.

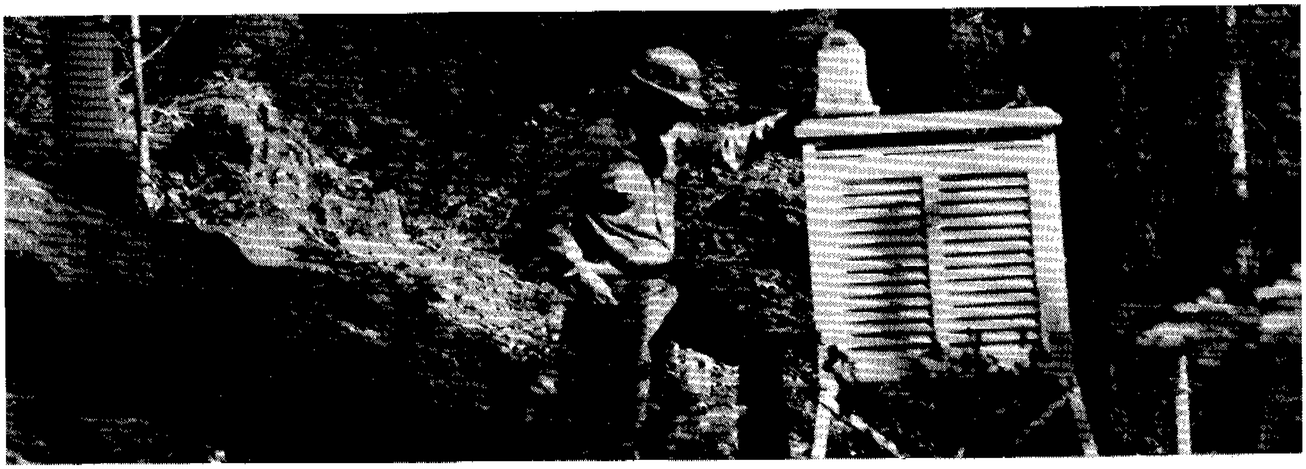
- --<u>Second-order responses</u>: biological implications of the combined effects of first order responses, including site quality changes, vegetative development, forest pest activity, habitat changes, and other biological consequences.

- --<u>Potential resource impacts</u>: implications for longer-term resource protection and management, considering multiple resource management needs.

The information presented in the remainder of this publication is organized in three sections corresponding to these categories, and entitled "<u>Basic Environmental Responses</u>", "<u>Biological Implications</u>", and "<u>Resource Management Implications</u>". Of course, the results discussed in any particular paper may include aspects of research ranging all the way from basic responses to resource management guidelines.

Much of the research initiated by Program participants cannot be considered completed in any sense. Biological responses to treatment need to be followed for a period of time long enough to establish a reliable basis for long-term prediction. Early results provide better information than has been available to date, however, and develop a holistic approach to understanding and defining complex interrelationships in forest ecosystems.

Program research provides the forester and land manager with significantly improved knowledge about the effects of timber harvesting -- including very intensive levels of utilization -- on the forest ecosystem. This information in turn affords an improved basis for prescribing harvesting practices to achieve desired multiple resource management objectives, and avoid environmentally undesirable or questionable practices.



BASIC ENVIRONMENTAL RESPONSES

Timber harvesting removes biomass from the site, reduces vegetative cover, disturbs soil and litter, and increases exposure. Initial ecosystem responses are changes in the basic physical and biological properties and functions of the site. Micrometeorological effects may include changes in temperature, humidity, air movement, energy exchange, and significantly greater short-term fluctuations. Soil and water effects may include increased overland and subsurface flows, changes in soil moisture, and changes in soil water chemistry and nutrient availability. Microbiological effects can include changes in fungal and microbial activity, and in associated processes related to decay, nitrogen fixation, and symbiotic plant-fungi functions.

Predicting the consequences of timber harvesting depends upon understanding and quantifying these basic cause-and-effect relationships. Program research has been heavily oriented toward studying these kinds of responses, termed "1st order responses". Improved knowledge of how harvesting activities affect basic ecosystem character will provide the basis for prescribing harvesting practices and for predicting the consequences of alternative practices.

In this section, researchers report observed or measured basic environmental responses to timber harvesting, under a range of harvesting prescriptions and stand conditions. Elapsed time since treatment is short on all study sites; consequently, the results reported here must be viewed as initial, short-term results. Continuing studies will track most responses over time, and may ultimately lead to modifying the results reported here.

WOODY MATERIAL IN NORTHERN ROCKY MOUNTAIN FORESTS: VOLUME, CHARACTERISTICS, AND CHANGES WITH HARVESTING

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ABSTRACT

In mature coniferous stands in the Northern Rockies, total volume of wood 3 inches in diameter (7.6 cm) and larger, ranges from 3,000 to 8,000 ft^3/a (210 to 560 m^3/ha). Typically about half of this volume is removed in logging, and the remaining residues include up to 50 percent or more sound wood, plus material in various stages of decay. In Wyoming, Montana, and Idaho over 450 million ft^3(13 million m^3) of residue may be left on site annually, but residue is being utilized to meet demands for wood.

KEYWORDS: wood volume, wood biomass, logging residues

INTRODUCTION

During the past 5 years the Residue Research Program measured and described woody material at over 3,000 sample points in mature forests and logged areas. This paper describes this effort, the woody material, and the changes in woody material that occur with harvesting.

Initially, the objective of the study was to examine woody material at specific sites before and after logging, as a basis for evaluating the potential for utilizing logging residues and the subsequent costs per unit of volume. It soon became apparent that within the different disciplines involved in our research effort, researchers described the forest in various terms. The measurement job evolved into a description of woody material before and after harvest activities. This paper summarizes these studies, and more detailed data are presented in forthcoming publications.[1], [2]

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[1] Benson, Robert E. and Joyce A. Schlieter. Forest residues in principal forest types of the Northern Rocky Mountain area. USDA For. Serv. Intermt. For. and Range Exp. Stn., Research Paper (in process).

[2] Benson, Robert E. and Joyce A. Schlieter. Volume and weight characteristics of a typical Douglas-fir/western larch stand, Coram Experimental Forest, Montana. USDA Intermt. Gen. Tech. Paper (in process).

STUDY SCOPE AND METHODS

Initially our interest was to generate detailed data on woody material at harvest study sites to serve as a basis for various cost, utilization, slash disposal, and water and nutrient studies. The generation of detailed data remained the primary purpose, but we began to receive repeated requests for estimates of total residue volumes and their utilization potential. In response to these requests, our efforts evolved into information gathering on two bases.

The first information base consisted of pre- and post-harvest data for the various study sites--usually several logging units formed one study site. The study sites included mixed conifers in north Idaho, Douglas-fir/larch stands in Montana, and lodgepole pine sites in Montana, Idaho, Wyoming, and Utah. These were used to develop a broad-based estimate of residue volumes for several of the major forest types in the Northern Rocky Mountains. This estimate was made by using existing forest inventory and management plan data to develop area by forest type strata to which we applied the residue data from intensive study sites.

Because of the limited amount of residue sampling and the way various data sources were combined, the statistical accuracy of this sampling provides a reasonable first approximation of volumes and, perhaps more important, a profile of residue characteristics that should be of value in broad-scale planning and resource assessment.

Our data are limited to old-growth sawtimber stands where the bulk of the harvesting - and most of the residue management problems - will occur in the future. Our studies were limited to the six major forest types in the Northern Rockies that usually present residue-management problems. The one major type not included is ponderosa pine, for in most cases, harvest of old-growth does not generate large residue volumes or pose comparable disposal problems.

For each forest type, we estimated the average volume per acre of wood 3 inches or larger in diameter (7.6 cm), described this material in terms of utilization potential. Additionally, we developed estimates of duff, litter, and tree crowns.

Standing trees were measured using conventional survey procedures of fixed or variable plots. Down material was measured using the planar intercept method on a grid pattern of random direction lines.[3] Crown weights were computed from formulas based on tree species and diameter.[4] These components and their volumes for a typical Douglas-fir/larch stand are shown in figure 1.

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[3] Brown, James. K. 1974. Handbook for inventorying down woody material. USDA For. Serv. Gen. Tech. Rep. INT-16. Intermt. For. & Range Exp. Sta., Ogden, Utah 84401.

[4] Brown, James K., J. A. K. Snell, and D. L. Bunnel, 1977. Handbook for predicting slash weight of western conifers. USDA-FS Gen. Tech. Rep. INT-57. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

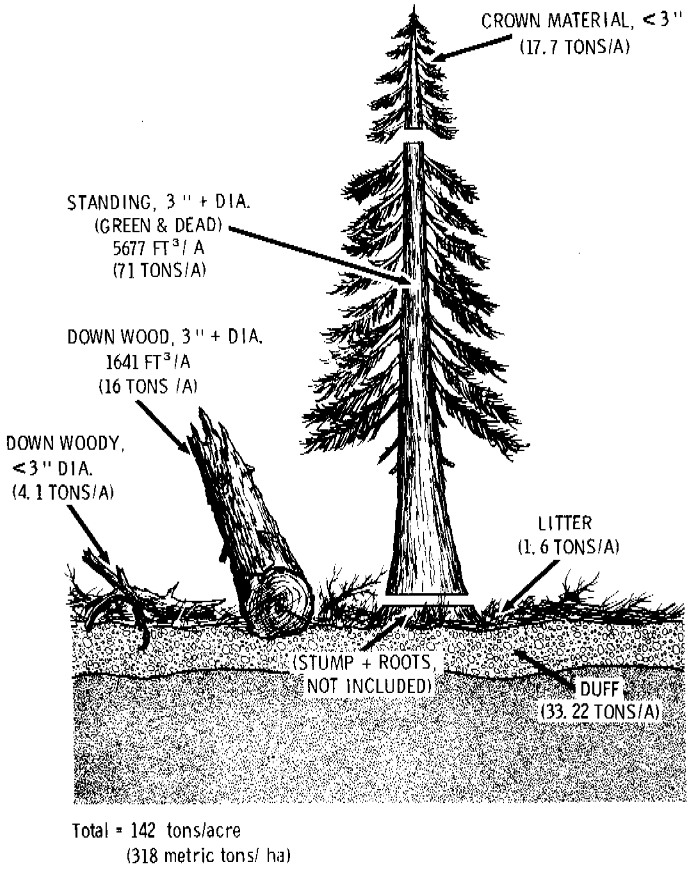


Figure 1.-- Components of woody material in a typical Douglas-fir/larch stand.

STUDY RESULTS

General Findings

General findings of the study are as follows:

1. A typical mature stand contains a considerably larger volume of wood than is accounted for in regular forest inventories or in the usual timber sale data. This wood is dead, down, and small material normally left as residue after logging.

2. Much of this residue is suitable for a variety of wood products.

3. The amount of wood and its condition is widely variable, particularly those components considered residues. Although we attempted to identify characteristics such as stand age, species, site, and aspect, that might be useful to predict the amount and condition of residue material in a given situation, no characteristic successfully served as a usable predictor.

This reflects our finding that residue in mature stands is generated from insects, blowdown, disease, and other factors that occur at infrequent and irregular intervals.

4. We were able to predict with some success the amount of residues generated in different utilization standards of logging given basic data for a specific stand.

Volume of Wood in Undisturbed Stands

The total volume of wood in mature sawtimber stands averages from 3,000 ft^3/acre (210 m^3/ha) in dry-site Douglas-fir stands to 8,000 ft^3/acre (560 m^3/ha) in grand fir stands (table 1). On the average only about half this volume is green, merchantable material (figure 2). A high proportion of moist-site western larch and grand fir is rotten material. Some of this rotten material is crumbly and could not be harvested with conventional equipment; some is solid rot--usually a sound core surrounded by sapwood rot.

There is substantial volume of sound dead material in lodgepole pine and in spruce-alpine fir types, averaging 60 to 70 percent of all dead material in the stand. This volume probably reflects fairly dry, cool summer conditions that inhibit decay.

One notable feature in all stands is the relatively small potential for utilizing additional green material--tops and small stems. Other than merchantable material, much of the green volume is cull material, which in part is suited for fiber products but is too rotten or poor form for roundwood products, such as sawlogs or poles.

The large amount of sound-dead material in mature lodgepole pine stands reflects recent bark beetle epidemics. In southwestern Idaho, a mountain pine beetle epidemic has killed up to 90 percent of the cubic volume in some stands. The trees remain standing and initially are sound; then the roots decay, the tree falls, and rot sets in. Frequently, the trees become jack strawed and remain several feet off the ground (figure 3). In these instances the wood remains essentially intact except for drying checks. Much of this material can be utilized but, in its current condition, presents a fire hazard, is difficult for large animals to move through, and usually inhibits regeneration.

In other forest types, the typical pattern seems to be a more gradual decay that creates residues in stages of deterioration from new, sound dead to partially rotted, to a shell of crumbly, rotted material.

Table 1.--Volume of wood by component in mature stands, residue study areas.[1]

Component	FOREST TYPE Lodgepole	Larch	Douglas-fir Moist Site	Dry Site	Grand fir	Spruce-Alpine fir[2]
	Volume, ft^3/acre					
Green Trees						
Merchantable logs	2225	3401	2546	1658	4283	2000
Cull	119	222	334	52	564	391
Top	457	132	105	75	208	300
Small stems	244	663	527	300	156	380
Sub total	3045	4418	3512	2085	5211	3071
Standing Dead						
No defect	436	86	180	0	24	153
Sound defect[3]	291	30	49	78		
Solid rot	139	493	36	22	256	68
Crumbly rot	0	302	55	0		
Sub total	866	911	320	100	280	221
Down						
No defect	356	108	267	43	281	455
Sound defect[3]	310	66	52	19	7	43
Solid rot[4]	213	124	137	181	309	106
Crumbly rot[4]	233	1196	398	527	1903	262
Sub total	1112	1494	854	770	2500	866
TOTAL, ft^3/a	5023	6823	4686	2955	7991	4158
(m^3/ha)	(351)	(478)	(328)	(207)	(559)	(291)

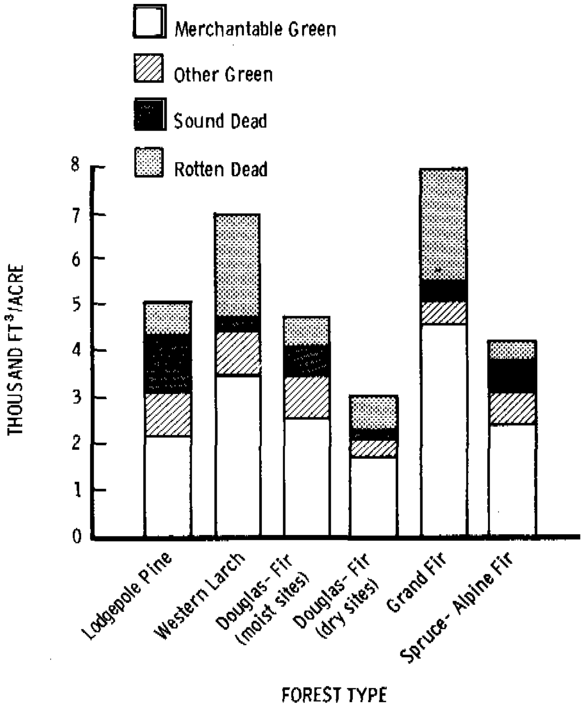
[1] Top volumes and stem volumes for small trees were compiled from recently published formulae based on species, dbh, and height. (Faurot, James C., 1977. Estimating merchantable volume and stem residues in four timber species. USDA-FS Research Paper INT-196. IF&RES, Ogden, Utah 84401).

[2] Breakdown of total into components estimated.

[3] Sound defect includes crook, sweep, fork, splits and drying checks that prevent use for solid wood products but not for fiber use.

[4] Solid rot includes pieces with rot but that can be handled in logging. Crumbly rot is material that will not hold together in logging.

Figure 2.-- Volume of wood 3 inches (7.6 cm) in diameter and larger per acre major forest types.



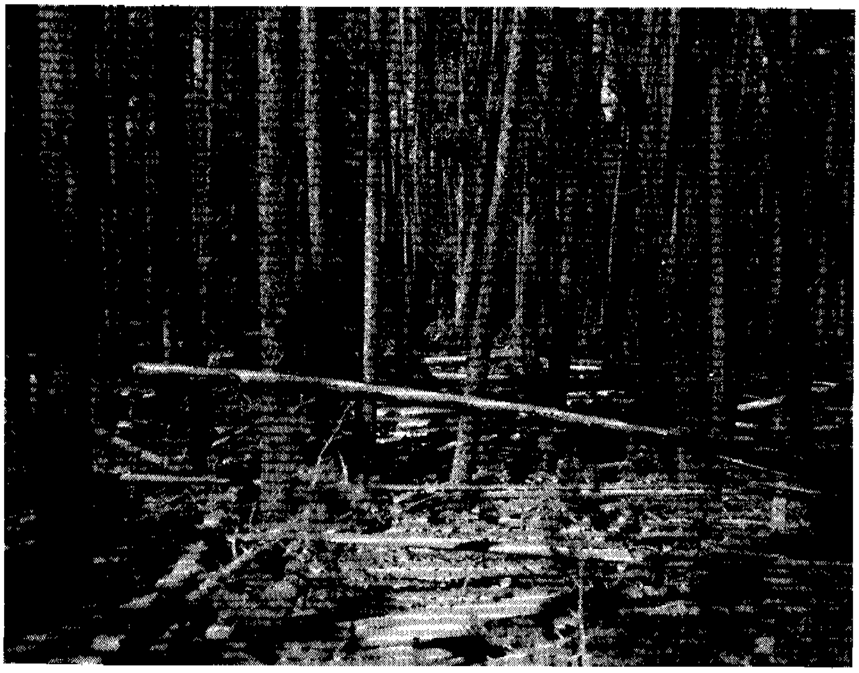


Figure 3.-- Dead and down sound material in a lodgepole pine stand.

Small material under 3 inch (7.6 cm) diameter on the ground, and crowns of standing trees make up additional wood biomass. The average weight of this material for three forest types in undisturbed stands is:

	Douglas-fir/ larch	Lodgepole pine	Grand fir
	- - - - - - - tons/acre	(tons/ha)	- - - - - - -
Crowns			
Woody	12.6 (28.2)	7.2 (16.1)	15.1 (33.8)
Foilage	5.1 (11.4)	3.0 (6.7)	8.3 (18.6)
Down woody	4.1 (9.2)	4.0 (9.0)	3.8 (8.5)
TOTAL	21.8 (48.8)	14.2 (31.8)	27.2 (60.9)

Changes Produced by Harvesting

Given this mix of wood materials in the natural undisturbed forest, what happens when a stand is logged? The changes produced by harvesting depend on the volume and condition of the preharvest stand, the type of harvesting system, and the utilization standards that dictate what will be removed and what will remain on the site. Generally, the more non-merchantable material in the original stand, the more residue is generated.

Harvesting systems include cutting prescriptions and logging methods. A partial cut--only a portion of the merchantable trees are removed--will generate less residue than if all stems are cut. In clear-cut study areas an estimated 3200 ft^3 per acre (224 m^3ha) of residue remained after harvesting compared to 2200 ft^3 per acre (154 m^3/ha) after partial cutting. Sites included in the study covered a range of stand conditions and forest types.

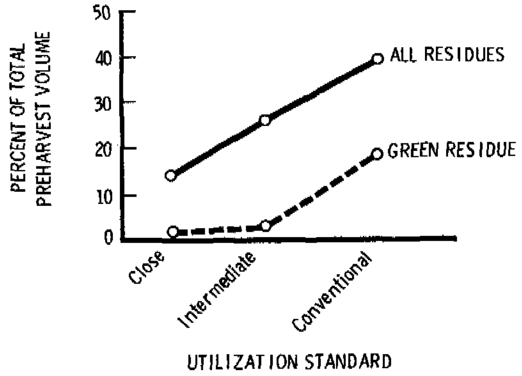


Figure 4.-- Proportion of wood left as residues with different utilization standards.

The specific utilization standard has the most influence on residue volumes. On 37 harvest areas that included both clear-cutting and partial cutting, the residual volumes were 14 percent of the total pre-harvest volume in close-utilization units, 26 percent in intermediate-utilization units, and 38 percent in conventional-utilization units (figure 4).

The exact standards varied somewhat among study areas[5], but, generally, conventional logging required removal of merchantable green sawlogs from trees 9 inches (23 cm) d.b.h., to a 6 inch (15 cm) diameter end. In intermediate-utilization units, merchantable sawlogs, sound dead, and logs from trees down to 5 inches (13 cm) d.b.h., were removed. Close utilization removed virtually all materials 3 inch (8 cm) diameter and larger.

Other research participants studied the amount and kind of material removed from the site compared to those remaining, as a basis for evaluating long-term soil, water, and nutrient regimes. The data we derived from the study areas, cutting units, and sub-treatments is too detailed for inclusion in this paper, but Table 2 provides a summary of the information.

Table 2.--Preharvest and post harvest volume of woody material

Harvest Condition	Preharvest Vol. 3"+	(7.6 cm)	Postharvest Vol. 3"+	(7.6 cm)	Fines	
	Ft^3/acre	(m^3/ha)	Ft^3/acre	(m^3/ha)	Tons/acre	(kg/m^3)
Clearcut						
Conventional utilization	6828	478	2614	183	10.8	2.4
Close utilization	6548	458	1193	83	9.3	2.1
Partial Cut						
Conventional utilization	6147	430	1834	128	7.8	1.7
Close utilization	5373	376	1191	83	6.1	1.4

Source: Benson and Johnston (1974)
Benson and Schlieter (in process)

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[5] Benson, Robert E. and Cameron M. Johnston. 1976. Logging residues under different stand and harvesting conditions, Rocky Mountains. USDA For. Serv. Res. Pap. INT-181, 15 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Depending on the cutting and treatment, 1,200 to 2,000 ft^3 per acre (84 to 182 m^3/ha) of residue remains on the site. On an oven-dry weight basis, this represents 15 to 35 tons per acre (3.4 to 7.8 kg/m^2) of material 3 inches (7.6 cm) and larger. Fine material - on the ground prior to harvest and crown components lopped or broken off during harvest - add to another 10 or more tons per acre (2 kg/m^2). In the areas where we measured fine material loadings, there is usually about 2 or 4 tons per acre (0.4 to 0.9 kg/m^2) on the ground prior to harvest. Harvesting increases by several fold the amount of downed branches, twigs, and foliage.

SUMMARY AND CONCLUSIONS

The data on volumes of residue summarized here are based on utilization practices and standards that were typical when we began our studies about 5 years ago. Since that time substantial progress has been made in residue use, particularly standing dead lodgepole pine for houselogs and other products.

The total residues generated each year by logging these six principal forest types in Montana, Idaho, and Wyoming total 355 million ft^3 (10 million m^3) (figure 5). Another 110 million ft^3 (3.1 million m^3) of residues are formed from harvesting other forest types. Some of this residue volume is already being utilized, but there is still a large volume of material potentially available. In the past, high cost of recovery and low-value product potential precluded removal, but current trends in the demand and value of wood for fiber and energy are rapidly changing the situation. In the future, more material will be removed from logged areas.

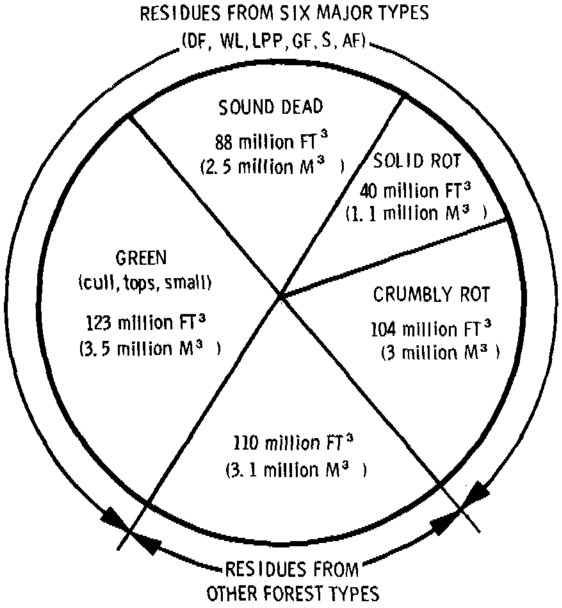

Figure 5.-- Wood residues generated annually from harvesting in Montana, Wyoming, and Idaho.

The demands for wood fiber combined with the technology of harvesting and management can result in the manipulation of on-site residues, and may prove an important factor in future land management prescriptions. Threshold values and guidelines must be developed so the proper amounts of residue remain on the site; or conversely, the proper amount is removed to optimize all aspects of management. These guidelines should define the amount of residual material as well as its size and arrangement.

Management, in its efforts to meet resource needs without damaging forest ecosystems, will need to incorporate data on the residue component into the planning process. It may become as important to know the amount and nature of what is left on a site as it is to know the volume of merchantable material harvested.

MICROENVIRONMENTAL RESPONSE TO HARVESTING AND RESIDUE MANAGEMENT

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ABSTRACT

The concept of energy balance is useful in analyzing the environmental changes and in predicting biological responses that follow timber harvesting and residue management. The physical properties of the surface have a large effect on the surface environment. Surface conditions such as radiation load and temperature have reached lethal levels following harvesting on several sites. Harvesting also aggravates and creates frost pockets that severely limit seedling establishment. Some predictive models are discussed that aid in prediction of environmental conditions and relate to biological implications. Methods of using residue manipulation to alter the microenvironment are suggested.

KEYWORDS: logging residue, temperature, net radiation, operational environment, energy budget

INTRODUCTION

Harvesting has specific effects on the microenvironment which in turn influence the subsequent development of the site. The condition of a microsite within several meters of the surface can vary considerably over space and time. When extreme conditions are created by harvesting they may hamper seedling establishment and cause successional development to take an undesirable path. The magnitude, frequency, and duration of any harvest-related changes are the crucial factors in relation to seedling requirements. Quantitative information based on these factors precedes the creation of practical models: models based on fundamental physical principles may be applied to a wide range of habitat types and harvest situations. Although universally accepted relationships are not yet fully developed, research aims at modeling biophysical responses to harvesting in pursuit of predictive models for land managers.

In this paper I examine the effects of harvesting and residue treatments on the microenvironment. A close consideration of the components of an environment and certain biophysical principles is necessary to an understanding of the natural complexity of causal relationships. Data resulting from field studies conducted by this program helps to clarify by quantifying relationships. The work of other researchers on microenvironmental responses, manipulation, and/or predictive models complements my intent to review possibilites and stimulate a new approach in management.

ENVIRONMENTAL-PHYSIOLOGICAL CONCEPTS

We reap the benefits of spectacular developments in science and technology every day. Since Geiger's book, The Climate Near the Ground, appeared in 1950, efforts to apply the principles of natural science and quantative physics to biologic systems have magnified. Papers and books discuss the principles of environmental physics with reference to plants (Wijk 1963; Gates 1962; Monteith 1973; Munn 1966; Rose 1966; Rosenburg 1974; Lowry 1969; Campbell 1977). As a result the emphasis and approach concerning the importance of environment to forest growth and uses has changed. While Toumey and Korstian (1947) recognized the great importance of environment, their emphasis was necessarily on qualitative determinations of environment-plant responses. This established the importance of environment, but a predictive understanding based on quantitative factors was not available.

We know that shade or drought or genetic factors affect growth, but this does not explain the process. Environmental processes affect plant processes only by changing the internal processes and conditions (Kramer and Kozlowski 1960). In essence, the key to understanding how plants respond to environmental variables depends on the interaction with physiological processes of the plant. If we are to manage for a certain species or community, we must know its requirements for survival, optimal growth, and completion of its life cycle.

Since the environment and physiological processes of organisms are related, how do we define environment? In the broadest sense the environment is the total surroundings of an organism (Allee and Park 1939), including the direct and indirect effects of the surroundings. Spomer (1973), defines the factors that directly affect organisms as the *operational environment*. This operational environment implies factors that interact between an organism's surroundings and the internal conditions of the organism. The interaction leads to an internal change in the organism in response to its environment.

The operational environment is characterized by factors significant to an organism's internal physiology such as: heat, light, moisture, nutrients, gases, and mechanical energy. Indirect factors - pH, aspect, elevation, temperature, soil texture - describe the potential for exchange. These are important only as they distinguish between causal factors and those that are correlated. Knowledge of the exchange levels of causal factors can establish the potential physiological activity of an organism. With heat, for example, the potential activity depends on the temperature difference between the organism and its immediate surroundings. The potential for change is described by entropy. Temperature is easily measured, but entropy is not measurable. However, the overall exchange can be closely approximated using resistance to flow.

$$\text{Flux} = \frac{C_s - C_a}{r}$$

Where: C_s is the concentration at the surface;
C_a is the concentration in the atmosphere and
r is the resistance to flow

Table 1 lists measurable indirect factors for each of the operational factors.

Table 1.-- Some operational factors, or those capable of being exchanged, and measurable parameters for each.

Operational factors	Measurable parameters
Heat	Soil temperature Air temperature Radiation
Moisture	Water potential Soil moisture Precipitation Evapotranspiration Snow accumulation Snow melt
Nutrients	Soil nutrients
Gases	Oxygen Carbon dioxide
Light	Quality Radiation
Mechanical energy	Wind Soil creep Frost heaving

It is important that we base our studies on the operational factors so that models and predictive relationships will be more widely applicable (Berglund 1974). Further, this permits us to measure only what is needed to answer our specific questions which Federer (1974) calls the rifle approach. This is opposed to the shotgun approach which measures as many things as possible hoping something will be useful. Models constructed based on these concepts will have more universal applicability.

METHODS

Barger (1980) describes the various aspects of the sites and treatments used in this study. The basic silvicultural prescriptions included group selection, shelterwood and clearcutting. At one site partial cuttings removing both the overstory and the understory were used. On all sites we used an uncut portion of the stand as a control.

Residue and seedbed preparation treatments were superimposed on the cutting units. Intensive utilization standards and conventional utilization standards left differing amounts of different-sized residues on the sites. Both treatments were broadcast burned at one site (fig. 1A). At two other sites residues were left unburned (fig. 1B). One treatment on all areas studied had all residues and advanced regeneration removed to 1 inch in diameter, leaving only low understory vegetation (fig. 1C). At one site residues were chipped and spread back on the site (fig. 1D). The four study sites represented a variety of habitat and timber types, with climatic conditions varying from warm/dry to cold/wet and elevations as high as 9,500 feet (2 900 m).

Following are brief descriptions of each site:

> Coram Experimental Forest is near West Glacier, Mont. Habitat types are various phases of the Abies lasiocarpa/Clintonia uniflora type (Pfister and others 1977) on elevations from 4,100 ft (1 250 m) to 5,200 ft (1 585 m). All treatment areas had an east facing aspect on 40-60 percent slopes.
>
> Lubrecht Experimental Forest is on the Blackfoot River approximately 35 miles northeast of Missoula, Mont. The habitat type is basically Pseudotsuga menziesii/Vaccinium caespitosum on gently rolling terrain at 4,000 ft (1 200 m) elevation with west to northwest aspects.
>
> Solo-Hemlock area is in extreme eastern Washington near Priest Lake, Idaho. Habitat type is Tsuga heterophylla/Pachistima myrsinities at an elevation of 4,000 ft (1 220 m). The treatment areas had a north aspect with 10-20 percent slopes. The stand was virgin timber 300-400 years old.
>
> Wyoming Site is in the Union Pass area of the Bridger-Teton National Forest, 40 miles southwest of Dubois, Wyo. Habitat type is Abies lasiocarpa/Vaccinium scoparium. The stand is lodgepole pine at elevations ranging from 9,200 ft (2 800 m) to 9,500 ft (2 900 m), with an east facing aspect on slopes from 0-20 percent.

Our objectives were to monitor the operational factors to determine their response to the selected harvesting and residue treatments. We chose to evaluate the microsites at or near the ground surface and not attempt to monitor conditions within the forest canopy. Many of the specific microsites monitored were selected because of other studies on regeneration, microbiology, entomology, etc. We also chose to base our measurements on data that would allow us to evaluate the energy budget components described by Geiger (1950). Interrelationships between various energy flow components can be represented by the following balance equation (Gates 1968; Lowry 1958), called the energy budget equation:

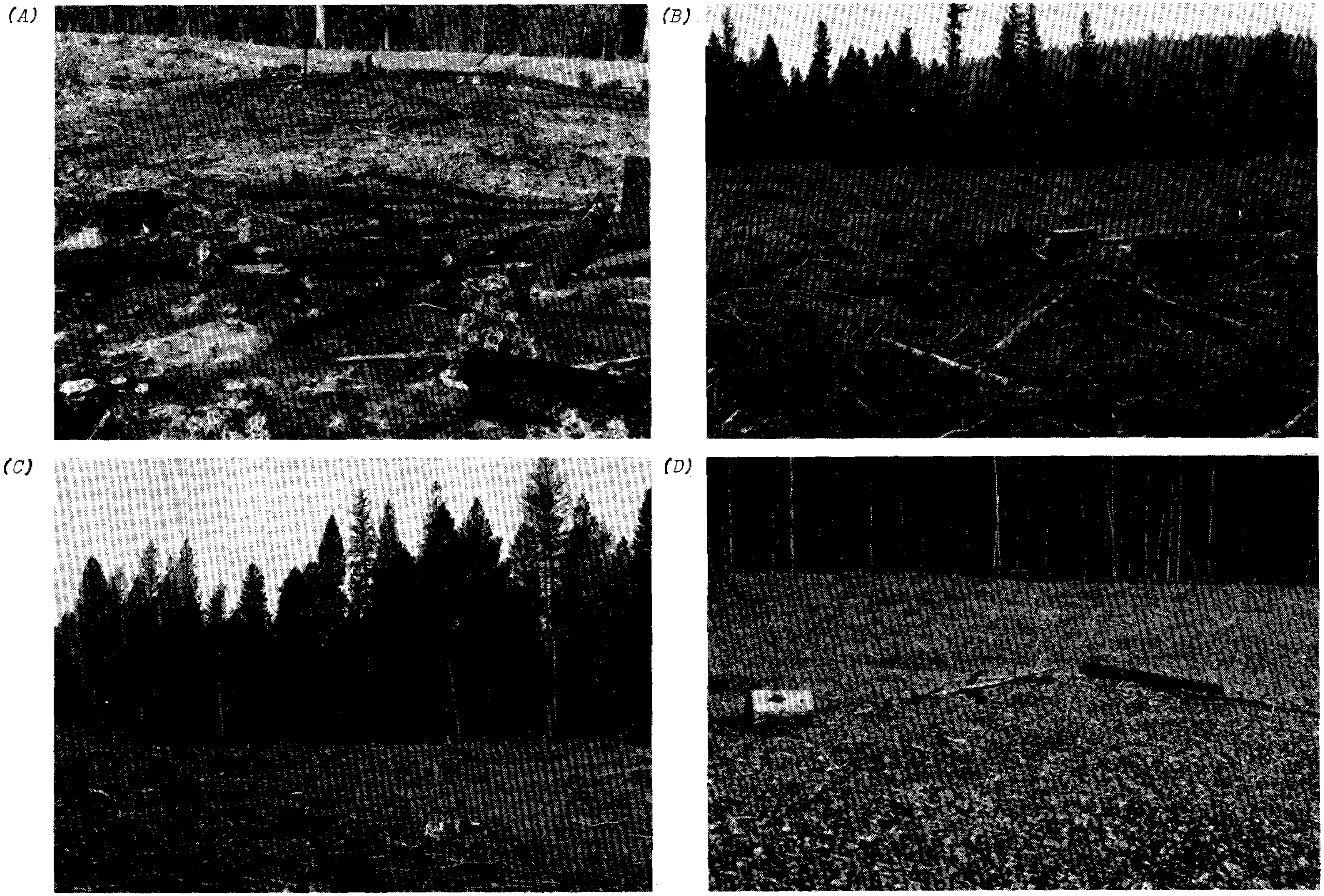


Figure 1.-- Residue treatments used following conventional utilization: (A) Broadcast burning; (B) Residues left in place; (C) All residue removed down to 1 inch diameter; (D) Residues chipped and spread back on the site.

Energy In = Energy Out

or

$$Rn = ET + H + G + M$$

In this equation the symbols are explained as follows:

Rn = the net amount of radiant energy available at the surface, called net radiation

ET = the net amount of energy used at the surface for evaporation, condensation, freezing, melting and transpiration, called evapotranspiration

H = the net amount of energy released from the surface to the air by convection, called sensible heat flux

G = the net amount of energy transferred from the surface into the soil and other materials below the surface, called soil heat flux

M = the net amount of energy used in metabolism, including respiration and photosynthesis. This term is usually so small it is ignored.

This balance equation can be used for a canopy surface, leaf surface, animal surface or soil surface. It permits a realistic assignment of cause for internal responses based on energy relationships.

Other climatic variables were also monitored in conjunction with other biological studies. Continuous records from 1973 through 1979 have been kept for certain treatments at Coram. Records at Lubrecht and Solo creek have been kept from 1977 through 1979 and at the Wyoming site in 1979. The following list indicates some of the parameters measured:

solar radiation
net radiation
photosynthetically active radiation
soil heat flux
precipitation
residue temperature
litter temperature
air temperature
wind speed and direction
soil temperature

Various instruments were used, including a newly-built automated system to put data on cassette tapes. As much of this data has yet to be analyzed and interpreted, the results presented here are only preliminary.

HARVESTING AND RESIDUE INFLUENCES

Radiation and Energy Fluxes

Cutting methods and residue or seedbed treatments both affect the amount of solar radiation entering the soil surface. Mean monthly (summer) solar radiation totals at Coram for uncut and partial cut stands were 25% and 65% respectively, of the amount received on a clearcut. The amount of light reaching the ground is a function of canopy density and of the percent of the stem removed in logging. Fifty-six percent of the crown weight was removed in the partial cut. Solar radiation differences in the winter were nearly the same.

Studies by Hornbeck (1970), Brown (1972), and McCaughey (1978) indicate that albedos are higher on clearcut surfaces than they are above the canopy. Residue and seedbed preparation treatment also alter the net amount of light incident on the surface (table 2). A glance at the table shows that reflectivity differs considerably among such common materials as needles (6%), wood chips (36%), and charcoal (2%). Other common surfaces such as grass, bare soil, bark, etc., are also quite different. The amount of solar and longwave radiation reflected affect the net amount of energy (net radiation) available at the surface.

Table 2.--Forest materials and their shortwave (albedo) and longwave incident radiation reflectivity (after Rosenburg 1974; Fowler 1974; Lowry 1969).

Surface	Albedo	Longwave Reflectivity
Snow (fresh)	80-95	5
Sand (dry)	25-45	5
Water (high sun)	5	2
Coniferous forest	10-15	2
Deciduous forest	15-20	-
Field crops	20-30	-
Clay soil (dry)	20-35	-
Peat soils	5-15	-
Needles (pine, dry)	6	-
Needles (spruce, dry)	11	-
Bark (pine, fresh)	19	-
Bark (pine, old)	21	-
Grass (fresh)	20	-
Grass (old)	24	-
Chips (pine, fresh)	36	-
Charcoal (lump)	2	-

Cutting methods at Coram had a considerable effect on net radiation at the surface. Daily totals were nearly the same in the center of a 16-acre clearcut and a 1-acre clearcut--400 cal/cm^2/day and 360 cal/cm^2/day, respectively (fig. 2). The diurnal progression for both clearcuts was also similar. But net radiation on the same day was 70% (123 cal/cm^2/day) and 46% (219 cal/cm^2/day) less for the uncut and shelterwood areas, respectively. Monthly mean daily amounts showed the same differences particularly from May through September (fig. 3). Differences during the winter months were not as great. It is interesting to note that for some months (i.e. December) the net radiation showed a net loss of energy. Data from the Lubrecht site (fig. 4) showed the same differences between the clearcut and uncut treatments.

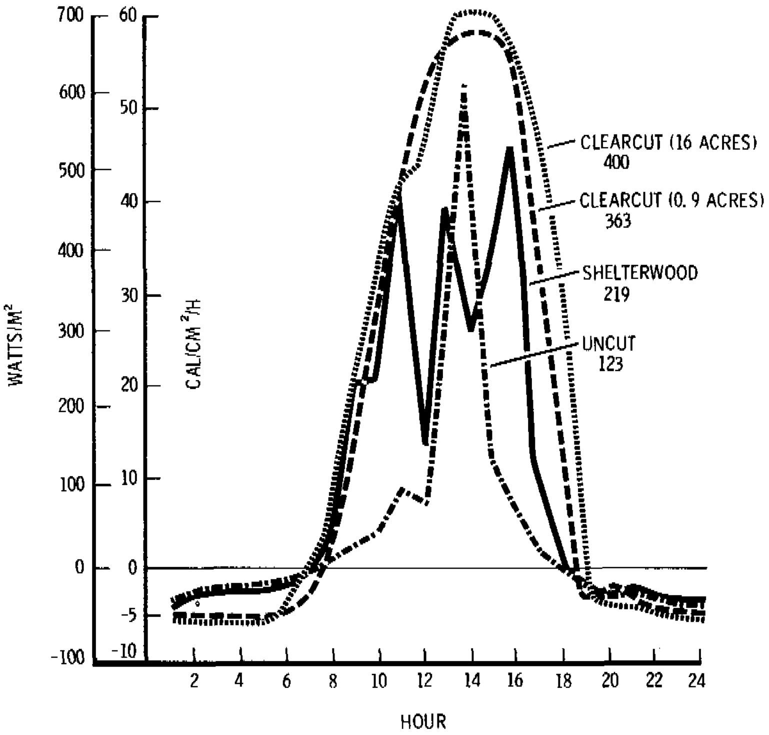


Figure 2.--Diurnal variation in net radiation by cutting method on June 18, 1976, Coram Experimental Forest. Daily totals are given for each treatment.

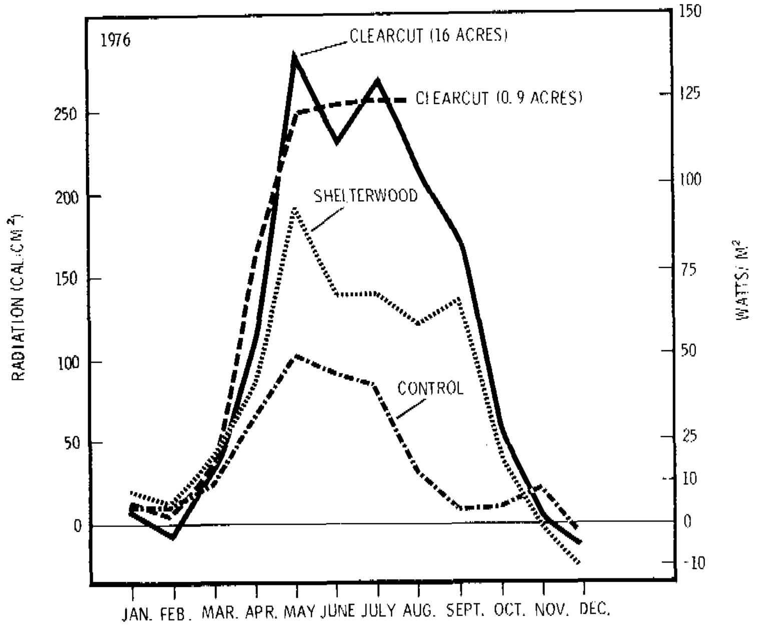


Figure 3.-- Mean daily net radiation by month for stands at Coram Experimental Forest.

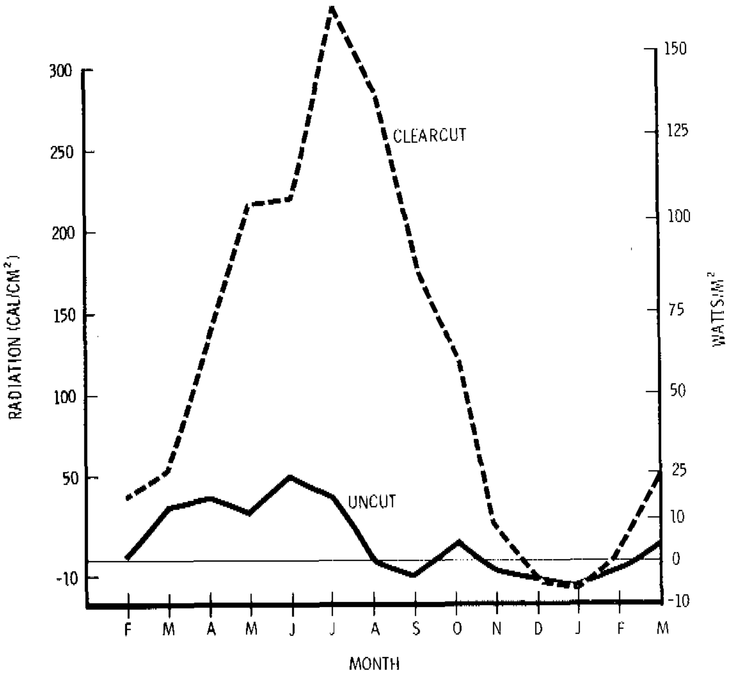


Figure 4.-- Mean daily net radiation by month for clearcut (15 acres) and uncut stands at Lubrecht Experimental Forest, 1978.

Night radiation values for the clearcuts on both sites were more negative than they were on the uncut sites. This indicated a greater loss of energy from the clearcut surface, resulting in cooler potential temperatures. The canopy of an uncut stand acts as a blanket holding in energy. McCaughey (1978) determined that net radiation was reduced 10% by clearcutting, as compared to the daily total above the coniferous canopy. The net effects of cutting differ above the canopy and at the soil surface.

Methods of seedbed preparation include leaving residues on site or removing various amounts of them, and burning and mulching. Theoretically, each of these alternatives should have a different effect on net radiation values. Preliminary analysis of our data indicates that on unburned surfaces where residues were left, net radiation was greater than where residue was removed. Net radiation is significantly higher over dense residue surfaces than over burned surfaces. Treatment areas with residues burned had higher net radiation values than unburned areas where residues were removed or chipped or where mineral soil was left exposed. Net radiation over areas where vegetation had grown back, however, was the same, whether previously burned or cleared. Data from our Wyoming site (fig. 5) show that flux density of net radiation was much higher on cleared and burned areas than in places scarified, or where residues were chipped and spread over the surface.

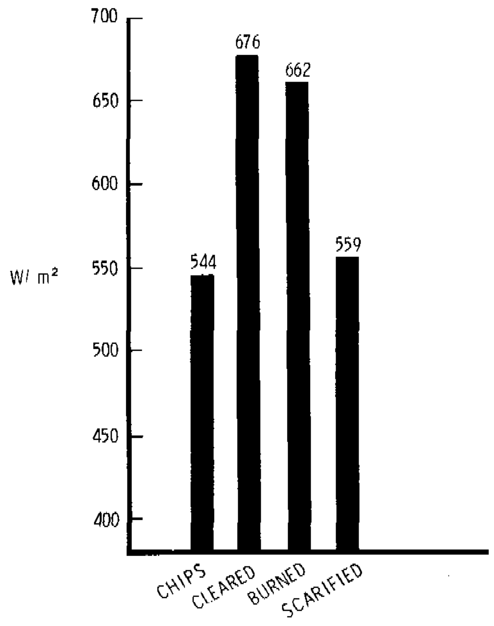


Figure 5.-- Net radiation over several surfaces in a clearcut at the Wyoming site, at noon on July 12, 1979. The differences between burned and cleared and between scarified and chip spread probably are not significant.

Thermal characteristics of surface materials and soil influence the distribution of the energy. The materials commonly encountered at our sites, along with their thermal properties, are listed in table 3. Our data allowed us to calculate approximate energy fluxes, to get an indication of the overall energy balance. We used Campbell's (1977) equations to calculate sensible heat flux, and subtraction to estimate evaporative flux (fig. 6) for data on one day in a clearcut at Coram.

Sensible heat flux, evaporative flux and soil heat flux were all negative since energy is dissipated away from the surface. Sensible heat flux was the largest throughout the day. The increase in evaporative flux at 1400 hours may have resulted from instrument location problems. Soil heat flux generally is greater where net radiation is greater. Measurements made for one day at the Wyoming site show that the sensible heat flux component was greater on the burned and cleared treatment areas than on the chip spread area (fig. 7). The soil heat flux component was greater on the burned area than on the others. Because surfaces were dry, evaporation fluxes under all treatments were lower than sensible heat fluxes.

Table 3.--Forest materials and their thermal conductivity and specific heat (after Fowler 1974; Lowry 1969).

Material	Thermal conductivity cal/cm^{-1} sec^{-1} ^{0}C^{-1}	Specific heat C cal gm^{-1} ^{0}C^{-1}
Peat	0.00015	0.44
Sand (air dry)	0.0004	0.20
Soil	0.0006	0.20
Clay	0.003	0.70
Wood	0.0003	0.27
Chips	0.00014	0.27
Bark	0.00015	0.40
Needles	0.00008	0.40
Charcoal	0.00012	0.20
Air	0.00005	0.24
Water	0.0015	1.0
Granite	0.011	0.21

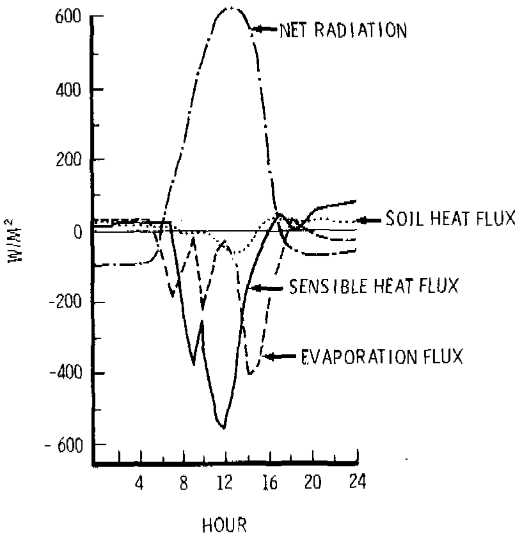


Figure 6.-- Diurnal variation in energy balance components at the surface of a broadcast burn, Coram Experimental Forest, east-facing 55% slope, July 28, 1976.

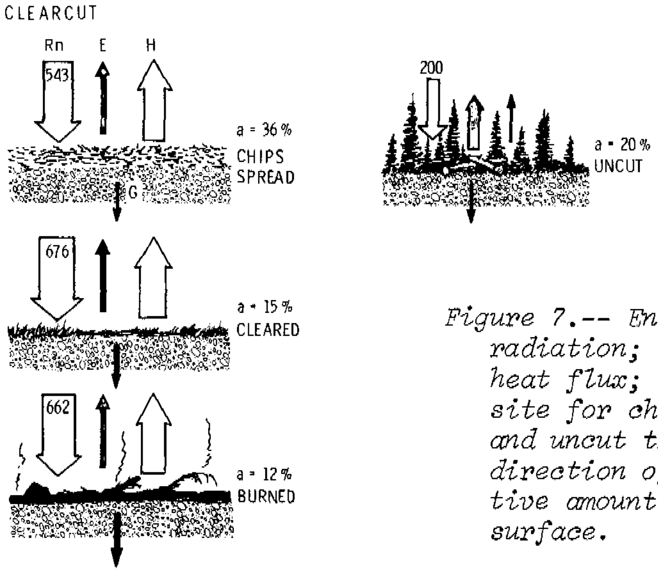
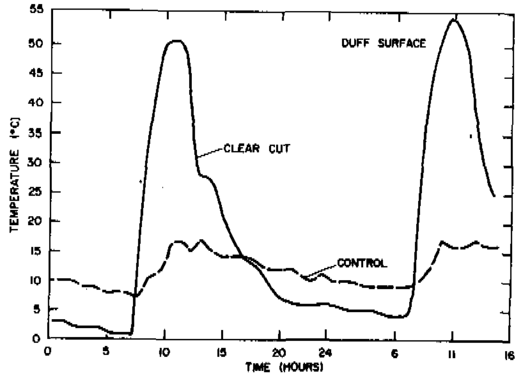


Figure 7.-- Energy balance components: Rn = net radiation; E = evapotranspiration; H = sensible heat flux; and G = soil heat flux at the Wyoming site for chips spread, cleared, broadcast burned and uncut treatments Direction of arrows shows direction of flow and width indicates the relative amount. "a" represents the albedo of the surface.

Temperature

Midsummer maximum surface temperatures were 25°C higher in clearcuts than in uncut stands. Temperatures in partial cuts of varying intensities were 10°C-15°C higher than in uncut areas. Temperature differences between clearcut and uncut stands were similar in different study areas. However, mean maximum temperatures differ by 20°C or more among study areas. Daily differences between temperatures of clearcut and uncut stands exceeded 40°C (fig. 8). Daily maximum temperatures on our study sites frequently exceeded 50°C, and were measured as high as 70°C. Daily and mean monthly maximum temperatures and the length of time above 50°C (fig. 9) indicate potential harmful levels of heat for seedlings (table 4). Maximum temperatures in uncut stands at Coram and Lubrecht exceeded 50°C but never lasted more than one consecutive hour. Conversely, temperatures in the clearcut at Coram remained 50°C for 4-5 hours. At Lubrecht, in the partial cuts where the overstory was not removed, temperatures frequently exceeded 50°C, but not for more than 2 consecutive hours. Temperatures in the clearcut at Lubrecht exceeded 50°C for 5-6 hours on clear days and sometimes reached 66°C or more. Temperatures in the uncut stand at Solo Creek (mature hemlock) never exceeded 30°C, but in the Solo Creek clearcut they exceeded 50°C for 3-4 hours, reaching 56°C. Data from several days in Wyoming indicate temperatures in the 9,000 foot clearcut exceeded 60°C for several hours, but remained less than 25°C in the uncut stand.

Figure 8.-- Diurnal temperature variation of duff surface for clearcut and uncut (control) study areas, Coram Experimental Forest.



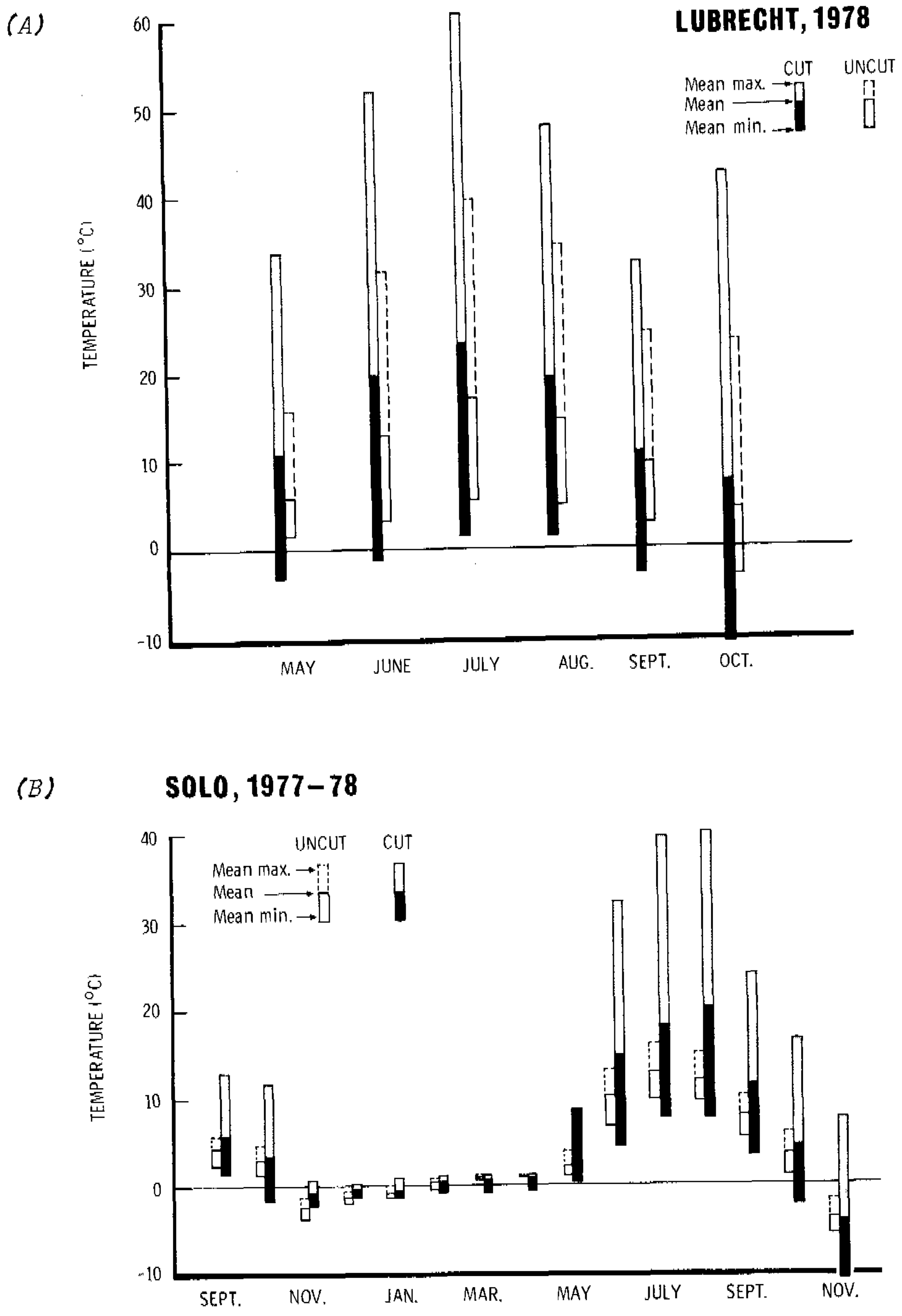


Figure 9.-- Mean maximum, mean, and mean minimum surface temperatures by month for Lubrecht (A) in 1978 and Solo Creek (B) in 1977 and 1978.

Table 4.--Number of hours during the growing season that surface temperatures were 50°C or greater.

	Solo	Lubrecht	Coram*
Uncut	0	4	0
Clearcut	39	194	111

*Not a complete summer period.

From May through October, mean monthly minimum surface temperatures were lower in the clearcuts than in uncut stands. Nightly temperatures in the Lubrecht clearcut frequently fell below freezing in the summer. In 1978 the longest period between freezes was 3 weeks. There is a biologically significant difference between the number of frost-free days experienced by the clearcut and uncut study areas at three of our sites (table 5). As with maximum temperatures, minimum temperatures for partial cutting treatments fell between those of the clearcut and uncut areas. Figure 10 illustrates the relative temperature differences between the various treatments on cold summer nights and on the following day.

Table 5.--Number of frost-free days at the surface for a summer period in 1978 for uncut and clearcut stands at Solo Creek, Lubrecht and Coram.

	Solo	Lubrecht	Coram*
Uncut	173	112	-
Clearcut	98	20	122

*Data not complete for summer period.

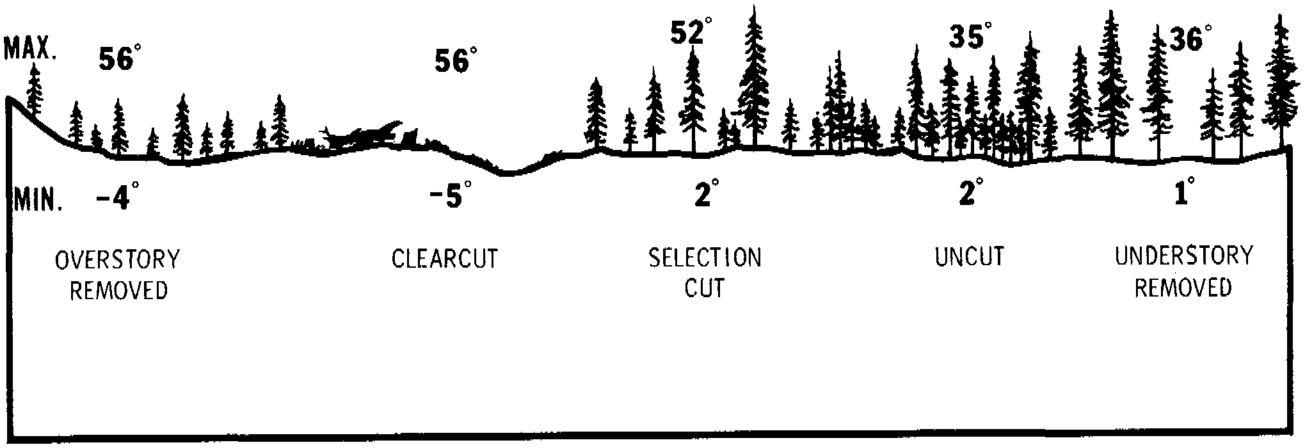


Figure 10.-- Daily maximum and minimum surface temperatures (°C) by cutting unit at Lubrecht, August 29, 1978.

It is logical that if surface temperatures are different for clearcut and uncut areas then soil temperatures are also different. Data from Solo Creek in July (fig. 11) show soils under the clearcut to be warmer at depths to 20 inches (50 cm). Data from Coram shows clearcut temperatures in midsummer to be 6°C-3°C higher from 1-10 inches in depth than those of the uncut stand. Studies at Newman Ridge (Shearer personal communication) have shown differences of 8°C at 10 inches below clearcut and uncut areas. Increases in net radiation and consequently heat flux at the surface of clearcuts produce increases in air temperature. Mean air temperature at Coram in midsummer at standard height increased 4°C following clearcutting. Other study results show increased air temperatures close to the surface.

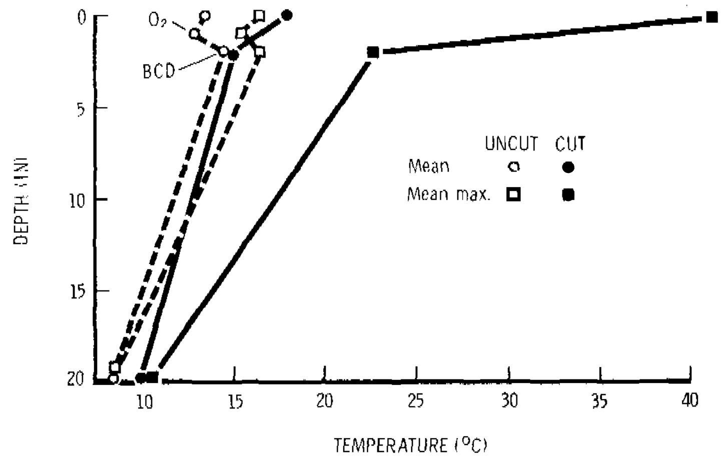


Figure 11.-- Mean maximum and mean temperature profiles by depth for July 1978 on uncut and clearcut sites at Solo Creek. O_2 is the humus layer and BCD is brown crumbly decayed wood.

Residue treatments and seedbed preparation treatments such as burning and scarifying have an additional affect on temperature regimes. The placement, color and thermal properties of surface materials help determine surface temperatures. Highly reflective and conductive materials have much cooler surfaces than absorbant materials with low conductivity (Cochran 1969; Fowler 1974; Lowry 1969). Common forest materials like litter, soil, logs, chips, charcoal, rocks, etc., have considerably different properties (table 3).

The following equation illustrates the relationship between surface properties and surface temperature:

$$\Delta T = \frac{\Delta G}{kcp}$$

where ΔT is the change in temperature, ΔG is the change in heat flux, k is the thermal conductivity and cp is the heat capacity.

Surface temperatures at two sites (Lubrecht and Coram) were very similar in both broadcast burned and cleared areas. Maximum temperatures on both treatments ranged from 50°C-60°C, and minimum temperatures were also nearly the same for both treatments. Temperatures at 9,200 feet (2 800 m) in Wyoming followed the same pattern.

Maximum daily temperatures for the two treatments were within 2°C-3°C of each other reaching 63°C on some days. Maximum temperatures at the chip surface were about 10°C lower. At Lubrecht, mean monthly maximum surface temperatures for the summer period were 10°C lower on bare soil than on litter. Differences in daily maximums were as much as 15°C (fig. 12).

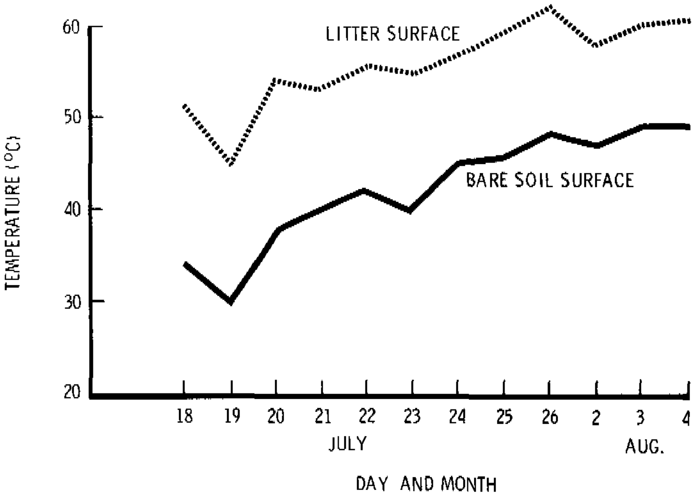


Figure 12.--Maximum daily litter surface and bare soil surface temperatures at Lubrecht, for some July and August 1978 days.

Since the surface temperatures differed on litter, bare soil, burned and chips-spread areas, we expected temperatures above and below the surface to differ (fig. 13). Temperatures above the surface (20 cm and 137 cm) at the Wyoming site were nearly the same for the cleared, burned and chips-spread treatments. Below the surface, however, temperatures were warmest for the burned treatment and cooler for the cleared and chips-spread areas (fig. 14 A and B). Burning by removing some of the litter, allows heat to penetrate faster and deeper. Spreading of the chips insulates soil from extreme surface variations. Clearing leaves a layer of litter deeper than does burning, but this litter has less of an insulating effect than chips. Figure 15 shows the diurnal progression of temperatures at different heights and depths with respect to the surface. The daily temperature wave is damped at 20 cm and the range is small even at 5 cm. Limited data at Lubrecht and Coram reveal the same trend of temperature with depth for the different surface treaments. Cochran's (1969) results illustrate the same trends.

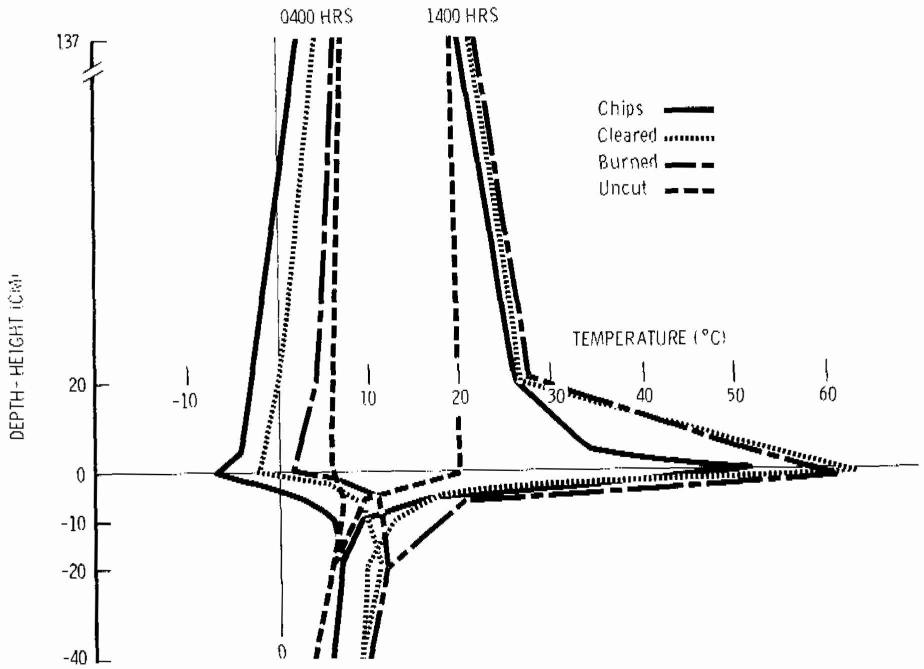


Figure 13.-- Temperature profiles at, above, and below the chip spread, cleared (residue removed), broadcast burned, and uncut surfaces for 0400 hours and 1400 hours, Wyoming site, July 10, 1979.

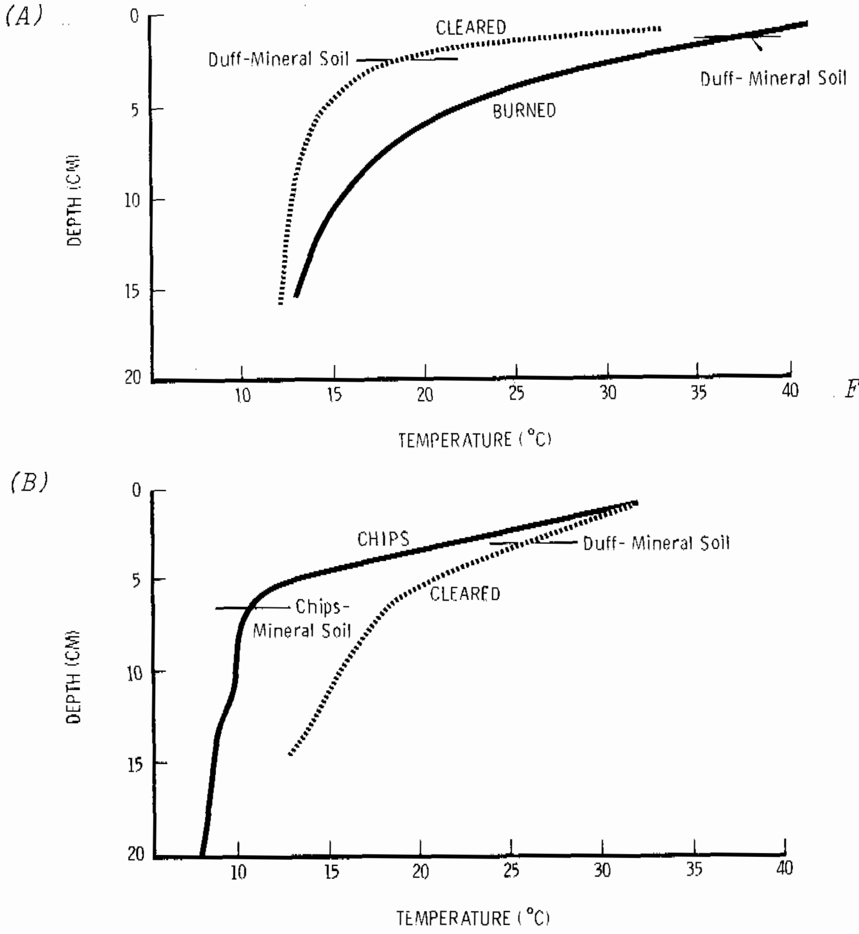


Figure 14.-- (A) Soil temperature profile below the surface of the cleared and broadcast burned sites at 1130 hours. (B) Soil temperature profile below the chip spread and cleared treatments at 1730 hours.

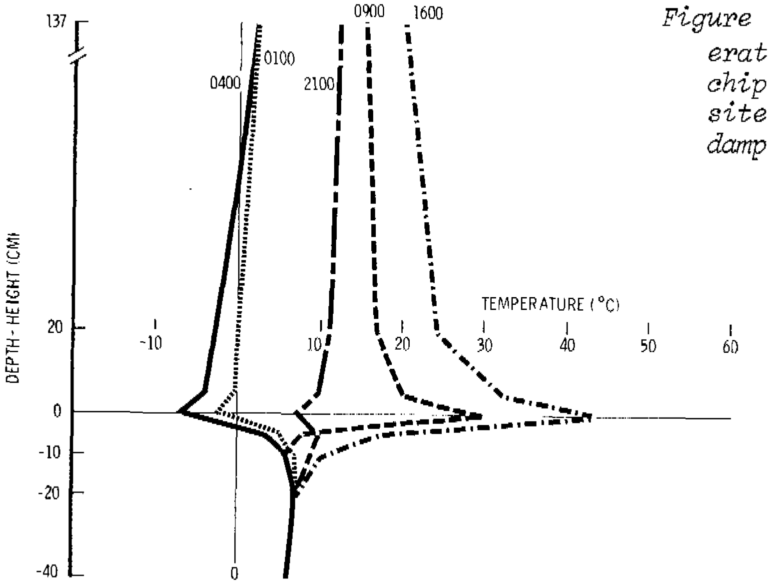


Figure 15.-- Diurnal progression of temperature profile above and below the chips on July 10, 1979 at the Wyoming site. Note that diurnal change is damped at 20 cm.

Upper surface and underside temperatures of fresh residues were monitored by probes inserted 5 mm below the surface. Maximum temperatures on the upper surface in the clearcut at Coram exceeded 50°C for several hours on most sunny days from April through September (fig. 16). Residue surface temperatures were very similar to that of the litter surface at Coram. Maximum temperatures at the center and underside of 4 inch pieces of residue were significantly less than those on the surface of the residue (fig. 16). At the clearcut, maximum temperatures throughout a 4 inch piece of residue were significantly greater than temperatures on the residue surface at the uncut stand.

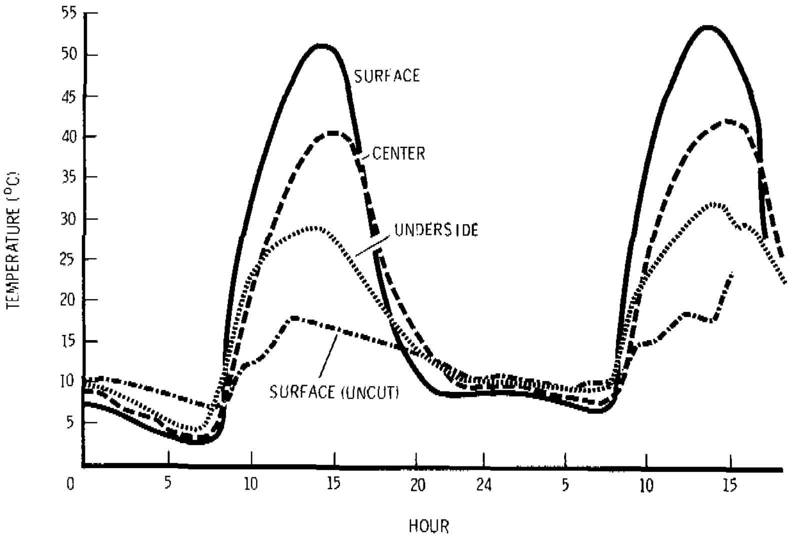


Figure 16.-- Diurnal change in temperature at the surface, center and underside of a 4-inch piece of residue suspended above the soil surface, compared with the residue surface in the uncut stand. Data from Coram Experimental Forest on September 14 and 15, 1975.

Brown, crumbly, decayed material (BCD) is the product of the environment and fungal activity on fresh residues over a period of several hundred years. BCD is an important habitat for mycorrhizal activity (Harvey 1980). Maximum temperatures within the BCD (4 cm below the surface) at Coram lying on the clearcut soil surface seldom exceeded 30°C in midsummer. Temperatures were greater and more varied in BCD on the clearcut than in the uncut. Typical maximums were less than 25°C (fig. 17).

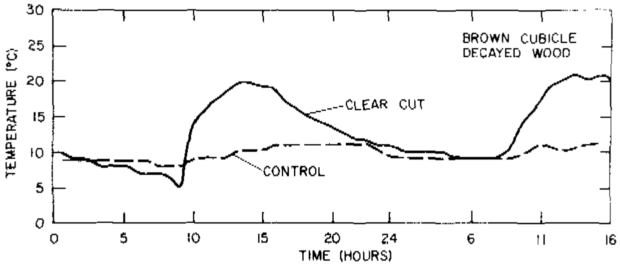


Figure 17.-- Diurnal change in temperature for brown crumbly decayed wood in clearcut and uncut (control) stands at Coram, September 14 and 15, 1975.

Data from a typical clear day in midsummer at Lubrecht revealed considerable differences between the temperatures of BCD, humus, and the surfaces of residue and litter (fig. 18). Large temperature differences occurred between microsites, and the air. The temperature profile with respect to depth was different for soil than for BCD (fig. 19). At 1100 hours BCD was as much as 6°C warmer at a depth of 2 1/2 cm, and the difference between soil and BCD was probably even greater later in the day. To this point the data reflect differences in clearcuts in full sunlight. Obviously, surface shading by residues, vegetation, or other objects would lower maximum potential temperatures and change the temperatures of all materials at various depths.

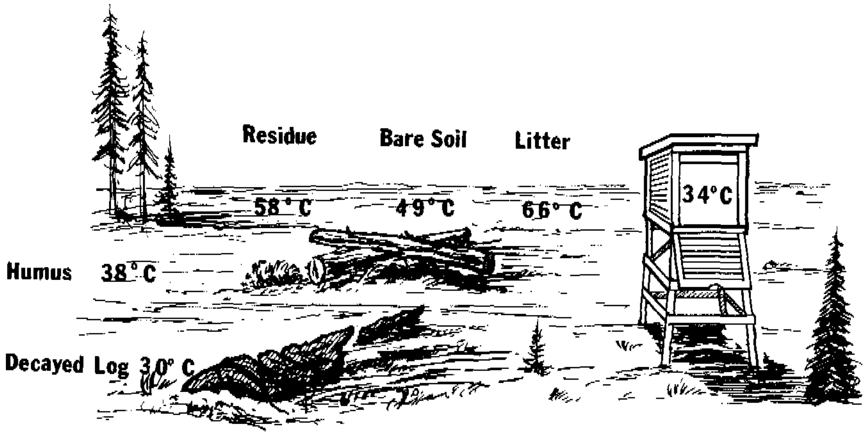


Figure 18.-- Maximum microsite temperatures in Lubrecht clearcut, August 4, 1978.

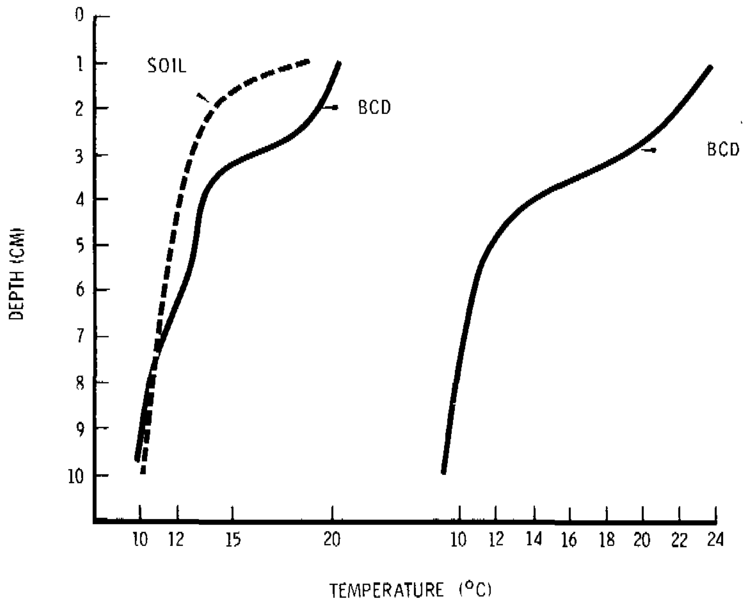


Figure 19.-- Temperature profile beneath the surface of soil and brown crumbly decayed wood (BCD), Lubrecht clearcut, May 18, 1979, at 1100 hours, and beneath BCD at 1200 hours.

Topographical differences between study sites interacted with the treatment induced differences described above. Nighttime temperature typically decreases with elevation, and in some sites blockages to cold air drainage produced localized frost pockets. Differences between the minimum surface temperatures and frequency of frosts at various Lubrecht sites (fig. 10 and 20) resulted from radiation cooling caused by cutting and cold air settling. Frost-free periods lasted much longer in the uncut and partial cut sites because their canopies retained more heat.

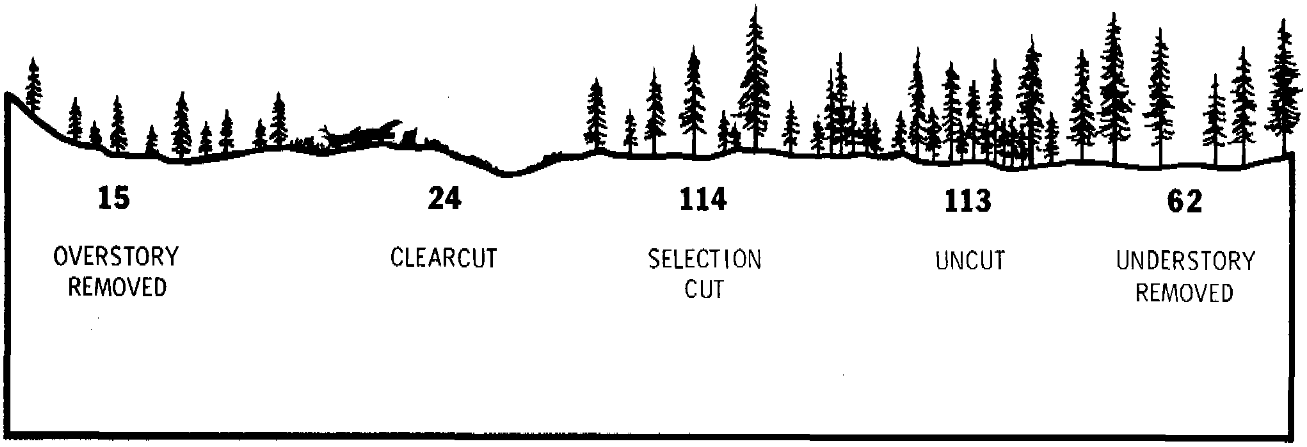


Figure 20.-- Number of frost-free days in 1978 by cutting method, Lubrecht Experimental Forest. Temperatures of -1°C or less at the surface are defined as frost.

At Coram, steep harvested slopes had a much longer frost-free period (based on air temperature) than did the local creek bottom (fig. 21) or two nearby valley stations (Hungry Horse and West Glacier). In the clearcut, radiation cooling of surfaces depressed minimum temperatures compared to those of the uncut stand. Clearcuts received freezing temperatures 10 days sooner than uncut areas, but 30 days later than the local creek bottom. Differences were not nearly as great as at Lubrecht. At Solo Creek, like Coram, freezing temperatures in midsummer were not a problem, although clearcutting did decrease the number of frost-free days (fig. 22).

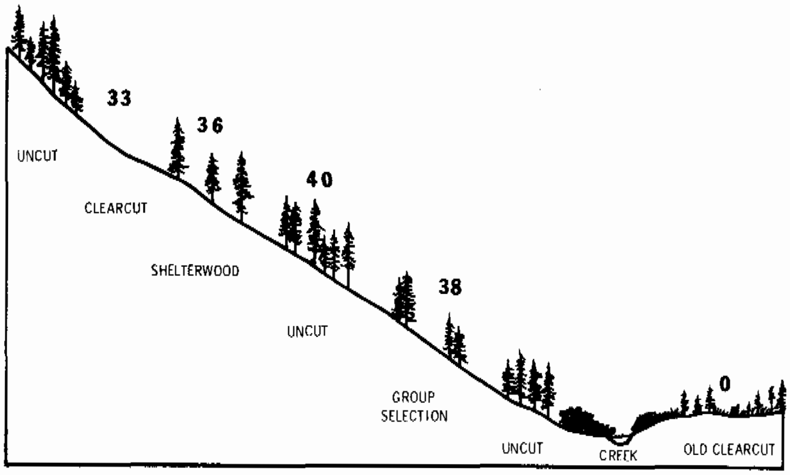


Figure 21.-- Number of days to the first frost in the cutting treatments following the first frost in the old clearcut below the treatments. Based on air temperatures at Coram in 1976.

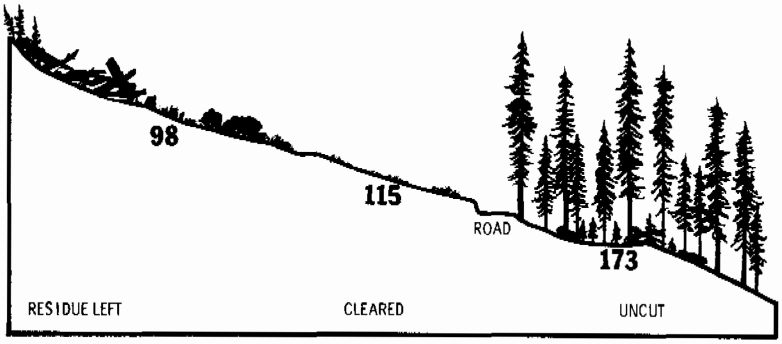


Figure 22.-- Number of frost-free days in 1978 by cutting and residue treatment, Solo Creek. Temperatures of -1^{o}C or less at the surface are defined as frost.

At the Wyoming site radiation cooling and cold air drainage problems also combined to create temperatures well below freezing (fig. 23). Nightly surface temperatures in July 1979 dipped below freezing 17 of 20 days on the chips-spread, 13 of 20 days on the cleared, and 2 of 20 days on the broadcast burned treatments. The cleared and chips-spread treatment areas happened to be in a level area below the burned and uncut treatments. Settling of cold air along with thermal properties increased radiational cooling and added to the cutting's effect. The clearcut merged with a meadow at the drainage, the mouth of which was "dammed" by timber, restricting cold air movement.

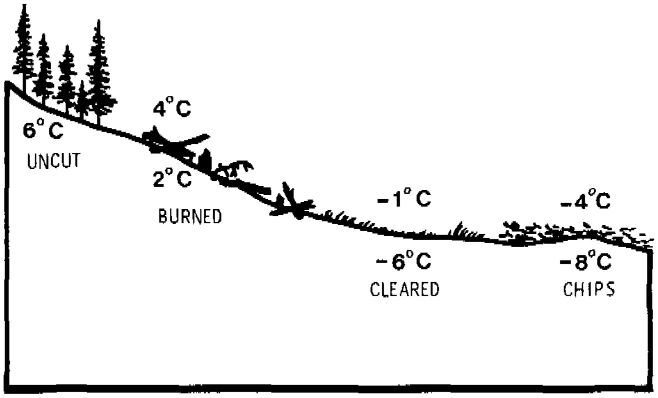


Figure 23.-- Minimum temperatures at the Wyoming site on July 10, 1979. The lower row of numbers represents temperatures at the surface; the upper row represents temperatures at 5 cm above the surface.

Moisture and Wind

The precipitation regimes of the study sites were considerably different, with annual totals of 18 inches at Lubrecht, 30 inches at Coram, 40 inches at Solo Creek and 35 inches at the Wyoming site. Our most intensive data came from the Coram site. The year before harvesting at Coram (1973) was extremely dry, and 1974 was somewhat less dry; 1975, 1976, and 1977 were wet years (table 6). Precipitation among cutting units varied considerably because of topographic features. The units were located at the head of a drainage featuring an elevation change of 1,000 feet, and the upper units received 15-20 percent more moisture during the growing season.

Uncut and partial cut sites receive less rainfall at the soil surface because trees intercept moisture. Compared to clearcuts, the uncut stand at Coram received an average of 25% less moisture at the surface, and the partial cut 15% less, during growing season. The percentage lost is greater in storms with small amounts of precipitation. Newman (1980) discusses these effects in more detail.

It is well known that soil moisture storage increases on sites following clearcutting, at least for a few years. This results from the elimination of transpirational losses. Residue and seedbed preparation treatments often alter these effects significantly. Treatments that loosen the surface soil may have adverse effects on moisture storage. Loosened soil dries quickly, and as soil moisture decreases the surface temperature increases (Cochran 1969). Moisture losses are greater from exposed mineral soil than from those protected by residues. Soils dry faster 5 cm below the surface of unburned and hard-burned mineral soil than below a litter-covered surface or a charcoal-covered surface. Hermann (1963) found the highest soil moisture tension occurred in soil with a bare surface. Organic layers conserve soil moisture, but produce high surface temperatures.

Table 6.--Precipitation received at the soil surface at Coram, by cutting method.

	Patch clearcut, 1 acre	Uncut control	Partial-cut	Clearcut, 16 acres
	- - - - - -	- - -inches-	- - -	- - - - - -
1975				
June	--	1.98	2.83	3.37
July	1.99	1.61	1.96	2.11
August	3.78	3.71	4.64	4.62
September	1.52	1.25	1.41	1.69
Totals		8.55	10.84	11.79
1976				
June	2.96	2.88	3.13	3.54
July	2.44	1.96	2.54	3.00
August	3.20	2.12	3.35	3.93
September	.95	.46	1.05	1.33
Totals	9.55	7.42	10.07	11.80
1977				
June	0.53	0.27	0.81	
July	.19	2.47	3.71	
August	--	1.94	2.96	
September	--	1.05	3.72	
Totals		5.73	11.20	

The shade of vegetation reduces evaporative losses and surface temperatures, but frequently not enough to compensate for the moisture used by the vegetation. Hallin (1968) found moisture tensions at 18 cm depths in revegetated cutovers to range from 18-85 atm and from 3-13 atm where vegetation was removed. Some materials, such as BCD, appear to act as moisture sinks (Harvey 1980). Newman (1980) and Packer (1980) provide more specific information about the soil moisture effects of various treatments.

Evaluating wind flow above and within forest canopies is extremely complex. There is great variation, but the differences are important. We did not evaluate in detail the effect of harvesting and residues on wind, but speed and direction at 10 feet in height were measured at Coram for each cutting treatment. Our data supports the results in the literature that wind speeds in the canopies of partial and uncut stands are less than those above clearcuts. Wind velocity and direction affect seed dispersal and natural regeneration (Shearer 1980). Much is known about the effects of opening sizes and canopy height on wind movement. Bergen (1976), Oliver (1971), and others discuss air flow within the forest canopy. If the understory is sparse, wind velocities at the height of canopies are lower than above or below canopies.

By changing wind patterns, clearcutting and partial cutting increase the susceptibility of a stand to blowdown. Considerable windthrow occurred around the clearcuts and within the partial cuts at Coram. Partially-cut sites on the Flathead National Forest, at least in the vicinity of Hungry Horse Reservoir, frequently experience blowdown.

Residues left on the site slow air movement near the ground. The amount, character, and placement of residues alter the wind speed with height. As a result, evaporation and convective energy exchanges are altered. Decreasing wind movement decreases minimum and increases maximum temperatures.

POTENTIAL BIOLOGICAL CONSEQUENCES

Light

The amount, quality, and duration of light are significant to biological processes. Light affects plant growth through both photosynthesis and the thermal balance that controls transpiration and other internal physiological processes. Light levels also affect the distribution and survival of other organisms.

Photosynthesis depends on a photochemical reaction that requires light energy to split water molecules. If other factors of heat and CO_2 are not limiting, photosynthesis increases in proportion to light intensity. Species have different intensity requirements at which maximum photosynthesis will occur. Foresters have labeled plants tolerant or intolerant. Certain of the chemical processes in photosynthesis are temperature sensitive or CO_2 sensitive. If either of these factors becomes critical under adequate light, photosynthesis will decrease. Any one of these three factors may become limiting in nature. Water is also critical to the photosynthetic rate which can be limited by dry or cold soils. The viscosity of water is increased in cold soils; this increases the resistance to movement and decreases the rates of chemical reactions. High light intensities and high temperatures indirectly limit photosynthesis by causing damage to tissues. Excessive supplies of CO_2 cause injury also.

Photosynthesis and respiration determine growth rate and production of biomass. Respiration rates or oxidation of the carbohydrates produced in photosynthesis are controlled by temperature and oxygen levels. Plants with photorespiration exhibit optimum respiration from $10^{o}C$-$25^{o}C$. Plants without photorespiration exhibit optimum respiration at about $35^{o}C$. Increases in temperature at certain levels increase respiration and decrease net photosynthesis. Lee and Sypolt (1974) found that basal area growth of a forest in West Virginia was reduced because high canopy temperatures reduced dry matter production. These high canopy temperatures resulted from high net radiation loads and cooler soil temperatures. The cooler soil temperatures decreased water absorption to the point where canopy transpiration exceeded the rate of water absorption. Lee and Sypolt (1974) suggested that high net radiation levels (greater than 0.7 $cal/cm^2/min$) may directly reduce net assimilation.

Light, as indicated in the above discussion, can increase the temperature of a plant leaf. This increase in temperature increases the difference between the vapor pressures of air and of the internal cavities of the leaf, thereby, increasing transpiration. This is what took place in the above example. Light also causes the stomates to open, allowing transpiration. Transpiration effectively cools the canopy. Light then indirectly causes dessication and lethal effects through increasing transpiration and evaporation.

The intensity of light and radiation outside of the visible spectrum increases the temperature of plants and other objects. Plants and animals have many mechanisms for controlling or reducing the effects, some of which will be discussed later.

Light is known to have potentially lethal effects on plants and to be effective in controlling or altering plant distribution. Reports indicate that high light intensities injure the photosynthetic process of some sensitive species (Ronco 1970), but this damage may be related more to light quality than intensity. Ultraviolet radiation is increased considerably at high elevations and apparently damages nucleic acids in the cells of some species (Caldwell 1971). Ultraviolet light appears to affect tree development and possibly influences species distribution (Klein 1978). Other wavelengths of light, such as far red, seem to reduce germination and affect other physiological processes. Many studies have shown shade to be beneficial to growth and survival. However, it is not stated whether light, temperature, or some other operational factors were altered.

Heat

Heat and energy exchange that changes temperature regimes are biologically significant. Temperature describes a body's potential for exchanging heat with its surroundings. Our study's results indicate that different kinds of microsites in the same locality at the same time do not have the same temperatures (fig. 19). Too often we have unwittingly assumed that measurement of air temperature will tell us what is going on at a particular location. The differences between air temperature and that of a plant or plant part can be significant. Small differences about threshold values can mean life or death, or produce significant differences in growth.

The lethal high temperature for most plant tissue is about 54°C; exposure of seedlings to 54°C for about 30 minutes will cause death. Research has documented the occurrence of high temperatures killing tree seedlings (Shearer 1967; Silen 1960). Our data indicate lethal temperatures do occur on residue and litter surfaces in clearcuts in the Northern Rocky Mountain area. Factors such as the age of plants and the insulation properties of their bark, determine the potential for exchange between the soil surface and the organisms. This, in turn, determines the temperature of tissues. We must recognize again that there are species differences and these factors need to be considered. For only a few species do we have complete records of maximum temperature tolerance and information on specific hardening behavior. Data indicate that temperatures several centimeters below the surface seldom, if ever, reach lethal levels, except during fires (Shearer 1975). Roots, therefore, are not likely to be killed by heat. Root growth is generally limited or stopped at about 35°C (Hermann 1977).

Low temperatures are often lethal to seedlings and other organisms, although plant tissue properly hardened or conditioned to low temperatures can withstand temperatures as low as -55°C. Species differences exist, but limits for native species are seldom exceeded. Planting of exotic species can lead to disasterous results if tolerance is not considered. Young seedlings, are particularly susceptible, and unseasonable frosts frequently are lethal or cause significant injury. Insect larvae and fungi can also be harmed by overly low temperatures. Data for our study sites indicates that frequent frosts do occur as a result of harvesting. These frosts apparently caused considerable mortality to planted stock and natural regeneration at the Wyoming site, and the potential exists at Lubrecht and in certain localities at Coram.

Temperature influences moisture balances in several ways. Surface temperatures influence air temperature gradients, and these influence vapor pressure gradients. As indicated earlier, the vapor pressure gradients between the atmosphere and leaf affect transpiration rates and consequently the internal water status of plants. As previously mentioned, cooler soil temperatures increase the viscosity of water, thereby, increasing the resistance to flow in the roots, which also affects the internal water status of plants. Temperatures, therefore, are influential in controlling water stress under some circumstances.

Temperature regimes also influence microorganisms in the soil and elsewhere. Mycorrhizal activity, which enhances water and nutrient uptake, is temperature related. As Harvey (1980) mentions, sites of mycorrhizal activity shift during the year as a result of temperature and moisture factors. Jurgensen (1980) and Stark (1980) discuss the relationship between temperature and nutrient cycling and nitrogen production.

Fungal activity, important in decomposing residue material, also is temperature and moisture dependent. Cool temperatures suppress activity and high temperatures are lethal to it. Residue temperatures of 60°C or less are lethal to some fungi (table 7) and stop activity by other species. High heat loads also evaporate moisture and create moisture streses, although fungi can survive and grow under more severe moisture stresses than most plants. Vegetative growth and spore germination are critical to the life cycle of fungi active in decay (Larsen 1980). Manipulating residue temperature and moisture regimes could increase decay rates.

Fungi that cause disease also are temperature and moisture sensitive. Harvesting activities that alter these factors on various microsites are likely to affect diseases such as root rots and possibly some canker and foliage diseases.

Table 7.--Lethal temperatures for mycelia of several species of wood inhabiting fungi.

Species	Temperature
Armillaria mellea	65°C
Fomes applanatus	65°C
Lentinus lepideus (moist)	>60°C
(dry)	>105°C
Merulius lacrymans	50-55°C
Fomes pini	65-75°C

Moisture

Moisture is frequently identified as a major factor limiting the growth and development of forest vegetation. Stem elongation and dry weight production can be decreased at water potentials of -0.5 bar. And the growth rate of seedlings is often substantially decreased at soil water potentials of -2 to -4 bars. It is not uncommon to reach these levels in the upper layers of soil. Commonly reached lethal levels can explain mortality of seedlings and sometimes mature plants. Large conifers have been observed to split open as a result of drought (Hungerford 1973). Many good articles discussing water deficits and plant growth are available (Kozlowski 1968a, 1968b, 1972, 1976, 1978; Slatyer 1967). Newmann (1980) and Packer (1980) discuss the specific site effects of water deficits.

Gases

Carbon dioxide is needed for photosynthesis and to produce dry matter. Although we know its importance in maintaining forest vegetation, we know very little about how CO_2 limits vegetation in forested systems. We also know very little about how forest activities such as timber harvesting influence levels of carbon dioxide. It generally is assumed that the levels of carbon dioxide are adequate, and we know that global supplies of carbon dioxide are increasing (Machta 1972).

Oxygen concentrations affect the respiration rates of organisms. Probably the most significant alteration of oxygen and carbon dioxide levels in forests can occur in soils. Various activities such as scarifying and skidding can either loosen the soil or compact it, thus altering gaseous exchange with the environment. Compaction reduces the exchange, which causes an accumulation of carbon dioxide and depeletion of oxygen. The result is a decrease in microbial activity and possibly root growth (Bollen 1974). Reduction in microbial activity can adversely affect the nutrient capital of the site. Residues or residue treatments that impede aeration or cause surface compaction will alter biological activity. A detailed discussion of such relationships is beyond the scope of this paper. Bolin (1970) discusses the carbon cycle and vegetative relationships; Harvey (1980) and Larsen (1980) discuss microbial relationships; and Jurgensen (1980) discusses nitrogen relationships.

Wind

Wind speed and direction affect biological systems in many ways. Since some species are more susceptible to windthrow because of rooting habits, harvesting prescriptions must take local situations into account. If one relies on natural regeneration for restocking, wind becomes an important factor in determining the proper size and method of cutting. Since species differences exist, wind can have differential effects.

Wind energy, particularly at high elevations and near coastal areas is also a factor in distributing species and damaging vegetation. Wind-carried particles of sand, etc., kill seedlings. Salt spray from ocean winds also causes damage. Constant strong winds, such as at high elevations, cause deformities.

Wind speed modifies the exchange of heat moisture and gases. An increase in wind speed decreases the thickness of the boundary layer, or cushion of air close to a surface, and decreases the resistance to exchange. When the resistance to heat, moisture, or gas exchange is reduced more heat, moisture, or gas is lost. Increases in wind speed can be effective in removing heat and cooling an object. Removal by wind of water vapor being transpired or evaporated from a surface increases water loss. Often this has adverse effects, causing dessication and possibly death if the supply of moisture becomes inadequate. During periods of rapid photosynthesis wind can be beneficial by keeping carbon dioxide levels higher near leaves. In still air, carbon dioxide supplies may be depleted near leaves, depressing photosynthetic rates. Some wind near the ground can help prevent freezing at the surface. Mixing of the air is more thorough, reducing radiative cooling. This principle is often used in orchards to prevent frost.

PREDICTING ENVIRONMENTAL CONDITIONS AND CONSEQUENCES

Managers need facts about existing environmental conditions, about vegetative requirements and how manipulation of vegetation will alter conditions. One way to get such facts is to monitor and measure what goes on. This is becoming more feasible in many cases, but we can't measure everything in all places. Modeling using existing information and selective monitoring based on studies and experience constitute another alternative. While it is obvious that many causal environmental relationships escape our description, we can predict some. Combining monitoring and mathematical modeling to predict environmental conditions and biological consequences offers some powerful management tools.

It is beyond the scope of this paper to discuss the details of many models and integrate them. I will, however, present some models and potentials for models that may be of benefit to managers, listing the source and where specifics for use can be obtained. Gonsior and Ullrich (1980) present a potential method for integrating specific models and information.

Since all available energy comes from the sun, it is important to know how much is received. Solar radiation is commonly measured at standard locations, but not in mountainous terrain. Latitude, aspect, slope, and cloud cover are input variables for a model described by Satterlund and Means (1978) for estimating solar radiation. With their model mean daily totals can be estimated to within 8 percent of measured values. The model uses estimates of potential direct beam solar radiation described by Fons and others (1960) and cloud cover data from a nearby weather station. Topographical shading in mountainous terrain, and the sizes and shapes of openings, also influence the amount of solar radiation received on the surface. Satterlund (1977) developed a way to predict shadow boundaries with a programmable calculator. The output of this model can be used to adjust the model for incident solar radiation (Satterlund and Means 1978).

Halverson and Smith (1974) also describe a computer model to calculate shading for any combination of date, slope and aspect at latitudes from the Mexican to the Canadian borders. Using this model one can estimate the increase or decrease in heat or light to the snow surface or in the vicinity of seedlings. Fisher and Merritt (1979) discuss the use of a model to calculate light distribution in small forest openings. The inputs are coordinates and heights of trees on the boundary, slope, aspect, latitude, day, time interval and point coordinates of interest in the opening.

Net radiation--the measure of the amount of energy available at the surface--is very significant. But net radiation values are not generally available for long terms. As a result, many attempts have been made to determine net radiation from solar radiation (Rosenburg 1974) The accuracy and utility of these are uncertain, however, since surface properties affect the exchange, and considerable variability exists between sites. These models, although empirical, are the best we have. The only other alternative is to measure radiation.

Temperature regimes, particularly the potential maximum and minimum temperatures by date and microsite, are extremely important to vegetation development. Considerable work has been done in evaluating leaf and canopy temperatures (Gates 1968; Raschke 1960). Gates (1975) has developed a model that predicts temperature based on radiation input, wind speed, humidity and characteristic dimensions. Other equations using some different variables are also available (Campbell 1977). Energy budget concepts can be used to evaluate the various energy fluxes.

Surface temperatures are very important for determining vegetation development. Potential maximum or minimum temperatures should be predictable with a certain degree of accuracy. A number of models have been developed for evaluating moisture and heat transport with respect to time and depth (Fosberg 1975; Rosema 1975; Mitchell and others 1975). Most of these models are quite complicated and require considerable amounts of data with very stringent criteria for measurement. We are attempting to develop a model to predict maximum growing season temperatures on a site. Such temperatures should be predictable using radiation input, thermal properties of the exposed surface and some characterization of temperature at a level within the soil. Other published models may also be available.

The theory and models for predicting temperatures at given levels within the soil have been described in detail (Wijk 1963; Campbell 1977; Lowry 1969 and others). Basically, the temperature/time/depth profile is influenced by heat input at the surface and the thermal properties of the soil.

Using conduction theory and numerical methods we have developed a model to estimate temperatures at any point within a piece of reside or log. We assume that surface temperatues and thermal properties are known. With more work and testing this model will also be able to estimate moisture levels. Temperature and moisture levels within residues should provide a basis for evaluating potential microbiological activity and decay.

Brown (1970) developed a model to evaluate the change in stream temperatures resulting from harvesting. It is based on solar radiation inputs, flow rate of the stream, and surface area exposed to sunlight. Predictions within 3°F of the true value are possible. Changes resulting from harvesting treatments or potential treatments can be evaluated.

Numerous attempts have been made to predict evaporation and transpiration. Equations and models exist that accurately estimate water loss from water surfaces, but evaluating losses from plant and other surfaces not saturated is more difficult. Some models evaluate potential evapotranspiration with good results. Models based on the energy budget concept and physical principles are being developed and used (Campbell 1977); although their foundation and accuracy are probably best, data collection requirements are rather stringent. A number of empirical approaches estimate potential losses using common climatic variables (Rosenburg and others 1968). These are not very effective in determining actual transpiration rates in the field. Methods based on physical principles such as the Penman equation, using net radiation, vapor deficits, temperature and diffusion resistances, are being refined and used to study actual situations (Campbell 1977). Much work remains to be done in forested situations to arrive at more usable models for management purposes.

Numerous models have been proposed that relate photosynthesis to environmental variables. Lommen and others (1971) have developed a model based on a diffusion theory of gases and physiological considerations. The model is extemely useful for understanding the variables that control photosynthesis under varying conditions. General predictions of physiologic characteristics and environments suited to photosynthesis are possible, but more research and evaluation are needed to develop models with more utility. Estimating rates of dry matter production in forested situations is difficult. Some empirical models are in use (Stage 1973) and future refinements of models such as this will include physical relationships.

HARVESTING AND RESIDUE MANAGEMENT TO MODIFY MICROENVIRONMENT

As we have seen, various cutting methods and residue and seedbed treatments significantly affect moisture and temperature levels. These differences result from changes in the energy balance. Evaluating energy budget terms in light of organism requirements should help us meet those requirements without producing undesirable side effects. Using these principles we can evaluate ways of changing the microenvironment by cutting and residue treatment. Table 8 summarizes methods of altering specific problem conditions.

In the northern Rocky Mountain region we have sites that are warm and dry, sites that are cold and wet, and others with all the variations in between. Surface and microsite temperatures can be reduced below lethal levels by reducing the incoming energy. Partial cutting, leaving residue material and scarifying are methods of reducing surface temperatures. Temperatures at lower depths will also be reduced, and moisture will be conserved by reducing evaporative flux. On sites where minimum temperatures may be lethal during the growing season partial cutting and leaving residues will reduce radiative heat losses and keep tempatures from going below freezing.

Situations exist where temperatures below the surface exceed that which is optimum for growth. If surface temperatures are not critical, mulching with chips will decrease temperatures below the surface while conserving moisture. Loosening mineral soil will create the same conditions. These treatments can aggravate the situation on high elevation cold sites, however, by decreasing temperatures. Leaving residues or partial cutting can reduce temperatures in the root zone. On high elevation or cold sites, temperatures within the soil profile may be increased by removing litter to mineral soil, by trapping heat through furrowing and planting on ridges, or by burning. Placing materials with high thermal capacities near seedlings can increase night temperatures. Moisture losses could be greater in these situations, aggravating already limiting conditions. But if moisture is not limiting, growth could be increased.

Mulching with materials such as wood chips or other materials high in reflectivity can decrease the amount of energy available at the surface and increase the heat load above the surface. The effect on seedlings and other vegetation can be lethal. At the other extreme, burning decreases reflectivity and causes more energy to be absorbed at the surface. Temperatures at the surface and below will be increased, which may be good or bad depending on previous temperature regimes. Overstory conditions and amounts of residue remaining also effect these conditions.

Table 8.--Possible solutions for potential, critical environmental conditions.

Potential problem	Possible solutions
Temperature	
1. Surface too hot or summer frost	1. Shade partial cut leave residues nurse crop 2. Alter thermal properties remove litter remove barriers to air flow compact surface water 3. Other change species lighten color of surface
2. Soil temperature	
a. Too high	1. Shade partial cut leave residues nurse crop 2. Alter thermal properties mulch loosen surface don't burn
b. Too low	1. More light open stand remove residues 2. Alter thermal properties remove litter burn heat trap put different surface 3. Other darken surface
Moisture	
1. Too low	1. Shade leave residues artificial shade size of opening 2. Lower consumption remove vegetation mulch 3. Other irrigate capture snow
2. Too much	Miscellaneous drainage increase evapotranspiration increase energy remove residues
Light	
1. Too much	1. Shade partial cut leave residues size of opening artificial shade
2. Too little	Miscellaneous open stand change species remove residues
Gaseous	
1. Atmosphere	
a. Too much or too little	Miscellaneous thin vegetation remove residues
2. Soil	
a. Too much or too little	Miscellaneous remove residues loosen soil

When major residue manipulations are not possible, or when limiting conditions already exist, one may be able to take advantage of microsites. If high temperatures are limiting, planting behind logs, stumps or other objects can be beneficial. When moisture is limiting, planting behind logs and stumps and in decayed wood may increase chances of survival. Avoiding low spots and planting near logs and stumps can also reduce the likelihood of frost damage.

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Silviculture and Residue Treatments Affect Water Used By A Larch/Fir Forest

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ABSTRACT

Three silvicultural systems--clearcut, shelterwood, and group selection--were coupled with four residues treatments, ranging from intensive to conventional utilization and broadcast burning, to evaluate the environmental effects of harvesting larch/Douglas-fir forests in Montana. Effects of the 12 treatment combinations on accumulated precipitation, water used during the growing season, and soil water status during the year, were evaluated for the first 4 years after harvesting. The study was conducted on a steep east aspect at about 4,500 feet (1 370 m) elevation.

Silvicultural treatments increased the amount of precipitation that reached the forest floor, most in clearcuts and group selections and less in shelterwoods. Snow accumulation which accounted for about 50 percent of the annual precipitation, increased about 80 percent in clearcuts, 50 percent in group selections, and 40 percent in shelterwoods when compared to uncut mature forest. During the growing season, the uncut mature forest used about 75 percent of the total annual precipitation. Differences in water use following harvesting were less than expected. Shelterwoods used about 4 percent, group selections 10 percent, and clearcuts 11 percent less than the uncut control. Rapid revegetation on all harvested areas, the residual stand in the shelterwoods, and soil water deficits in the uncut forest apparently ameliorated some differences between uncut forest and treated areas. As a function of differences in accumulated precipitation, and water use during the growing season, water present in the soil profile remained highest on clearcuts and lowest in uncut mature forest, with shelterwood and group selections falling between the two. Residue treatments had relatively minor effects on precipitation accumulation, water use, and soil water status. Of these, the two treatments with broadcast burning had the greatest effect.

KEYWORDS: Water use, precipitation, soil water, *Larix occidentalis, Pseudotsuga menziesii,* larch/Douglas-fir, silvicultural systems, residues management, broadcast burning, clearcutting, shelterwood, group selection, Northern Rockies, evapotranspiration.

INTRODUCTION

Hydrologic effects of harvesting or any other timber related activity have long been a concern of hydrologists throughout the Northern Rockies. DeByle (1976) noted that hydrologic responses such as increased soil erosion, channel cutting, and stream siltation have been studied most and are best documented. Nutrient changes as affected by silviculture treatments have been addressed by DeByle and Packer (1972), Packer and Williams (1976), Stark (1979), DeByle (1980), Stark (1980). However, the effects of forest residues, or lack of residues, on more subtle responses such as changes in evapotranspiration, microclimate, insolation, and streamflow have had little study emphasis in the Northern Rockies, but are now receiving more attention. Fowler (1974) discusses the major physical processes that create differences in local microclimate and emphasized how forest residues may affect microclimate. Microclimate in turn enhances or limits forest establishment. Rothacker (1970), Cline and others (1977), and Packer (1967) pointed out the variability in responses as affected by climate, soils, geology, vegetative type, site history, and stand treatment intensities and discussed site recovery following stand treatments.

A continuing concern in the extensive larch/fir forests of the Northern Rockies is the influence of harvesting activities upon the hydrologic attributes and functions and, in turn, the effects on other factors. This includes factors such as seedling establishment, available water for vegetative growth, potential for transport and loss of nutrients, soil microbiology, soil stability, water surpluses and deficits as they affect streamflow, and others.

The principal objective of the study described herein was to evaluate on-site water use in a larch/Douglas-fir (*Larix occidentalis/Pseudotsuga menziesii*) forest as affected by silvicultural-harvest-cutting and residues-management treatments.

The purpose of this report is to provide some of the basic information concerning on-site hydrology as affected by the aggregate influences of three silvicultural systems--clearcut, shelterwood, group selection--and four residues treatments in a typical larch/Douglas-fir forest in Montana.

STUDY DESCRIPTION

Area

The study area is located on the 7,400-acre (2 984-ha) Coram Experimental Forest on the Hungry Horse District of the Flathead National Forest, in northwestern Montana, sections 25, 35, and 36; T31N, R19W (fig. 1), 7 miles (11.2 km) NNW of Hungry Horse Reservoir Dam and 7 miles (11.2 km) due south of the town of West Glacier, Montana. Coram Experimental Forest was initially established, and has been used, to study the ecology and silviculture of western larch/Douglas-fir forests (Schmidt and others 1976), but has had no use for watershed related research except by Schmidt (1978).

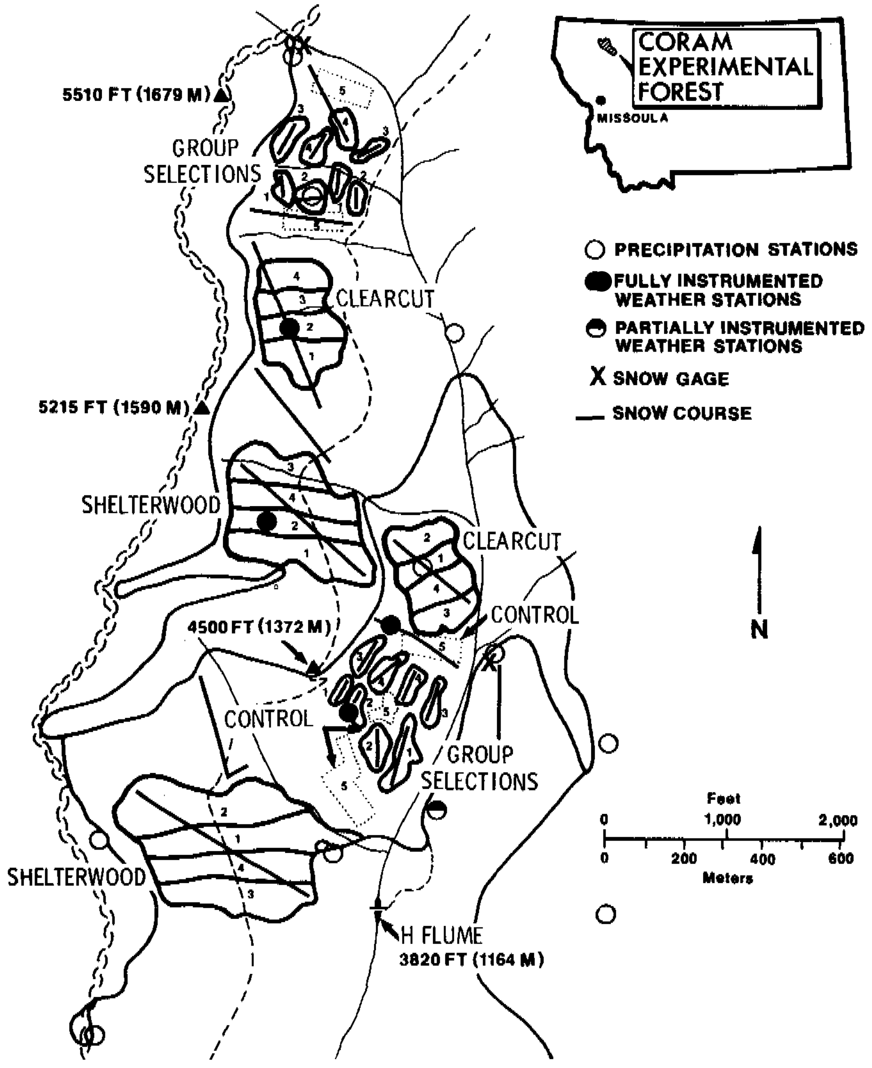

Figure 1.--Coram Experimental Forest Study area showing precipitation stations and silviculture-residue treatment locations. Residue treatments were: (1) intensive utilization and burn, (2) conventional utilization and burn, (3) residues removed, and (4) understory protected.

The main study site (fig. 1) occupies an east facing slope between the elevations of 3,940 feet (1 182 m) and 5,300 feet (1 590 m) in the northern most portion of Abbott Basin. Slopes on the cutting units range in steepness from 30 to 80 percent (17° to 39°) and average about 55 percent (29°). The mountain slope soils are of the loamy-skeletal soil families (McConnell 1969; Klages and others 1976) derived mostly from underlying Helena (Siyeh) limestone and dolomite of Precambrian Age, and a thin mantle of glacial till of Pleistocene Age (Johns 1970).

The timber type on the study area is larch/Douglas-fir (Cover Type 212, Society of American Foresters 1954). This type is composed primarily of western larch and Douglas-fir. Associated species include subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*). The study area falls primarily in the *Abies lasiocarpa/Clintonia uniflora* habitat type, with the following phases represented: *Aralia nudicaulis, Menziesia ferruginea, Clintonia uniflora,* and *Xerophyllum tenax* (Pfister and others 1977; Bernard L. Kovalchik 1974, unpublished data[1]).

The Continental Divide is a primary climatic control for Coram Experimental Forest. Two kinds of air masses give rise to the two main winter climatic events. Pacific maritime polar air masses bring most of the 35 inches (89 cm) of mean annual precipitation[2] in Abbott Basin of Coram Experimental Forest, 50 to 65 percent of which is in the form of snow, depending upon elevation. These air masses probably account for 90 percent of all winter precipitation and 70 to 90 percent of summer precipitation. Arctic continental polar air mass invasions produce light amounts of snowfall but their main contribution to local climate is extreme cold.

Variations in summer precipitation are caused by local thunderstorms and upper level barometric lows. Precipitation from thunderstorm events is characterized by both high intensity and spatial variability, whereas precipitation caused by upper level barometric lows is typically of low intensity and long duration.[3]

Abbott Creek, in the immediate vicinity of the study area, is a perennial stream only in the lower portion of the basin. It emerges at the extreme lower end of the Basin and flows for approximately 950 feet (380 m) before passing through a 4-foot H-flume. The stream is typically non-flashy and is characterized by low peaks and high sustained flow.

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[1] On file at Forestry Sciences Laboratory, Missoula, Mont.

[2] From Average Annual Mountain Precipitation, Montana Map (1953-1967 period).

[3] Personal communication with Bernie Burnham, Meteorologist, U. S. Department of Commerce, NOAA, National Weather Service, Missoula, Mont.

Treatments

The overall design of this study coupled three silvicultural systems with four residues treatments for a total of 12 treatment combinations. In addition, control plots were established in the uncut adjacent mature forest. All treatments and the controls were replicated twice.

The three silvicultural harvest-cutting systems (fig. 2) consisted of:

1. Two shelterwoods of 35 and 22 acres (14.2 and 8.9 ha) where about half of all standing timber was cut.
2. Two sets of eight group-selection cuttings (small clearcuts), averaging 0.8 acre (0.3 ha) and ranging from 0.3 to 1.4 acres (0.1 to 0.4 ha), where all standing timber was cut within each of the groups, and intervening timber between the groups was left uncut.
3. Two clearcuts of 14 and 17 acres (5.7 and 6.9 ha) where all standing timber was cut.

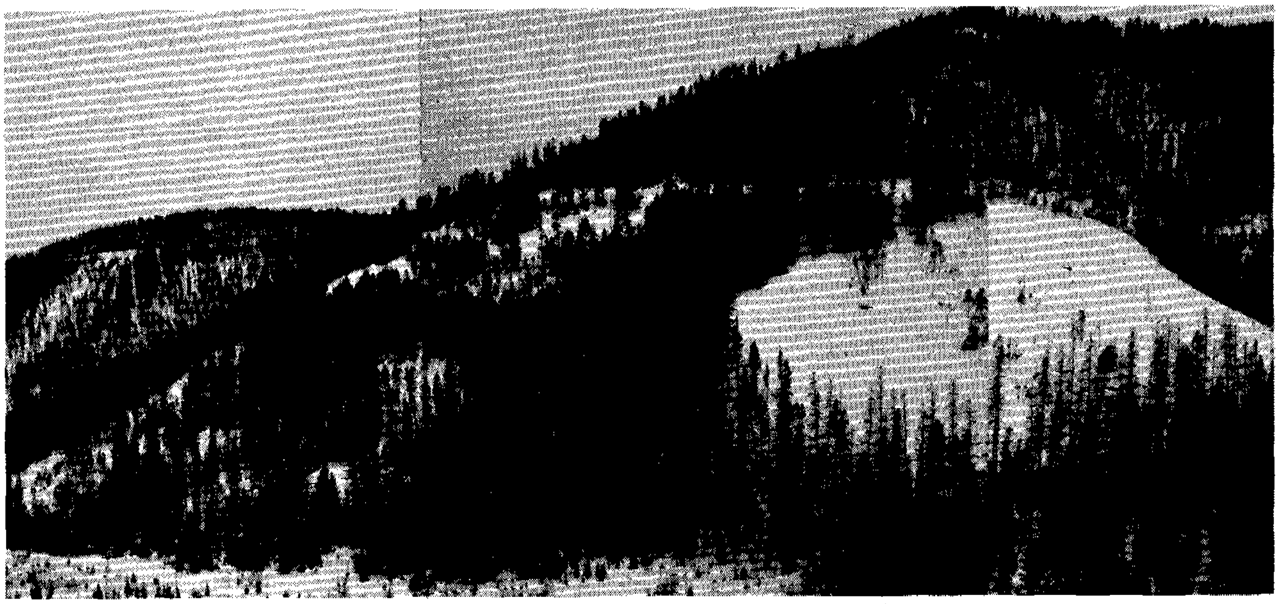


Figure 2.--Panorama of the larch/fir study site on Coram Experimental Forest. Shown are: (1) lower shelterwood at far left, (2) lower group selections at left center, (3) lower clearcut at lower right, and (4) upper shelterwood at upper right. Picture was taken the first winter after logging was completed.

The four residues utilization treatments consisted of:

	Treatment	Trees Cut	Harvest Utilization Standard	Subsequent Treatments
1.	Intensely utilized and broadcast burned.	All trees except designated overstory shelterwood trees.	Remove all material (live and dead, standing and down) to 7.6-cm (3-inch) small end diameter, 2.4-m (8-foot) in length, and 1/3 sound.	Broadcast Burned
2.	Conventionally utilized and broadcast burned.	All trees except designated overstory shelterwood trees.	Remove all sawtimber material (live and recently dead) to 1974 Forest Service standards: 17.8-cm (7-inch) d.b.h. and 15.2-cm (6-inch) top diameter, 2.4-m (8-foot) in length, and 1/3 sound.	Broadcast burned
3.	All residues removed (Intensive fiber utilization).	All trees except designated overstory shelterwood trees.	Remove all material (live and dead, standing and down) to 2.5-cm (1-inch) d.b.h.	None
4.	Understory trees protected (Understory trees under 17.8-cm (7-inches) d.b.h. were left uncut, but were subject to damage and loss during the cable logging process).	All trees 17.8-cm (7-inches) d.b.h. and over, except designated overstory shelterwood trees.	Remove all material (live and dead, standing and down) to 7.6-cm (3-inches) small-end diameter, 2.4-m (8-feet) in length, and 1/3 sound.	None

Cutting was completed in 1974 and the prescribed burns completed in the fall of 1975. All of the skidding was with a cable logging system--both uphill and downhill.

METHODS

All instrumentation was installed on or in close proximity to the immediate study site to measure harvesting and treatments effects. Off-site watershed information was not obtained except for streamflow and average annual precipitation. It is presented as background information for this study.

Precipitation

Both forms of precipitation were gathered continuously during the study (fig. 3). Precipitation quantity, duration and intensities were measured, but only quantity was evaluated. Rainfall events generally occurred between April 1 and November 1.

Figure 3.--Precipitation was measured throughout the study period on this and other all-weather continuous recording precipitation instruments.

RAIN

The major precipitation instrumentation consisted of five permanently located tipping bucket recording rain gauges and eight scattered Pacific rain cans. Tipping buckets were located at fully instrumented weather stations (fig. 1) in a lower uncut-control and group-selection unit, and in an upper clearcut and shelterwood unit. Their charts were checked daily and collected weekly.

Tipping bucket gauges provided the bulk of the precipitation data used in this study. Daily, monthly, and annual summaries were prepared by silvicultural treatment for comparative analysis. Rain can data served as a back-up to the mechanical recording devices, provided supplementary precipitation data for the unmonitored silvicultural and control treatments, and aided in the evaluation of individual storms. Pacific rain cans were set out seasonally in conjunction with the permanent stations and at eight other semi-permanent locations surrounding the study site. Each was checked weekly or after every major storm. A single snow gauge was used year round to record both rain and snow in a clearcut adjacent to study site.

SNOW

Twenty-six snow courses (fig. 1) were established within all silvicultural treatments and control areas to measure snow accumulation and melt, redistribution, elevational effects, and variability among and between silvicultural treatments, residue treatments, and control areas. Following logging snow course sample points were randomly selected, permanently marked, and remeasured.

Samples were taken monthly during accumulation and weekly during melt with a standard Federal snow sampler directly downhill from each snow course sample point. Both depth and water equivalent were recorded to the nearest 0.5 inch (1.3 cm). Condition of soil and duff under the snowpack were noted. Supplementary snow samples to evaluate residue treatments was performed about the first of April in 1977 and 1978 in the two clearcuts and shelterwoods by taking 30 samples within each residue treatment.

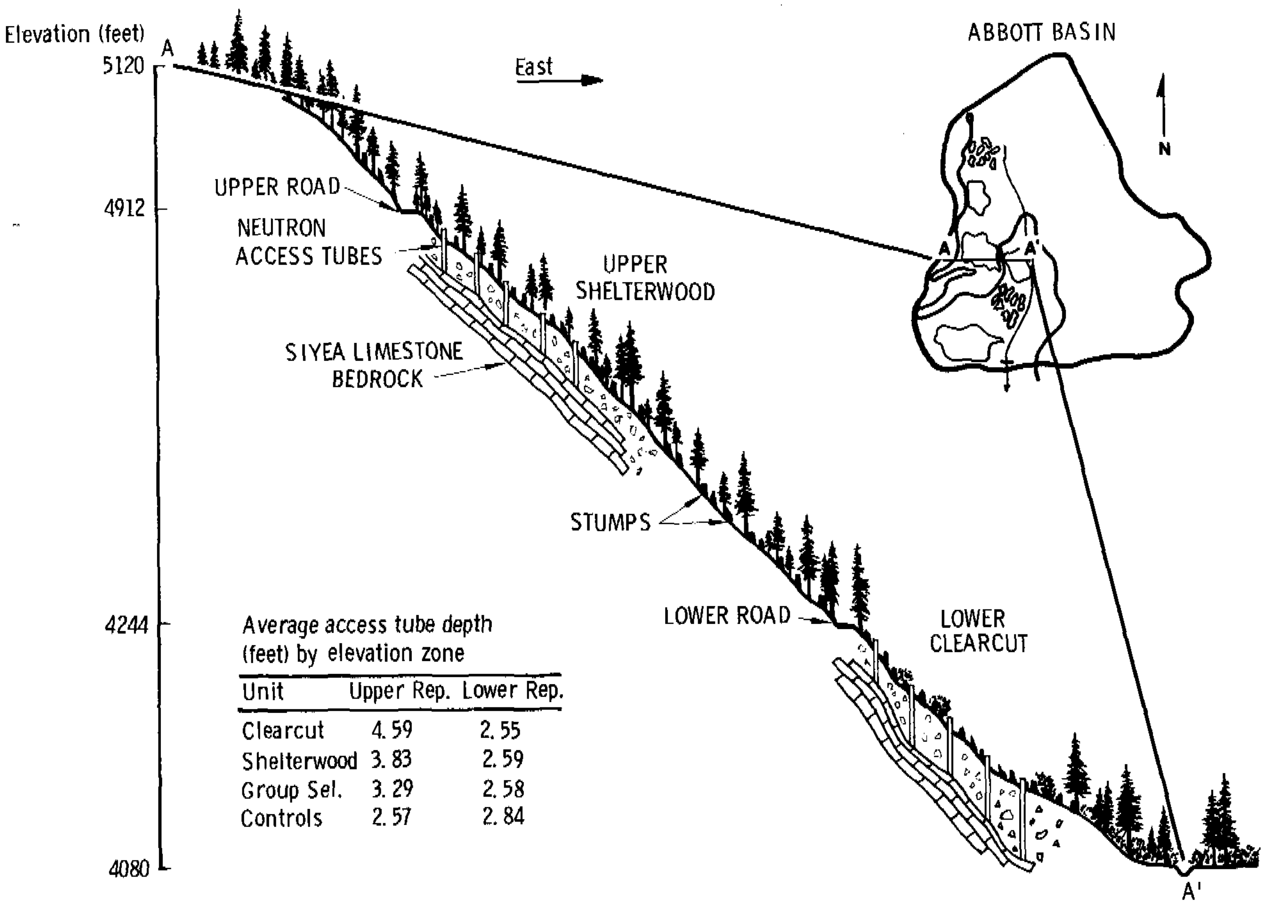
Eight snowmelt lysimeters (Haupt 1969) were installed to more precisely monitor silvicultural effects on snowmelt rates. Lysimeters were located within an upper and lower control area and each of the six silvicultural treatments at the same aspect and elevation in order to minimize treatment and climatic influences. The lysimeters were attended almost daily through the snow accumulation period and once or twice a day during intense melt periods.

Snow-water equivalent (inches) from the snow courses and lysimeters was used to calculate annual precipitation within the treatment areas and to estimate areal snow-water equivalent for silvicultural and residue treatments.

Soil Water

Before logging, 10 permanent points were systematically located at 100-foot (30.5-m) intervals within each of the four residues treatments in each of the clearcut and shelterwood cuttings and the control areas. Five points were located within each of the eight group-selection cuts (small clearcuts) at various intervals within the cutting, depending on the size of opening.

Half of these 280 permanently established points were randomly selected to measure soil water use with the neutron probe. Access tubes were installed in drilled holes at each of these points up to 10 feet (3.05 m) deep or to bedrock, as illustrated by figure 4. The resulting number of soil water sampling points were 5 per residue treatment, 20 per silvicultural treatment, and 10 per each control in each of the two replicates.



Average access tube depth (feet) by elevation zone

Unit	Upper Rep.	Lower Rep.
Clearcut	4.59	2.55
Shelterwood	3.83	2.59
Group Sel.	3.29	2.58
Controls	2.57	2.84

Figure 4.--Profile of the Coram study site, showing installation of neutron probe access tubes.

Measurements were made at 1-foot (30-cm) increments, starting at 0.5 foot (15 cm) below the soil surface, throughout the growing season (fig. 5). The neutron probe calibration curve was checked before and after each daily measurement with a set of tristandards.

Figure 5.--Soil water was measured with a neutron probe several times during each growing season.

Soil moisture loss by measurement period was determined for each residue treatment (5 points) and control (10 points) by the following procedure:

$$\frac{\text{Total loss (inches) at each point}}{\text{Soil depth at each point}} \times \text{Average soil depth}$$

Water Use

A simple water balance procedure was used to calculate consumptive water use during the growing season (May 1 to October 15) on all treatment areas and controls. The general equation that describes the process is:

$$\text{Consumptive Use} = \text{Input} \pm \Delta\ \text{Soil Moisture}$$

where Consumptive Use = evapotranspiration plus interception, Input = precipitation (measured in open areas as close to the site as possible); and Δ Soil Moisture = change in soil water within the profile as determined by a nuclear moisture gauge.

Although soil water may have passed through the root zone and mistakenly attributed to consumptive use, most moisture levels were already on the decline at the time of initial measurement in early spring. We assumed that no appreciable amounts of water were lost below the root zone after our first spring measurement.

A modified N.P.D.C. (Neutron Probe Data Conversion) computer program was used to compile total daily use for the measurements period.

Early and late season daily use rates, not covered by actual field measurement (heavy dashed lines in figure 6) were calculated in order to provide comparable use periods for each year. This procedure may cause consumptive water use to be overestimated as much as 0.5 inch (1.3 cm) per year. However, the errors in total use differences between residues treatments is very minor (between 0.1 and 0.2 inches [0.25 and 0.51 cm]) per year, well within the precision of this study. Due to insufficient daily use rate near the beginning of the 1975 growing season, total water use was not calculated for that year.

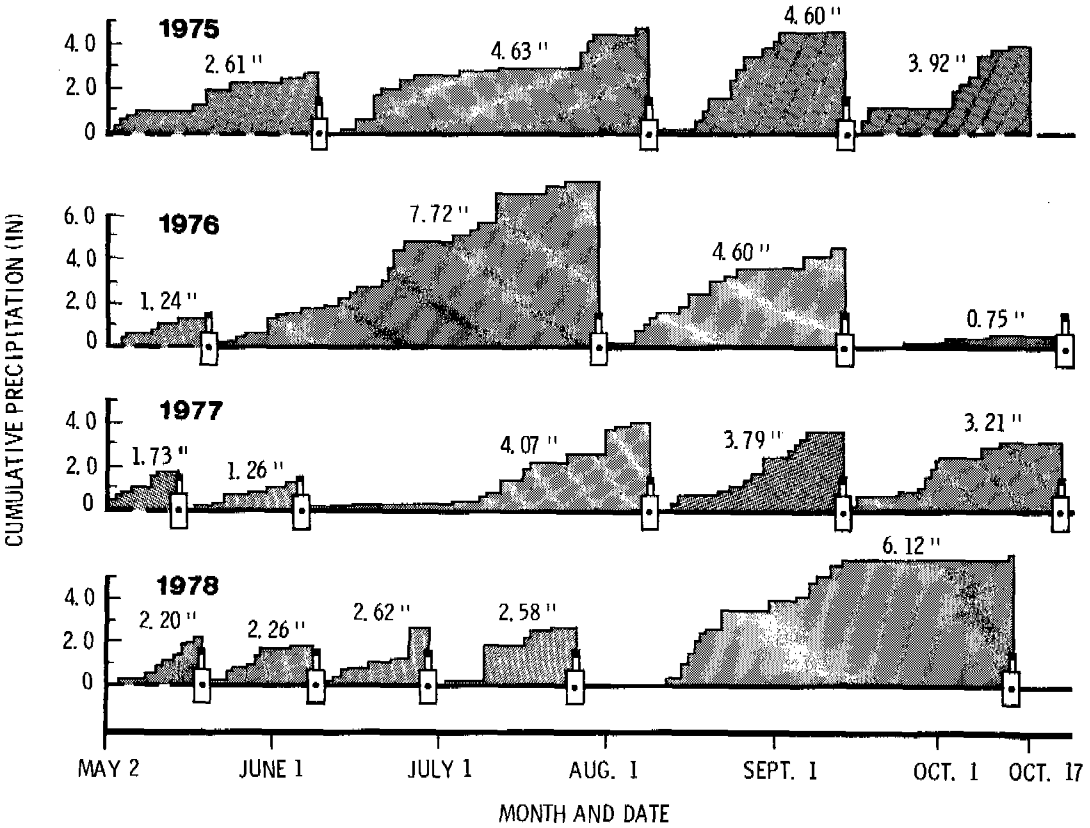


Figure 6.--Soil water measurement dates and cumulative precipitation for the measurement periods during the 1975 to 1978 growing seasons.

Streamflow

A 4-foot H-flume was installed immediately below the study area to provide general streamflow pattern and baseline hydrograph data for Abbott Basin on Coram Experimental Forest. The flume began operating at the beginning of the 1975 water year (October 1, 1974). This coincides with the completion of most of the treatments; thus no preharvest streamflow data was generated. The nature of the watershed did not permit differentiation of treatment effects, so effects, if detectable, would reflect only a composite of all treatments. Streamflow hydrograph data (appendix A) and general watershed parameters (appendix B) are presented as general reference material. These hydrographs are similar to some other northwestern Montana hydrographs (Montana DNR 1978).

RESULTS AND DISCUSSION

These results illustrate how silviculture and residues treatments differentially affect precipitation, soil water content, and amount and periodicity of water used during the growing season. Additional axillary relationships are also presented.

Precipitation

Annual precipitation on the immediate study site averaged about 5 percent below normal during the period of study compared to the 30-year average annual precipitation of 25.3 inches (64.3 cm) (USDA, SCS 1977). Precipitation averaged 24 inches (61.0 cm) (for both calendar year and water year), but varied annually between 29 inches (73.7 cm) during 1976, and 23 inches (58.4 cm) during 1977 (water year October 1 to September 30). About 50 percent of the total precipitation came in the form of snow.

SILVICULTURE TREATMENTS

Harvesting under the three silviculture treatments differentially reduced the density of the overwood, and consequently increased the amount of precipitation that reached the forest floor. However, these differences were also a function of storm size (intensity and duration) and elevation.

Rain

Precipitation reaching the forest floor was greatest on clearcuts and group selections, intermediate on shelterwoods, and least in the uncut mature forest (table 1). This, however, was directly related to rainfall per 24-hour period. As shown in table 1 and appendices C and D, storms that produced only 0.1 inch (0.25 cm) in the clearcut openings in a 24-hour period, resulted in only about one-third of it reaching the forest floor in the uncut mature forest and about three-fourths in the shelterwood. However, if the storm exceeded 0.5 inch (1.27 cm), two-thirds or more reached the forest floor in the mature forest and nearly 90 percent reached the floor in the shelterwoods. As indicated in table 1 and appendix D, the amount of interception "losses" was directly related to the standing tree volume. The prediction equations (precipitation in 0.01-inch [0.03-cm] increments) describing this relationship are:

$$\text{Rain reaching forest floor per 24-hour period in mature forest} = -0.03826 + 0.75019\,(\text{rainfall in clearcut})$$

$$r^2 = 0.99 \qquad s_E = 0.065$$

$$\text{Rain reaching forest floor per 24-hour period in shelterwood} = -0.01709 + 0.91103\,(\text{rainfall in clearcut})$$

$$r^2 = 0.98 \qquad s_E = 0.033$$

TABLE 1.--Rainfall reaching the forest floor as a function of silviculture treatment (including reserve stand volume) and storm size (rainfall per 24-hour period)[1]

Rainfall per 24-hour period			Percent of clearcut	
Clearcut	Shelterwood	Mature stand	Shelterwood	Mature stand
------------(Inches)------------			------------(Percent)------------	
0.100	0.074	0.037	74	37
.300	.256	.187	85	62
.500	.438	.337	88	67
.700	.626	.487	89	70
.900	.803	.637	89	71

---

[1] Standing green timber served as the principal interception on the study area; and cubic volume averaged:

	$feet^3$/acre	M^3/ha
Clearcut	15	1
Shelterwood	1799	126
Mature Forest	4047	283

Snow

Silvicultural treatments dramatically affected snow accumulation, particularly in the upper elevation replicates where snow played a very important role (fig. 7). Snow accounted for about 50 percent of the total precipitation during this study. Based on the snow water equivalent on April 1, the following tabulation displays the marked effect of treatments when compared to the uncut mature forest:

	Increase over the Mature Forest	
Treatment	Upper Replicate	Lower Replicate
	------------(Percent)------------	
Clearcut	83	73
Group Selection	50	14
Shelterwood	42	50

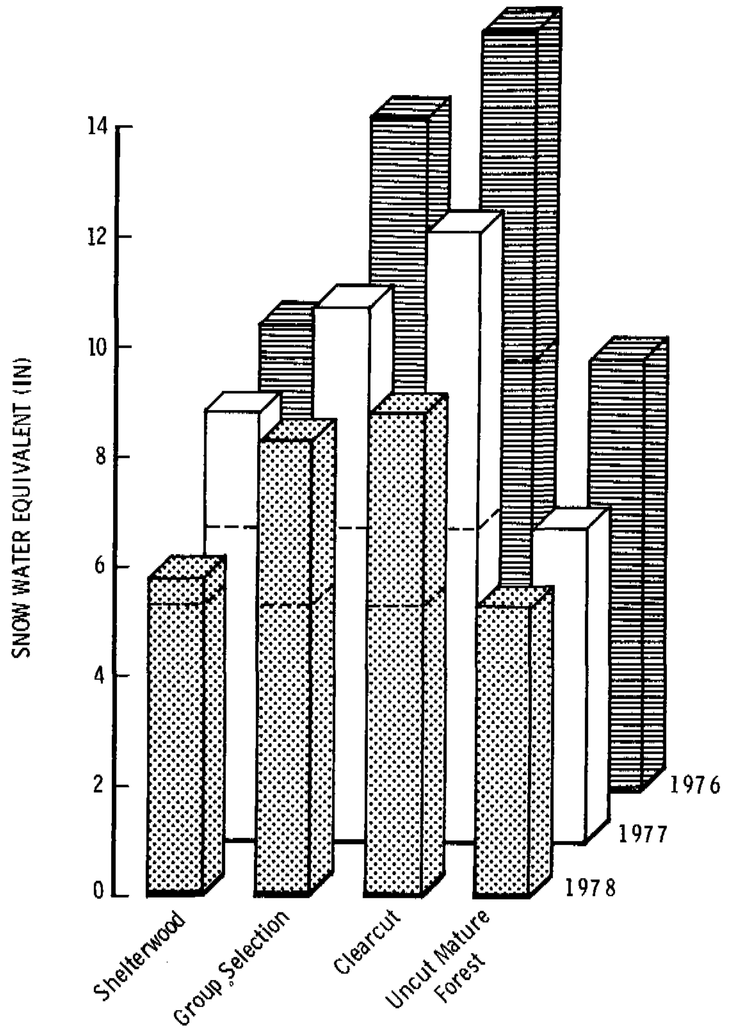


Figure 7.--Snow water equivalent on April 1 of the upper elevation replicate, by silviculture treatment.

Even though the relative differences of snow accumulation on the various treatments are much the same on the upper and lower elevation replicates, the absolute differences by elevation are substantial. However, data for the lower replicate, particularly on the group selections, were more variable than the upper replicate, possibly due to variations in exposure and the earlier melt that normally occurs on the lower replicate (fig. 8).

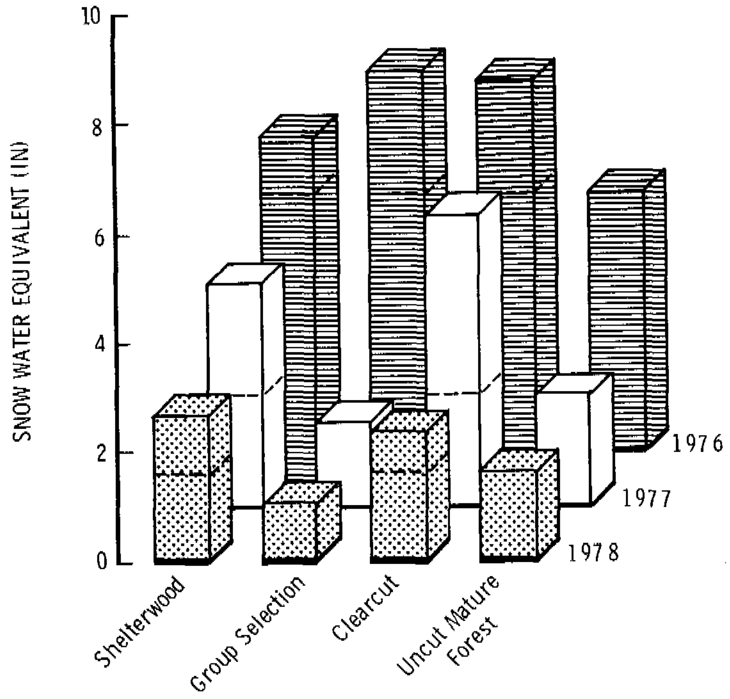


Figure 8.--Snow water equivalent on April 1 of the lower elevation replicate, by silviculture treatment.

RESIDUE TREATMENTS

Rain

We have no data to show how residues treatment affects the amount of rain reaching the forest floor. However, we would expect the understory-protected treatment to intercept slightly more rainfall than other treatments and thus reduce the amount reaching the floor.

Snow

No differences in snow accumulation or melt could be attributed to residue treatment effects. Snow accumulated about equally on all residue treatments within each silvicultural treatment. Elevation and aspect were probably responsible for more variation in snow accumulation and melt than were the individual residue treatments.

Soil Water

Water present in the soil at any given time was a function primarily of silvicultural treatment and seasonal meteorological events. Silvicultural treatments affected soil water status more than residue treatments. Soil water content under the uncut-mature stands generally started the growing season with about 30 percent water (based on volume) but dropped to about 12 percent each year at the low point (fig. 9). Although depleted to about the same moisture percentage every year, the time that these low levels were reached varied by year, reaching the lowest points as early as mid-July and as late as mid-October.

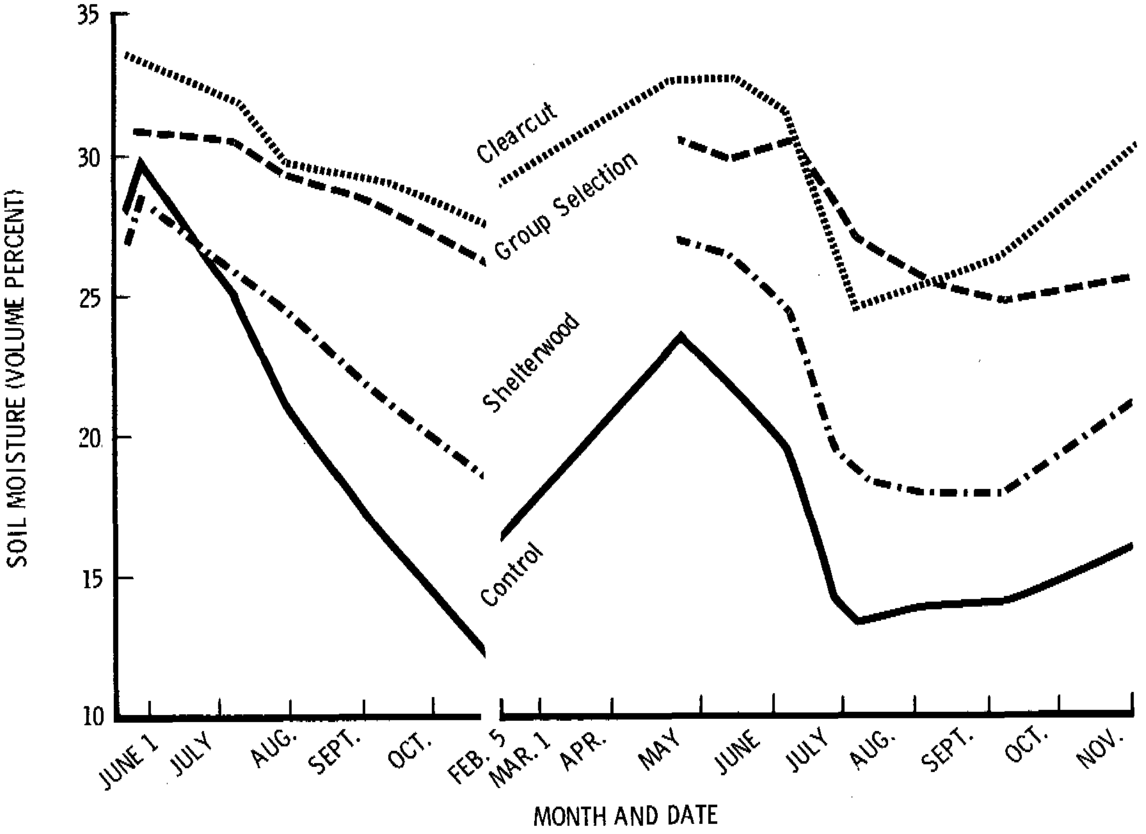


Figure 9.--Average soil moisture found in the soil profile in the uncut mature forest and the shelterwood, group-selection, and clearcut silviculture treatments.

As shown in figure 10, soil water status was relatively stable in the lower soil profiles and more erratic in the upper profiles. Of course, the upper profiles were responding to precipitation as well as intensive water consumption by the lower vegetation. Since vegetative demand for water was high at the beginning of the growing season, and soil moisture was below field capacity, little if any precipitation passed through the upper soil profile before it was extracted by the vegetation.

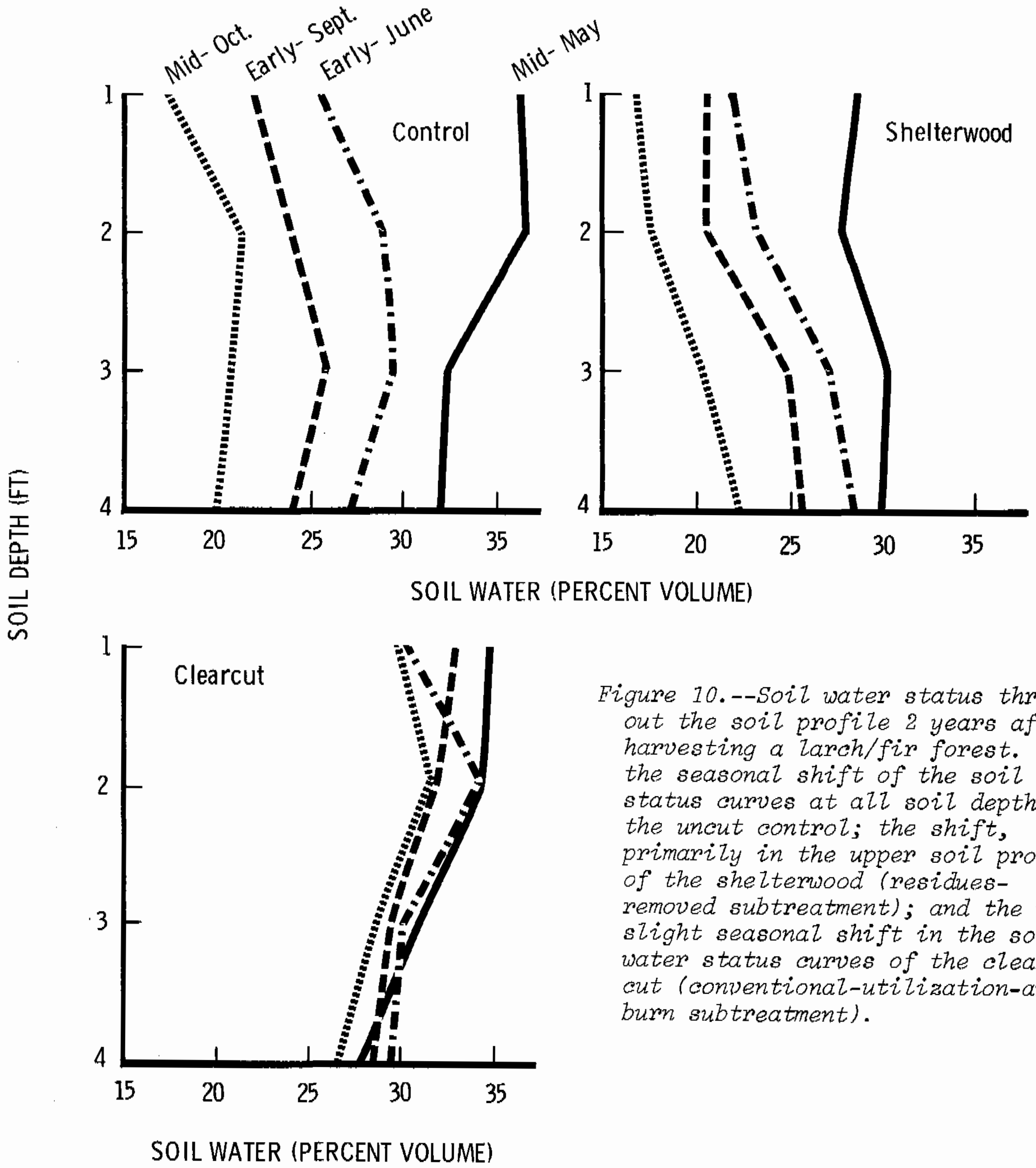


Figure 10.--Soil water status throughout the soil profile 2 years after harvesting a larch/fir forest. Note the seasonal shift of the soil water status curves at all soil depths in the uncut control; the shift, primarily in the upper soil profile, of the shelterwood (residues-removed subtreatment); and the very slight seasonal shift in the soil water status curves of the clearcut (conventional-utilization-and-burn subtreatment).

SILVICULTURE TREATMENTS

Silvicultural treatments produced the most differences in soil moisture levels, as illustrated in figure 9. Differences were generally most apparent at the end of the growing season. Clearcuts retained the highest percentage of moisture and the uncut-mature stands the lowest percentage. Soil moisture levels in shelterwood and group-selection treatments ranged between these two extremes. For the 3-year period, the clearcut, group-selection, and shelterwood treatments averaged 14, 8, and 5 percent more soil moisture than in the mature forest at the end of the growing season in the lower elevation replicate and 9, 11, and 2 percent more, respectively, in the upper replicate. More precipitation was received in the upper replicate, which decreased soil moisture deficits.

Snowmelt recharged the soils under all treatments to about their same respective levels each year, with the exception of the spring of 1977. This year, the uncut-control areas failed to reach full recharge by roughly 1.7 inches (4.3 cm) of water. Soil moisture levels in the fall of 1976 were about normal, but a below average snowpack that winter failed to produce enough water to overcome the fall deficit in the uncut controls (fig. 9). The harvested areas came into winter with less of a deficit than the controls; the snowpack, even though below normal, was adequate to recharge those profiles. For example, at the end of the 1976 growing season, soils under the uncut-control stands needed 5.4 inches (13.7 cm) to reach recharge while those in the shelterwood and clearcut needed 4.1 and 2.6 inches (10.4 and 6.6 cm), respectively. Another contributing factor discussed earlier was increased snow accumulation in the clearcuts, group selections, and shelterwoods in relation to the mature forest--a result of redistribution.

RESIDUES TREATMENTS

No consistent trends or differences in soil water status, could be attributed solely to the various residue treatments.

Water Use

The uncut mature larch/fir forest within the study area used about 75 percent of the 24-inch (61-cm) average annual on-site precipitation. Water use within the treatments was nearly always less than that of the uncut forest but varied substantially by treatment and year. A detailed summary of water use by silvicultural and residue treatment for 3 years of the study are presented in appendix E.

SILVICULTURAL TREATMENTS

Of the silviculture treatments, the shelterwoods ranked as the highest water user, followed by the group selections, and then the clearcuts (fig. 11). During the 3 years of complete measurements (1976, 1977, 1978) shelterwoods on the average used 4 percent less water than the uncut forest, group selections 10 percent less, and clearcuts 11 percent less.

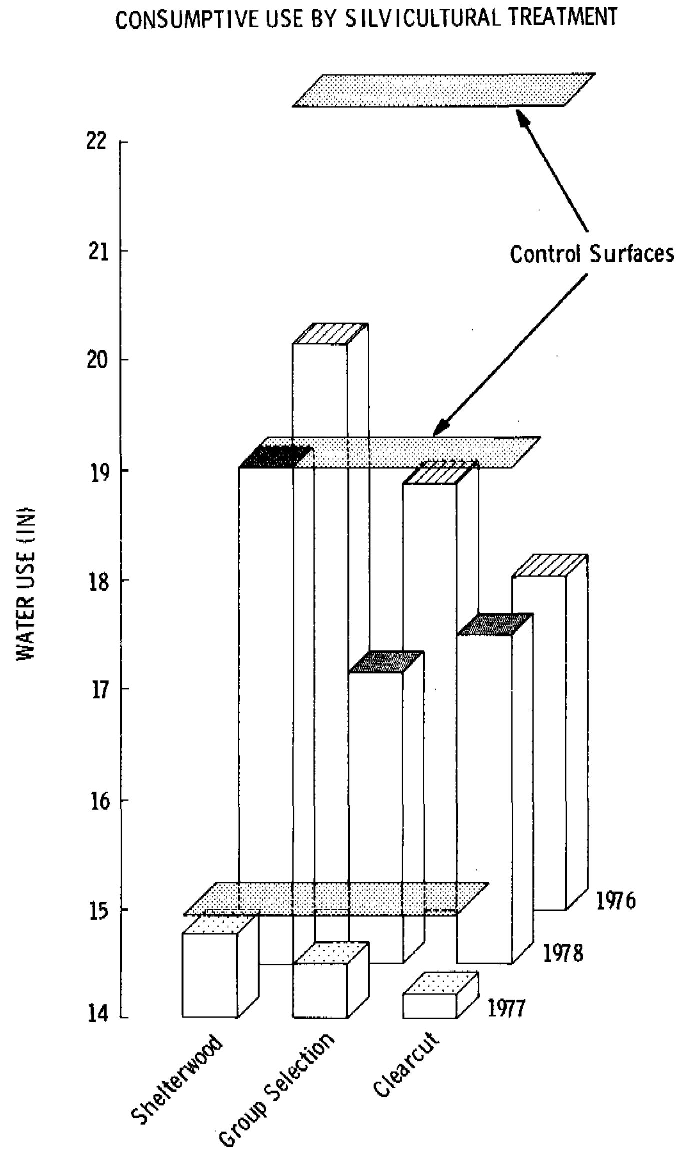


Figure 11.--Average water use on areas treated with three silvicultural methods, the second, third, and fourth year after harvesting was completed.

As indicated in figure 11 and appendix E, the relative amounts of water used by the different treatments remained about the same during the second, third, and fourth year after the harvesting was completed. However, the magnitude of the differences declined during that period. In the second year (1976) after harvesting, the clearcuts used 18 percent less water than the controls, the group selections 14 percent less, and the shelterwoods 8 percent less. By the fourth year (1978), these differences had declined to 9, 11, and 1 percent, respectively. Of course, during that same period, understory vegetation had begun its rapid recovery and was demanding substantial amounts of water (Schmidt 1980).

Accumulative water use curves for the different silvicultural treatments paralleled each other early in the growing season, but became increasingly divergent as the season progressed (fig. 12). Very little difference in accumulative use was apparent between the three silvicultural treatments until late July, but the uncut mature forest areas diverged early in the growing season. Concurrent with water use divergence was the beginning of significant water use from the lower end of the soil profiles. Heavy frequent rains are common in June, but July and August are normally hot and dry in this area.

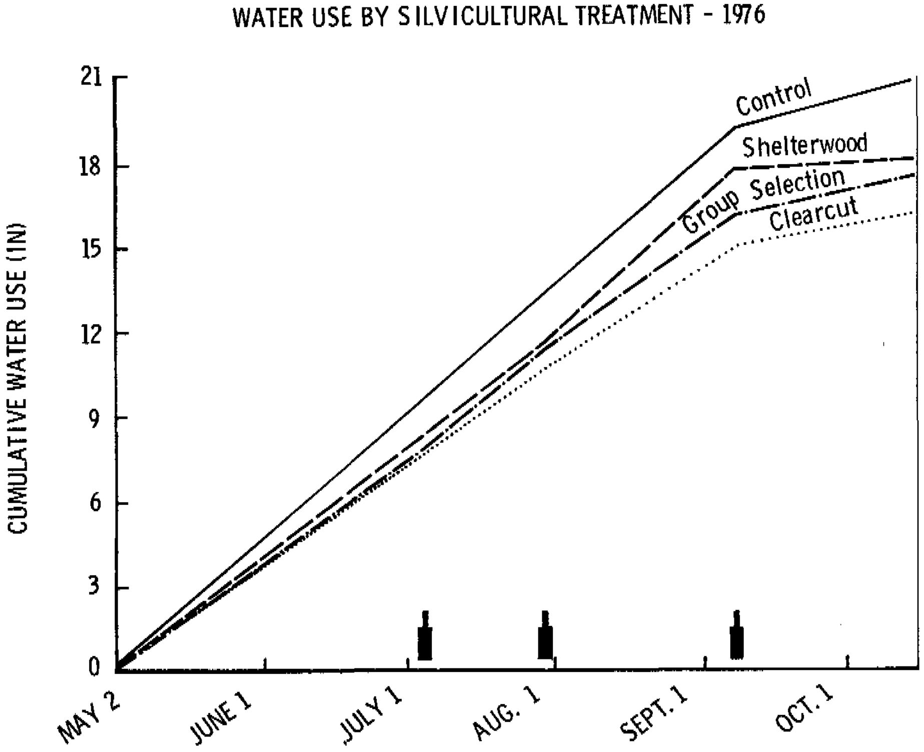


Figure 12.--Accumulative water use during the growing season on areas with differing silvicultural treatments, 2 years after harvesting was completed.

The differences shown between the treatments and the controls (uncut mature forest) are conservative. Actual differences under regular management would probably be greater for several reasons. A limited amount of preharvest water use data indicated that preharvest water use differences existed on some of the sites. For example, the uncut mature forest on the area later harvested for a shelterwood, was using more water than its corresponding control. The soils on the control of one of the replicates were shallower and consequently a smaller total water reservoir was available for evapotranspiration. Our controls (uncut mature forest) probably were not fully independent of the treatments, and as a result had less total water available. We had more snow in harvested areas than in controls and we must assume that it came from redistribution of snow from adjacent uncut forests where our controls were located. As the summer depletion proceeded, the heavily vegetated areas extracted the readily available water, but as water became in short supply, evapotranspiration and soil water use diminished. When the soil water supply exceeded the demand (water not limited), such as in 1976, our water use data reflected the ability of the on-site vegetation to use water. The dry season of 1977 resulted in about 18 percent or 3.2 inches (8.1 cm) less water use than the 1976 and 1978 averages, demonstrating the effects of water deficits (fig. 11).

RESIDUE TREATMENTS

Water use on the four residue-treatment areas lined up as expected when data from all silvicultural treatments are combined (fig. 13). When water use is ranked most to least, the understory-protected treatment used the most, followed by the residues removed, intensive utilization and burned, and conventional utilization and burned. Average use difference between the heaviest (understory-protected) and lightest (conventional-utilization-and-burned) users was about 1.7 inches (4.3 cm) or about 10 percent for the 3 years of measurement.

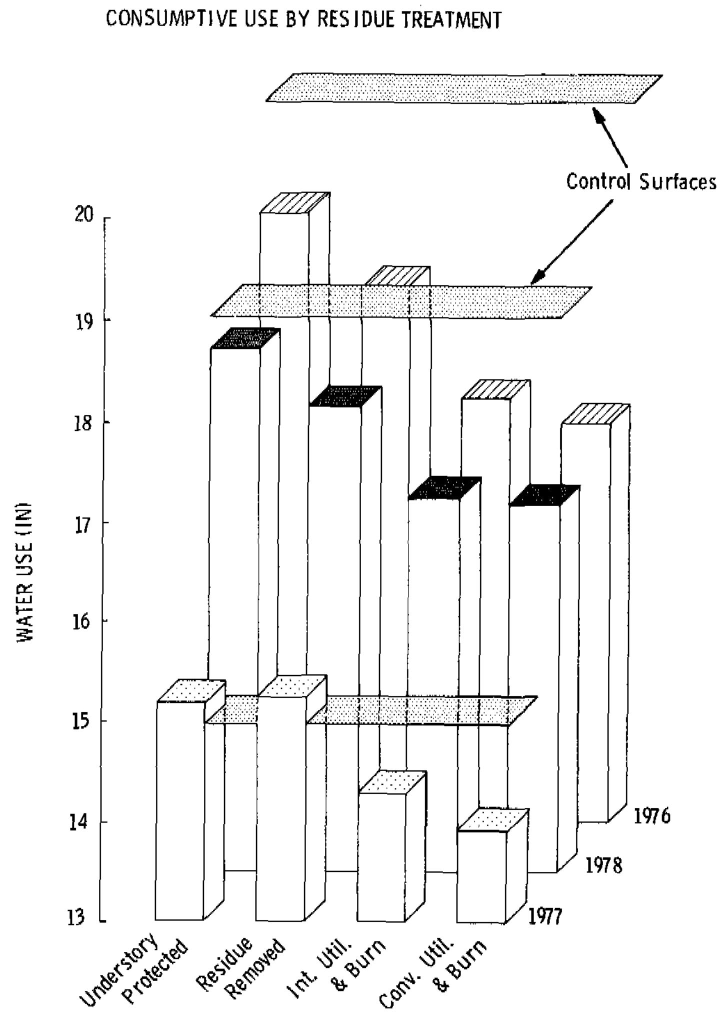


Figure 13.--Water use as affected by residues treatments (combining all silviculture treatments) 2, 3, and 4 years after harvesting a larch/Douglas-fir forest.

The most consistent difference in water use was between the two burned and two unburned treatments. Differences between burned and unburned treatments averaged 1.4 inches (3.6 cm) the second year after harvesting (the first year after burning), but differences had decreased to 1.1 inches (2.8 cm) by the fourth year (1978). Percentagewise, these differences averaged 7 and 6 percent, respectively, (appendix D).

Silviculture treatment effects on water use tended to overshadow residue treatment effects. Figures 14, 15, 16, and 17 demonstrate the water use patterns when all treatment combinations are shown together for the second, third, and fourth years after harvesting.

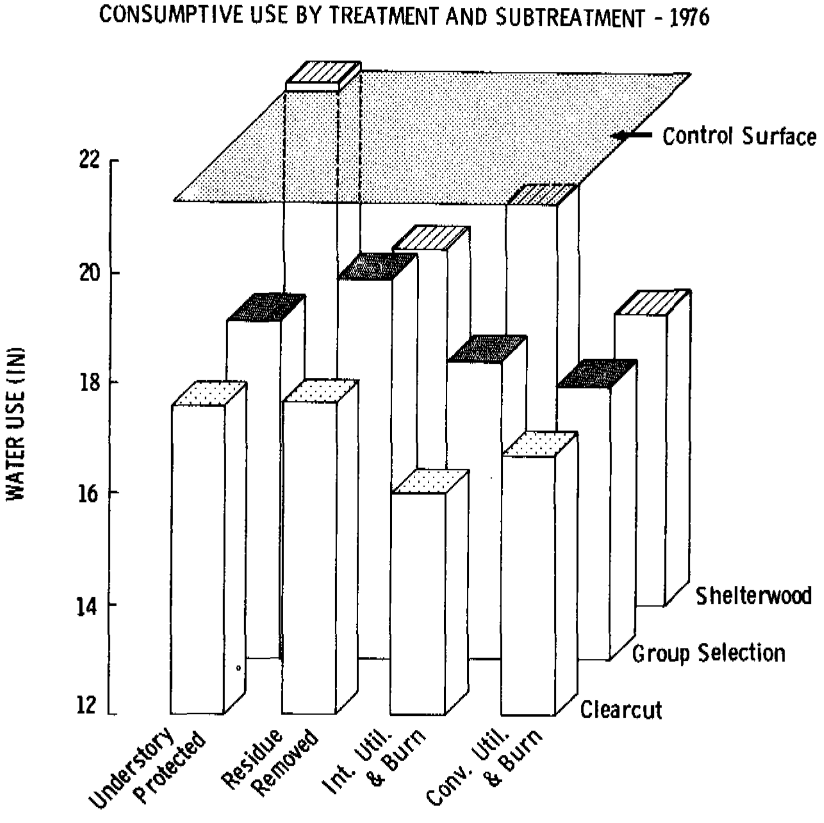


Figure 14.--Water use following the 12 silviculture and residues treatment combinations 2 years after harvesting.

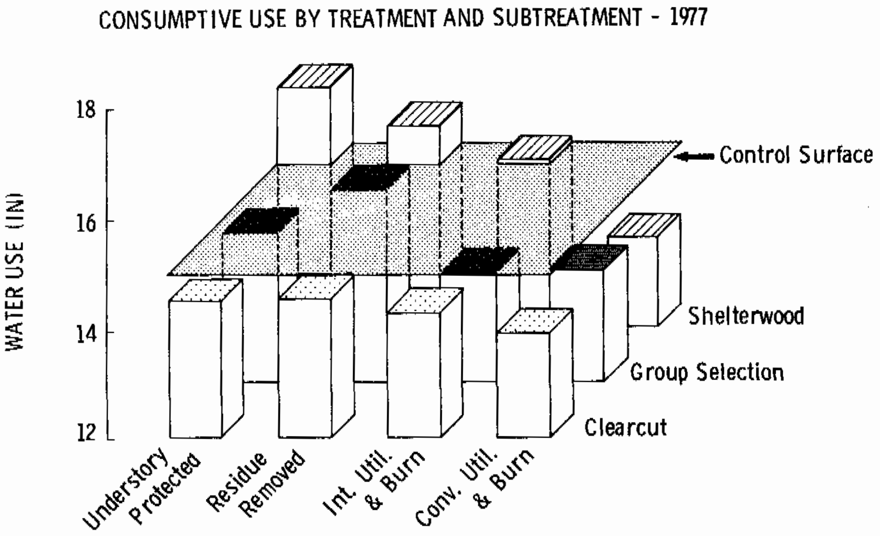


Figure 15.--Water use following the 12 silviculture and residues treatment combinations 3 years after harvesting.

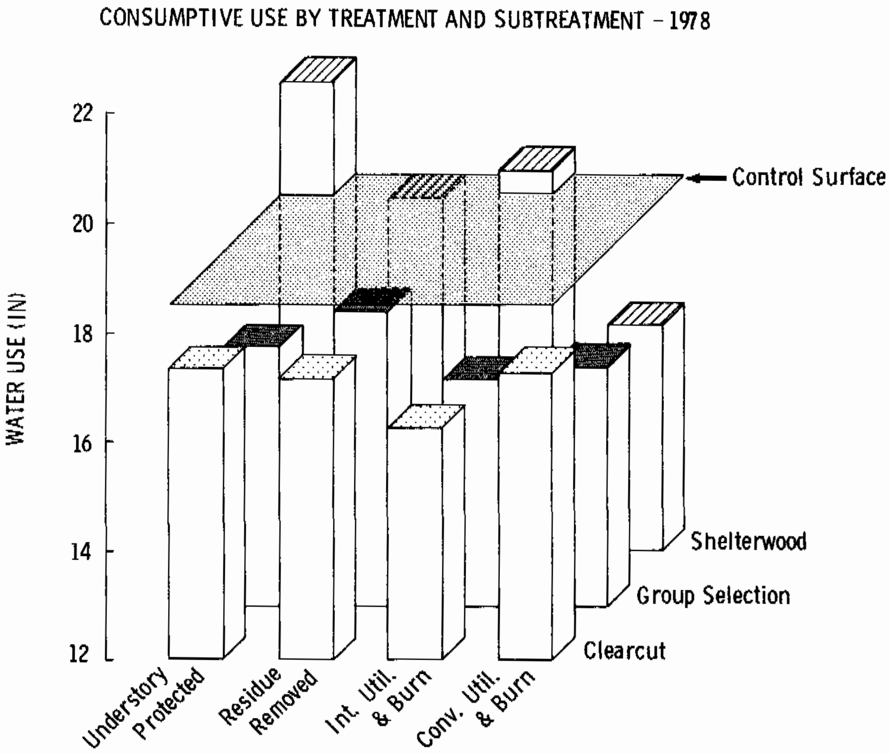


Figure 16.--Water use following the 12 silviculture and residues treatment combinations 4 years after harvesting.

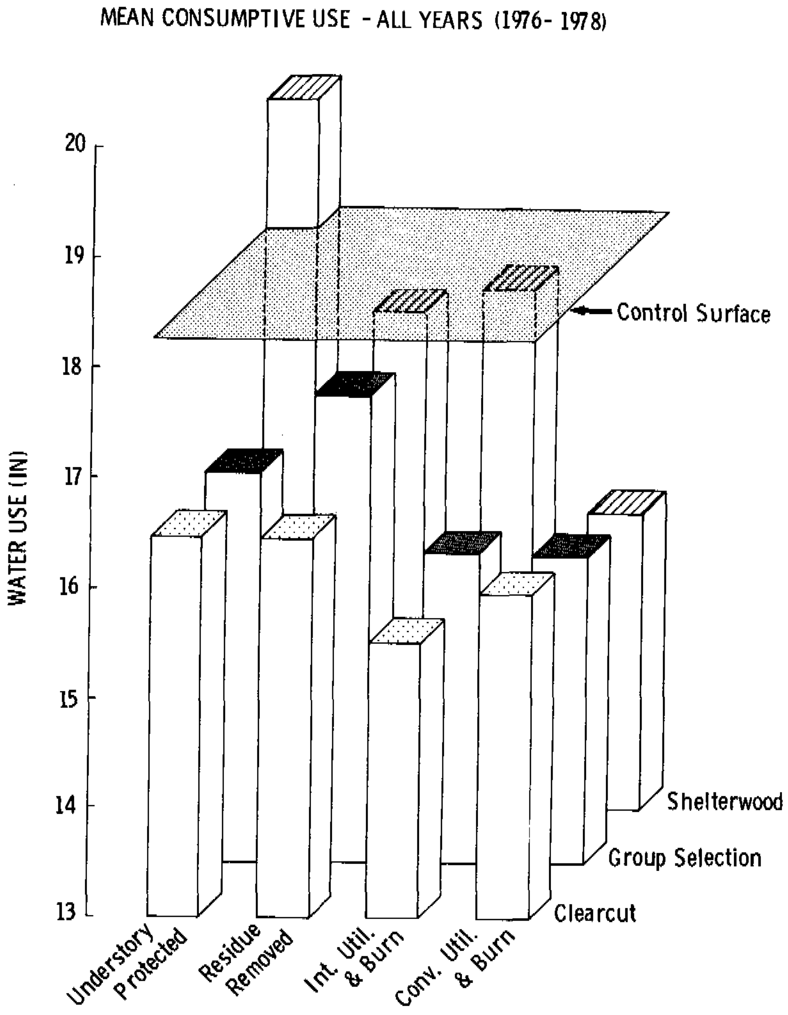


Figure 17.--Water use summary for the second through the fourth year after the 12 silviculture and residues treatments were imposed in a larch/fir forest.

The most conspicuous water user is the understory-protected treatment in the shelterwood. It consistently used more water than the uncut-control areas. The differences became even more conspicuous as the study progressed. However, this same understory-protected treatment was little different than the other residue treatments on the group selections and clearcuts. As it turned out, although there was a determined effort to save the understory trees and shrubs in this treatment, only in the shelterwood was this accomplished very effectively. This is shown in the analysis of the understory vegetation of these treatments (Schmidt 1980). These water use data correspond to the understory-vegetation measurements--the greater the residual understory vegetation, the greater the water use.

The residue-removed treatment ranked second in water use, but this was most obvious on the clearcuts and group-selection cuttings. This corresponds directly with the dramatic increase in herbs and small shrubs on this same combination of treatments and the lack of this low-vegetation response on the residues-removed/shelterwood treatment combination (Schmidt 1980). Although this treatment consistently used more water than its two burned counterparts, the differences averaged only about 6 percent or 1.0 inches (2.5 cm) during the study period (appendix E).

There were no substantial differences in water use between the two burned treatments on the group selections and clearcuts where broadcast burning was reasonably consistent. However, on the shelterwood treatment, more water was used on the intensive utilization and burn than on the conventional utilization and burn. This may be related to the cooler burning on the intensive utilization and burn (Artley and others 1978; Schmidt 1980). However, caution is in order because only the upper replicate shelterwood data are used here--the lower replicate shelterwood was not burned.

WATER USE PATTERNS

Water use began early in the season, peaked around mid-July, and tapered off more rapidly than it had begun. Figure 18 illustrates an average daily water use envelope that encompasses the range of water use by all treatments evaluated in this study. As indicated in this envelope, daily use maximums in mid-July peaked at nearly 0.16 inches (0.4 cm) and the minimums peaked at about 0.10 inches (0.25 cm). As expected, the uncut controls were in the upper layer of the daily use envelope and the burned treatments on the clearcuts and group selections were found in the lower layer of the use envelope.

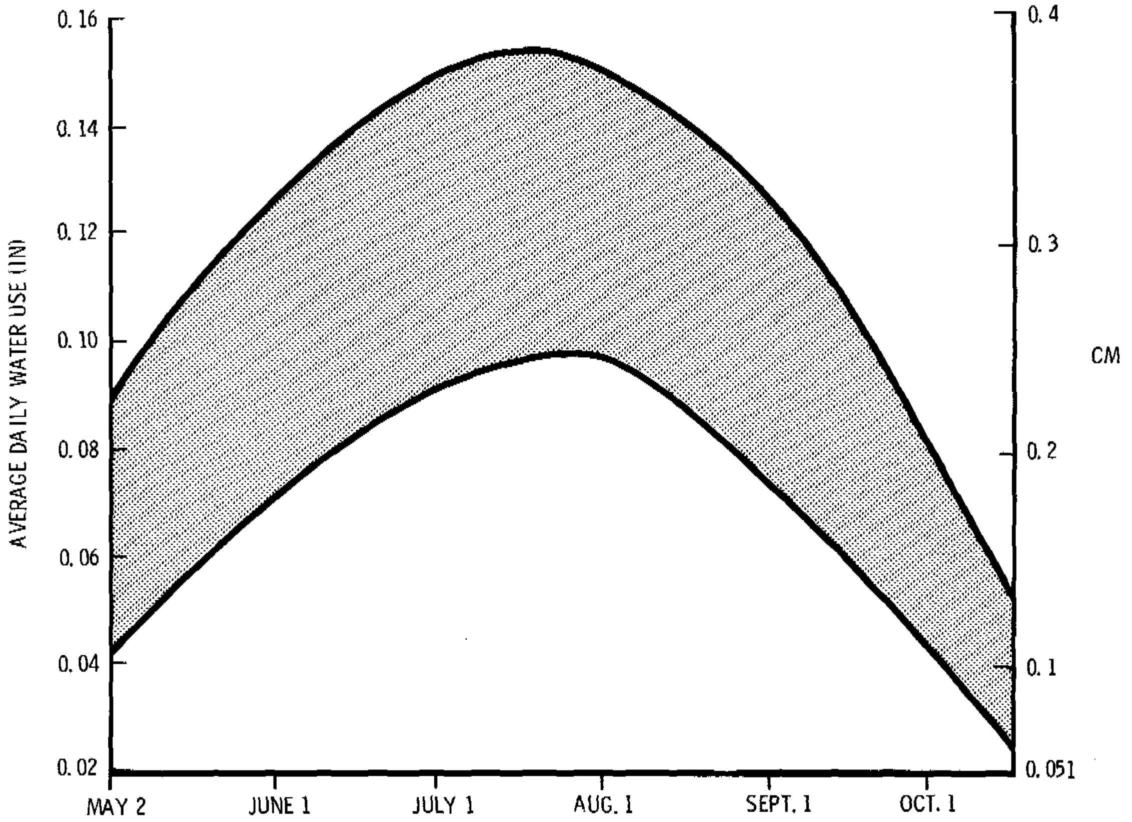


Figure 18.--Average daily water use envelope during the growing season encompassing a range of silviculture residue treatment combinations in a larch/fir forest.

Lowest daily water use occurred at the end of the growing season (previously defined as May 2 to October 17) when soil moisture was at its seasonal low and the frost had already taken its toll of the herbs and shrubs. Interestingly, the understory-protected treatments of both clearcuts were the lowest water users at the end of the growing season, yet were high mid-season users.

The most predictable and least variable use patterns were displayed by the residues-removed treatment followed by the conventional-utilization-and-burn and the understory-protected treatments.

The greatest variation in daily water use occurred consistently in mid-July on all replicates and treatments. Both upper and lower clearcuts consistently demonstrated the greatest variability in the pattern of water use. This observation is consistent with the range in treatment diversity that resulted from the imposition of silvicultural and residue treatment combinations.

The trends shown in this study are in agreement with Tew (1967), Johnston and others (1969), and Zeimer (1964). They found that the period of greatest water use occurred early in the growing season and that average daily water use decreased as availability of moisture decreased. Tew (1967) reported that 4.7 inches (12 cm) was used from May 25 to July 13 while 1.2 inches (3 cm) was used from July 13 to September 22. Evapotranspiration data from two sagebrush watersheds in northwest and south-central Wyoming (Sturges 1979) also fits very nicely in the lower third of the daily use envelope that we developed in this study (fig. 15). Rich and Thompson (1974) listed average daily evapotranspiration rates for some mixed conifer species in different localities. All but three of the rates listed are easily encompassed within our envelope.

Daily and annual consumptive use rates are being governed by many factors. Kovner (1956) suggests that evapotranspiration opportunity is usually related to extent of cover on an area rather than its character. Cline (1974) related soil moisture loss during the growing season to not only degree of occupancy and type of vegetation existing on a site, but also aspect and the resulting potential evapotranspiration for a particular site. Cline and others (1977) reported that on a south slope, invading shrub species rapidly reoccupied the soil mantle, and after 4 years, the shrub monoculture probably extracted more water from the soil during the extremely dry summer than did the original stand. Effects of slope and aspect on solar radiation and subsequent water consumption are also discussed by Cline and others (1977) as well as Lee (1964, 1967) and Douglass (1967), and are believed to play a major role in regulating consumptive use. Stearns and Carlson (1960) found that soil moisture correlated best with soil temperature, evaporation-pan data, and solar radiation.

Streamflow

There were no noticable departures from expected values in either peak flow or base flow of Abbott Creek. The probable reasons for this are: (1) there were no preharvest streamflow data for making comparisons, (2) the watershed is not a closed system, (3) the hydrologic and geologic divides do not coincide, and (4) the equivalent clearcut area was only 5 percent of the gauged watershed.

The chemistry of Abbott Creek (at the flume) was not significantly changed according to Stark (1979, 1980).

Other information concerning the Abbott Creek watershed appears in appendix A and B. It is presented primarily to document streamflow pattern in this drainage and geographic area.

SUMMARY AND CONCLUSIONS

This report has mainly been devoted to describing the combined effects of conventional silviculture treatments and different residues management treatments on water input, status, and amount and pattern of use during the growing season in a larch/fir forest. Basic hydrological relationships will be examined in more detail in subsequent reports. We feel the important findings in this study were:

1. Silviculture treatments affected the amount of rain and snow that reached the forest floor. In the case of rain, these differences were substantial with the small rain storms (< 0.2 inch [0.5 cm] per 24-hour period) and relatively minor with the larger storms. For example, about a third of a 0.1-inch (0.25-cm) rain storm reached the forest floor in the uncut mature forest and about three-fourths reached it in the shelterwoods. Differences were directly related to amount of standing timber and the interception it provided. In the case of snow, differences were due to redistribution of snow. For both rain and snow, the most water reached the forest floor in clearcuts and group selections, a moderate amount reached it in shelterwoods, and the least reached it in the uncut mature forest.

2. Soils were generally fully charged with water at the beginning of the growing season under all treatments (exception: the uncut mature forest did not fully recharge during one winter). Soil water gradually decreased during the growing season--first in the upper soil profile and later in the lower profiles--and reached its lowest point (about 12 percent) in September and October. However, the low point varied by year and silviculture treatment. Soil water content was relatively stable in the lower profiles, but more erratic near the soil surface in response to precipitation and rapid use.

3. The mature larch/fir forests used about three-fourths of the annual precipitation (24 inches [61 cm]) on the study area. All silviculturally treated areas used less water than the uncut mature forest. Of the three silviculture treatments, clearcuts used the least water, group selections a moderate amount, and shelterwoods the most--18, 14, and 8 percent less, respectively, than the uncut forest the second year after harvesting. These differences diminished the next 2 years, but averaged 11, 10, and 4 percent, respectively, for the entire study period.

4. Of the residues-management treatments, the understory-protected treatment was the biggest water user. It was followed by the residues-removed treatment and the lowest users--the two burned treatments. These water use data corresponded to the amount and type of understory vegetation growing on the treated areas--the more vegetation, the greater the water use. In the understory-protected treatment, particularly under the shelterwoods, far more residual trees and shrubs survived logging than in other treatments. The residues-removed treatment resulted in a substantial increase in the herbaceous and small shrub components. The two burned treatments set vegetation back substantially for this study period, but it was rapidly recuperating and its water use can be expected to increase.

5. Present trends indicate that treatment related differences in on-site water use, in relation to the uncut mature forest, will be relatively short-lived. The increasing water use on all treatments, the parallel rapid revegetation, and the differences in effective precipitation on the treatments point in that direction. This trend is likely accelerated on this particular study site where treatments are in close proximity and there are opportunities for snow redistribution.

6. Water use began in April, accelerated, peaked in July, and rapidly decelerated after that. Maximum daily use approached 0.2 inch (0.5 cm) in mid-July. Most soil water use was in upper soil profiles early in the growing season, but this use gradually moved downward as the growing season progressed.

7. Although speculative at this time, it appears that water use differences due to silviculture and residues treatments will be relatively minor as early as 10 years after treatment under conditions similar to those in this study. Understory vegetation in larch/fir forests recovers rapidly and apparently ameliorates differential treatment effects on water use.

8. It appears that under conditions similar to those found in this study, at least 10 percent of a drainage could be clearcut or 20 percent selectively cut with no stream channel degradation from increased peak flows.

9. Snow redistribution between uncut and harvested areas can be expected to continue for a long period, possibly as long as 50 to 75 years. However, redistribution will gradually decline as the new stand of trees approaches the height of the adjacent uncut forest.

10. Soil moisture appears to be the primary limiting factor for vegetative growth in larch/fir forests growing on soils similar in depth and character, and comparable precipitation regimes, as those in this study area. Soil water is efficiently extracted throughout the soil profile where vegetation fully occupies the site.

ACKNOWLEDGMENTS

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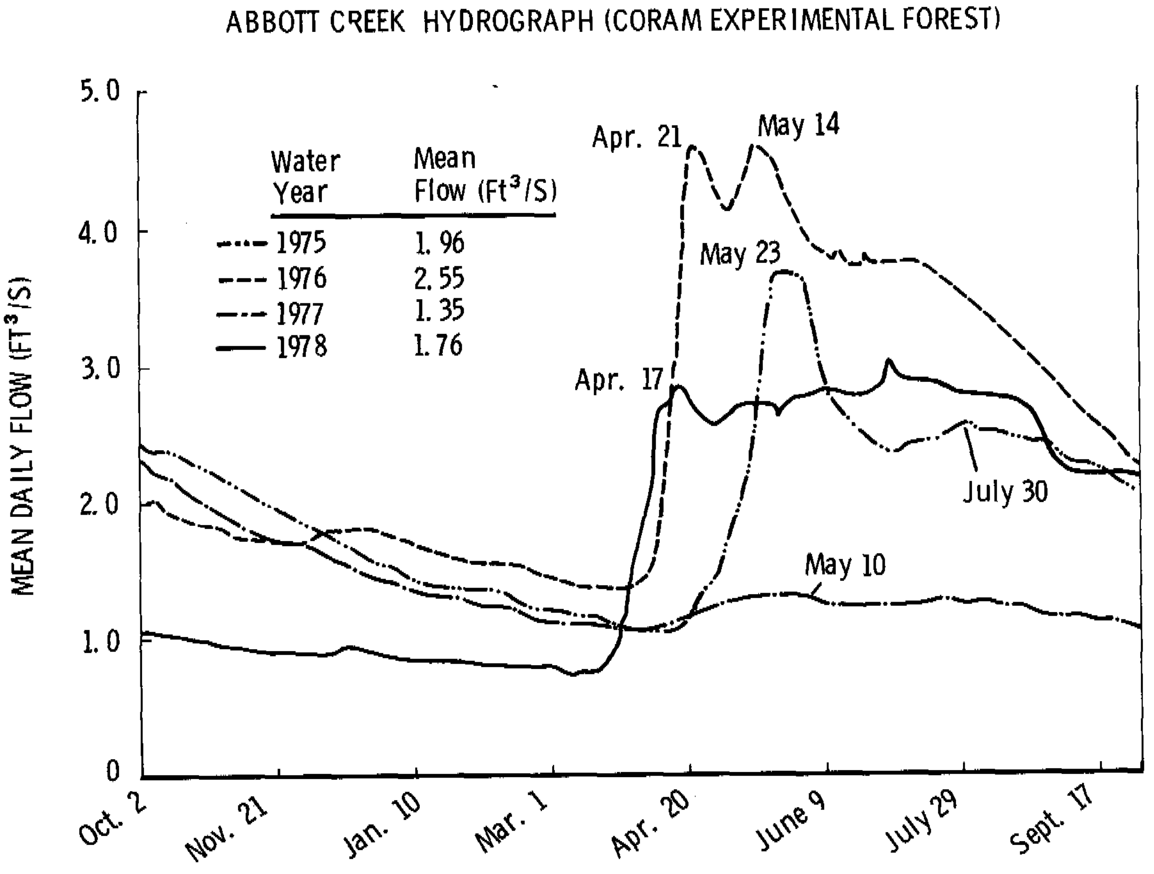
APPENDICES

Appendix A.--Hydrograph for Abbott Creek on Coram Experimental Forest--1975 to 1978.



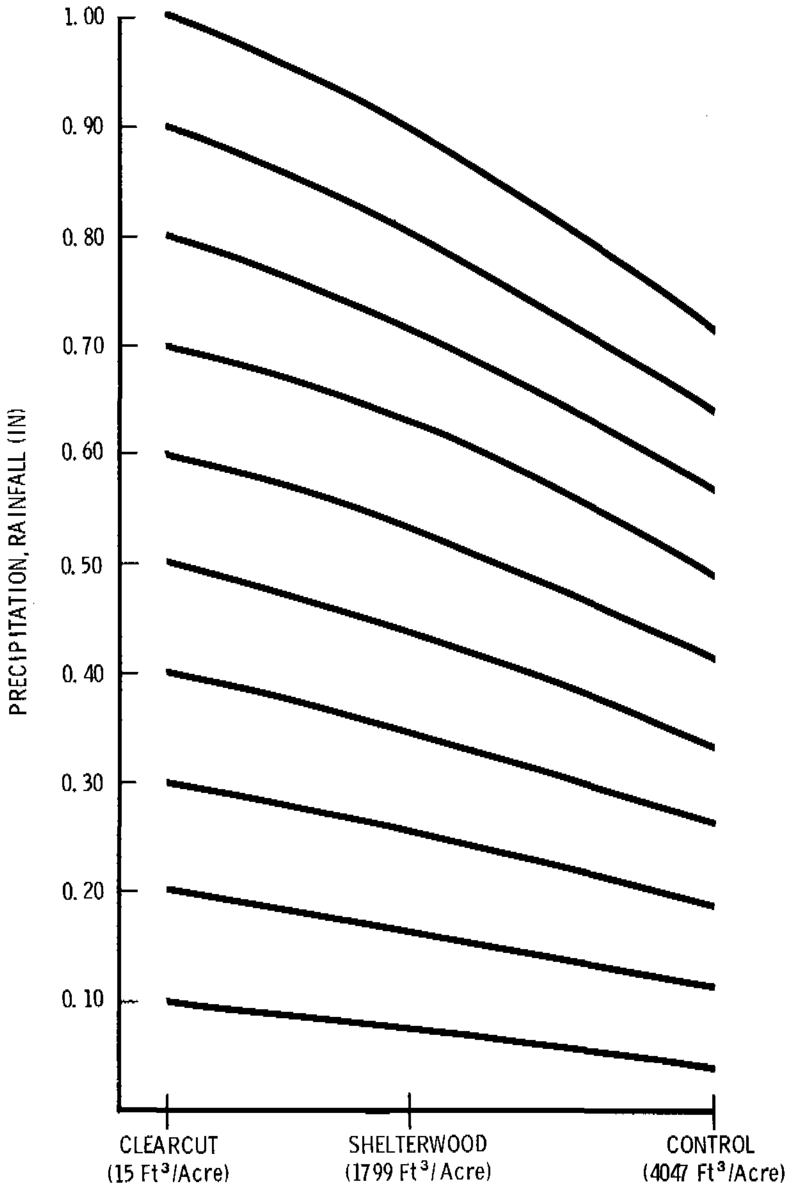
Appendix B.--Characteristics of Abbott Basin watershed and study site on Coram Experimental Forest.

Gauged watershed	1,116 acres (452 ha)
Study area (E. Aspect)	368 acres (149 ha)
Area harvested	100 acres (40 ha)
Study area as percentage of gauged watershed	33 percent
Harvested area as percentage of gauged watershed	9 percent
Equivalent clearcut area as percentage of gauged watershed	5 percent
Aspect of study area	East
Mean elevation	
Lower replicate	4,310 feet (1 314 m)
Upper replicate	5,030 feet (1 533 m)
Mean basin temp.	42° F (5.5° C)
Average annual precipitation - watershed (1955-67)	35 inches (89 cm)
Average annual precipitation - study site (1975-78)	25 inches (64 cm)
Average annual runoff - calculated (1953-67)	14 inches (36 cm)
Average annual runoff - measured (1975-78)	15 inches (38 cm)

Appendix C.--Rainfall reaching the soil as a function of silviculture treatment and rainfall per day in a larch/fir forest.

Rainfall per 24-hour period			Percent of clearcut		Percent of mature stand	
Clearcut	Shelterwood	Mature stand	Shelterwood	Mature stand	Clearcut	Shelterwood
(Inches)			(Percent)			
0.10	0.074	0.037	74	37	270	135
.20	.165	.112	82	56	179	122
.30	.256	.187	85	62	160	118
.40	.347	.262	87	66	153	115
.50	.438	.337	88	67	148	114
.60	.529	.412	88	69	146	114
.70	.626	.487	89	70	144	112
.80	.712	.562	89	70	142	112
.90	.803	.637	89	71	141	112
1.00	.894	.712	89	71	140	112

Appendix D.--The relationship of total rainfall per 24-hour period to the amount of rain reaching the forest floor in clearcuts, shelterwoods, and uncut mature forests (with corresponding stand cubic volumes).



Appendix E.--Water use during the growing seasons (May 1 to October 15) of 1976 to 1978 by silviculture and residue treatments.

Year	Intensive Utilization and Burn[1]	Conventional Utilization and Burn[1]	Residue Removed	Understory Protected	Uncut Mature Forest Control	Average
	-----------------	-----------------	---(Inches)---	-----------------	-----------------	-----------------
1976						
Clearcut	16.0	16.8	17.7	17.6	-	17.0
Shelterwood	19.2	17.4	18.4	21.4	-	19.1
Group selection	17.4	17.0	18.9	18.2	-	17.9
Control	-	-	-	-	20.8	-
Average	17.5	17.1	18.3	19.1	20.8	-
1977						
Clearcut	14.2	13.9	14.5	14.5	-	14.3
Shelterwood	15.0	13.7	15.7	16.4	-	15.2
Group selection	14.0	14.0	15.5	14.7	-	14.6
Control	-	-	-	-	15.0	-
Average	14.4	13.9	15.2	15.2	15.0	-
1978						
Clearcut	16.3	17.2	17.2	17.3	-	17.0
Shelterwood	19.0	16.2	18.4	20.6	-	18.6
Group selection	16.1	16.4	17.3	16.8	-	16.7
Control	-	-	-	-	18.7	-
Average	17.1	16.6	17.6	18.2	18.7	-
All Years						
Clearcut	15.5	16.0	16.4	16.5	-	16.1
Shelterwood	17.7	15.8	17.5	19.5	-	17.6
Group selection	15.8	15.8	17.2	16.6	-	16.4
Control	-	-	-	-	18.3	-
Average	16.3	15.9	17.0	17.5	18.3	-

[1] The lower shelterwood was not burned and data from these plots are not included in this summary.

LOGGING RESIDUE DISPOSAL EFFECTS ON SURFACE HYDROLOGY AND SOIL STABILITY OF LODGEPOLE PINE FORESTS

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ABSTRACT

In the high-elevation lodgepole pine forests of western Wyoming, the most effective logging residue disposal treatment in terms of surface runoff and erosion control is chipping the residue and respreading it as a protective mulch. This treatment has serious disadvantages--almost complete suppression of vegetation and elimination of natural lodgepole pine reproduction. The most adverse soil and vegetative characteristics, the poorest surface runoff and erosion control, and the slowest watershed recovery occur where logging residue has been dozer piled and burned. Chipping and removing the chips is a superior treatment for watershed protection, but its practicality is contingent upon a market for chips or small timber products. Broadcast burning remains the most effective residue treatment in terms of protection of soil and vegetal characteristics, control of surface runoff and soil erosion, and rapidity of watershed recovery following logging.

KEYWORDS: lodgepole pine, logging residue disposal, dozer-piling, broadcast burning, soil stability

One of the most efficient methods of harvesting mature or overmature lodgepole pine and regenerating the new forest is clearcutting, followed by the disposal of logging residue, and then by natural or artificial seeding, or planting. Most commercial lodgepole pine forests earmarked for timber production do not respond well to partial cutting. One reason is the intolerance of young lodgepole pine to shade; another is damage of new forest growth by dwarf mistletoe infection from remaining overstory trees.

In clearcut forests, the soil and vegetative characteristics that influence the hydrologic stability of the forest floor can be altered drastically, especially if logging residue is piled and burned. One immediate effect of this treatment is the baring of soil surfaces between windrows of residue, thereby making these surfaces vulnerable to the impacts of water erosion.

Results of a recent study on eight harvest units and four unlogged units of a larch/Douglas fir forest in western Montana show that tractor logging produces changes in soil and vegetative characteristics that improve the hydrology and soil stability of the forest floor. The study also shows that broadcast burning of the logging residue exerted effects on these soil and vegetative characteristics that are detrimental for runoff and erosion control. However, the moderate degree of runoff and soil erosion hazard and its brief duration indicates that this treatment is probably not permanently damaging to these watersheds (Packer and Williams, 1976).

The extent to which these conclusions apply where lodgepole pine forests on similar (gently sloping) terrain are clearcut and the logging residue is either piled and burned, broadcast burned, chipped and respread on site, or chipped and hauled away, is not known and needs investigation. This paper describes the immediate, two-year and four-year effects of these residue disposal treatments on lodgepole pine forest watersheds in western Wyoming.

STUDY AREA AND METHODS

In the summer and autumn of 1971, four 20-acre tracts of lodgepole pine in the Union Pass area of the Bridger-Teton National Forest were clearcut. Each of these tracts was divided into four 5-acre blocks and different logging residue disposal treatments were applied. On two of the tracts half of the logging residue was disposed of by dozer-piling into windrows that were burned. The other half of the residue was broadcast-burned. Logging residue on the other two tracts was chipped. The chips were respread uniformly on the forest floor on half of the blocks in these two tracts and removed completely from the other half.

Although the harvesting of timber from these tracts was completed in the fall of 1971, the windrowed residue was not burned until the fall of 1972 and the broadcast residue was not burned until the summer of 1973. The chips were spread on the blocks designated for that treatment in early summer of 1973. Lodgepole pine planting and seeding was completed by July 1973.

Three sets of 60 rainfall-simulating infiltrometer plots were established on the study areas, one set each in 1973, 1975, and 1977. Within each set of plots, 48 were located on the four clearcut tracts and 12 in adjacent unlogged forest. Twelve of the 48 plots on the clearcut tracts were located on each tract, three on each of the four blocks comprising each tract. This study design facilitated evaluation of the effects of the different logging residue disposal treatments on soil and vegetal characteristics, overland flow and soil stability behavior. The design also provided means for comparing such behavior on logged and unlogged forest land.

Except for a one-time measurement of soil particle-size distribution, all soil and vegetal characteristics were measured on all plots each year. Bulk densities of the 0-1 inch and 1-2 inch depths of the soil mantle were determined from replicated volume-weight soil cores taken at random locations within the plots. Total pore space was determined from tension-table measurements on the soil bulk density cores. Soil particle size distribution was determined from one-third of the composited bulk soil samples taken from the 0-1 inch and 1-2 inch depths of the soil mantle at random locations within each plot. Water-stable aggregate distribution was determined from another one-third of the composited bulk soil samples, and soil organic matter content was determined from the remaining one-third. Vegetal characteristics, consisting of live plant cover density, litter cover density, logging debris cover density, rock cover density, ash cover density, depth of chips, and size of bare soil openings were measured with a point analyzer on 100 points established on transects within each plot.

A rainfall simulator was used to apply water to each infiltrometer plot at a constant rate of 3.26 inches per hour for 30 minutes. Runoff from trough rain gages was collected at 5-minute intervals to provide a record of rainfall amounts and intensities. Plot runoff, including both water and eroded soil, was caught at 5-minute intervals and recorded. This discharge was retained as part of the total runoff and eroded material from each plot.

LOGGING AND RESIDUE TREATMENT EFFECTS

Both the logging and residue disposal treatments significantly influenced soil and vegetative characteristics and altered surface runoff and erosion behavior.

Effects on Soil Properties

BULK DENSITY

The effects of residue treatments on bulk density of the surface 2-inches of soil are shown in figure 1. The highest bulk density in 1973 occurred on the blocks where chips were spread over the surface. These higher bulk densities were caused by compaction from tractors used to spread the chips.

The next highest bulk densities occurred between windrows on blocks where the logging residue was dozer piled and burned. These bulk densities also are related to tractor compaction.

Four years later, in 1977, the highest bulk densities were between windrows on blocks where the logging residue was dozer piled and burned. The lowest bulk densities were found on control plots in unlogged areas adjacent to the clearcut tracts.

In general, between 1973 and 1977, soil bulk densities improved on the blocks where chips were respread and also on the blocks where chips were picked up and removed. In contrast, soil bulk densities on sites from which residue had been removed by dozer piling failed to recover or improve.

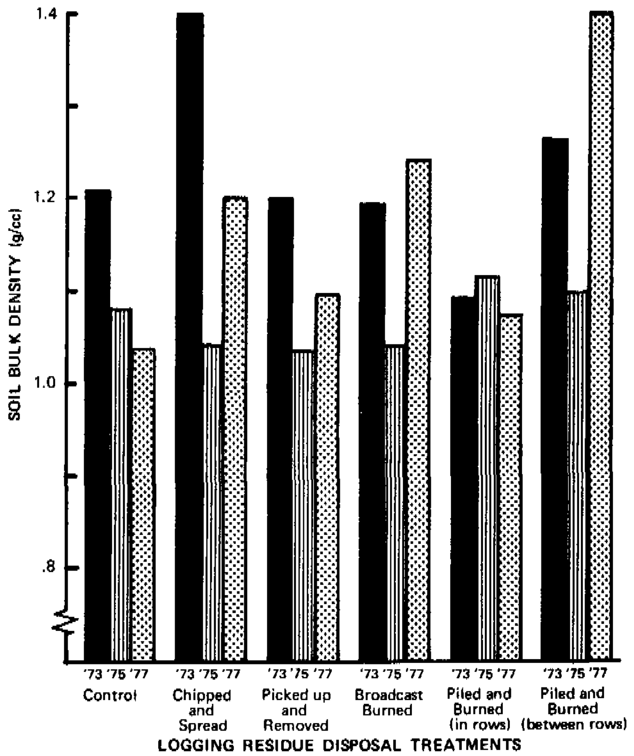

Figure 1.--Bulk density of the surface 2-inches of soil associated with various residue treatments on lodgepole pine clearcuts.

TOTAL POROSITY

The effects of the residue treatments on total porosity of the surface 2-inches of soil are shown in figure 2. In 1973 the lowest (poorest) soil porosity occurred on blocks where the residue was chipped and respread. These, of course, were the sites having the highest bulk densities. Similarly, the next lowest soil porosity occurred on sites having the second highest bulk densities, namely, where the residue was removed by dozer-piling.

By 1977, soil porosity on those sites where chips had been respread had improved substantially. On the other hand, the lowest porosity occurred on sites from which residue had been removed by dozer-piling.

Between 1973 and 1977, no significant changes occurred in the soil porosity on blocks where the residue had been picked up for chipping but not respread, on broadcast-burned blocks, or beneath the burned windrows on dozer piled blocks. By 1977, the highest soil porosity was encountered in the adjacent unlogged forest areas where the bulk density was lowest.

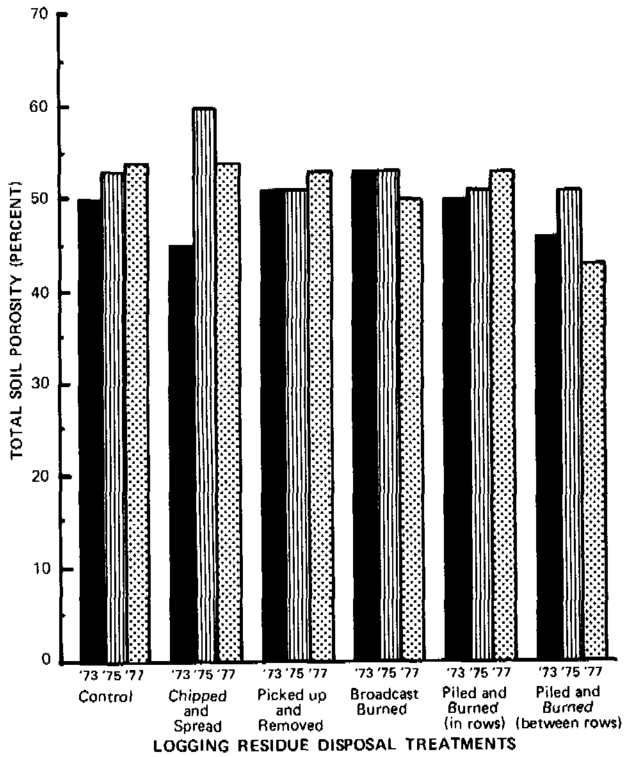

Figure 2.--Total porosity of the surface 2-inches of soil associated with various residue treatments on lodgepole pine clearcuts.

ORGANIC MATTER CONTENT

The effects of the residue treatments on organic matter content of the surface 2-inches of soil are shown in figure 3. In 1973, the organic matter content of the soil ranged from about 5 percent to 8 percent. In 1975, the highest organic matter content, 12 percent, was measured on sites where residues were picked up for chipping but not respread. This increased level of organic matter is believed to be due to the incorporation of fine residue, such as pine needles, into the soil during logging operations and the subsequent removal of residue for chipping. By 1977, these finer organic components had disappeared, principally through oxidation, and the organic matter content had decreased to about 6 percent.

In both 1975 and 1977, the highest organic matter content, nearly 11 percent, occurred on sites where the logging residue had been chipped and respread. The lowest organic matter content in these years occurred beneath dozer piled and burned windrows. The destruction of organic matter near the soil surface by burning the large concentrations of residue in windrows probably accounts for these low levels of organic matter.

In 1977, the second lowest level of organic matter occurred on sites from which residues were removed by dozer-piling. If a grading blade is used on a bulldozer to windrow or pile logging residue, a substantial amount of the surface soil can be scraped off and added to the windrows or piles. Significantly, during the 4-year period from 1973 to 1977, organic matter content of the surface 2-inches of the soil mantle increased where the residue treatments did not involve burning and decreased where burning was part of the disposal treatment.

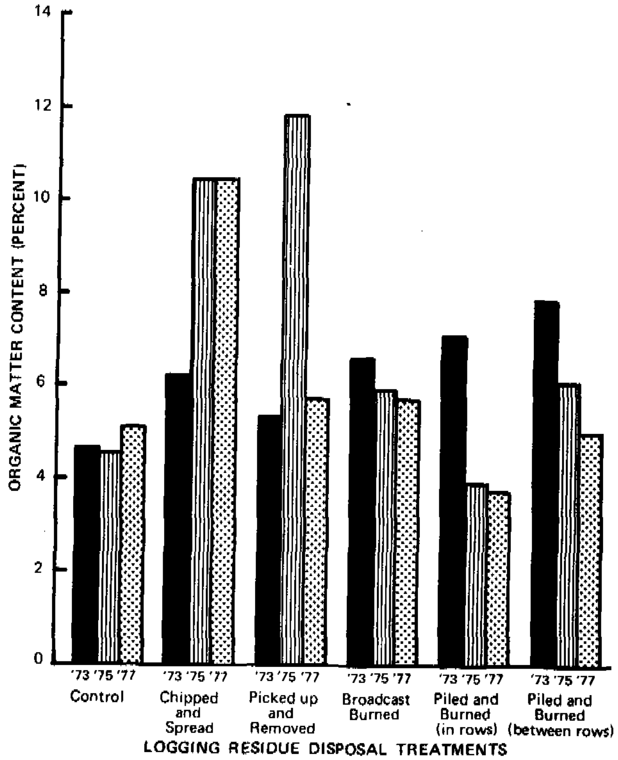

Figure 3.--Organic matter content of the surface 2-inches of soil associated with various residue treatments on lodgepole pine clearcuts.

pH

The effects of the residue treatments on the pH of the surface 2-inches of soil are shown in figure 4. The only significant change was the increase in pH associated with burning windrowed residues. These windrowed residues burned hotter than the broadcast residues. The increased pH is attributed to the release and concentration of both monovalent and divalent cations and nitrates as the residues are oxidized by fire. These increases have persisted throughout the 4-years since the windrows were burned.

Effects on Vegetative Characteristics

VEGETATIVE COVER DENSITY

The effects of logging and residue treatments on the density of vegetation covering the ground are shown in figure 5. Prior to logging, total cover density at the ground surface (including plants, litter, and logging residue) was similar to that on the unlogged control tracts--about 99 percent. Because the density of vegetative cover on the logged units was already nearly complete, even the addition of large quantities of residue had little effect on total cover density measurements, increasing them, on the average, less than 1-percent. Following logging, the cover densities of those blocks where residue was chipped and respread were still about 100-percent, although the cover was mainly chips rather than plants and litter. This cover of chips was still intact in 1977, 4-years after spreading.

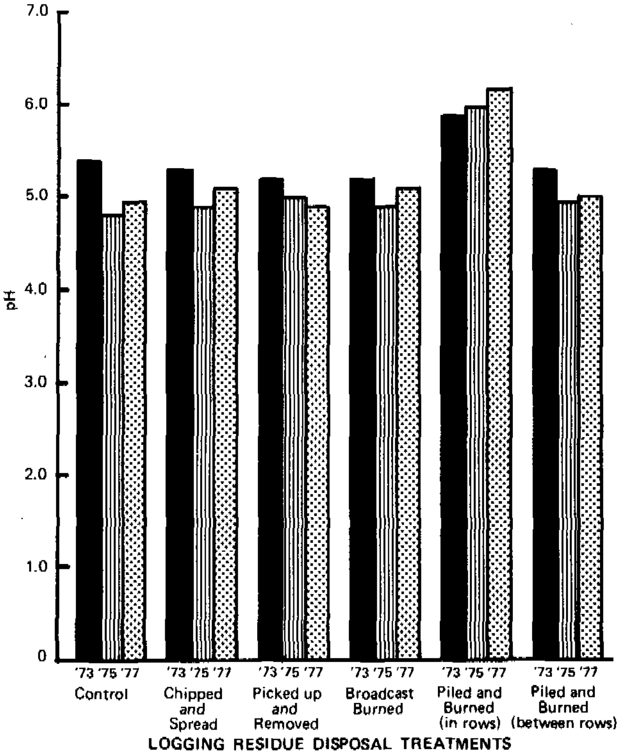

Figure 4.--pH of the surface 2-inches of soil associated with various residue treatments on lodgepole pine clearcuts.

On sites where residue was picked up for chipping but not respread as chips, cover density in 1973 was reduced to 67-percent. In 1975 and 1977, largely through the regrowth of grasses and forbs, cover density increased to between 80 and 90 percent, which is sufficient to provide effective watershed protection.

Logging and residue removal by broadcast burning in 1973 left cover densities of from 80 to 90 percent. Densities in excess of 80 percent have persisted on the broadcast-burned blocks through 1975 and 1977.

On the windrowed and burned sites, cover densities after burning averaged 47-percent, consisting mainly of unburned residue. Cover densities of 40 to 48 percent, have persisted through 1975 and 1977 on these sites.

On the areas between windrows, where the residues were removed by bulldozing, cover densities averaged 28 percent in 1973. By 1977, the average cover density on these sites was only 30-percent. It is significant that little, if any, improvement of cover densities has occurred on these sites during the 4-year period following logging and residue disposal. This failure of plant cover to respond rapidly is not surprising considering the high altitude (9,600 ft) and short growing-season (about 60 days) that characterize lodgepole forests at Union Pass. Plant recovery on protected but previously overgrazed subalpine ranges having similar altitude and growing season requires as much as 50 years or more (Ellison, 1954).

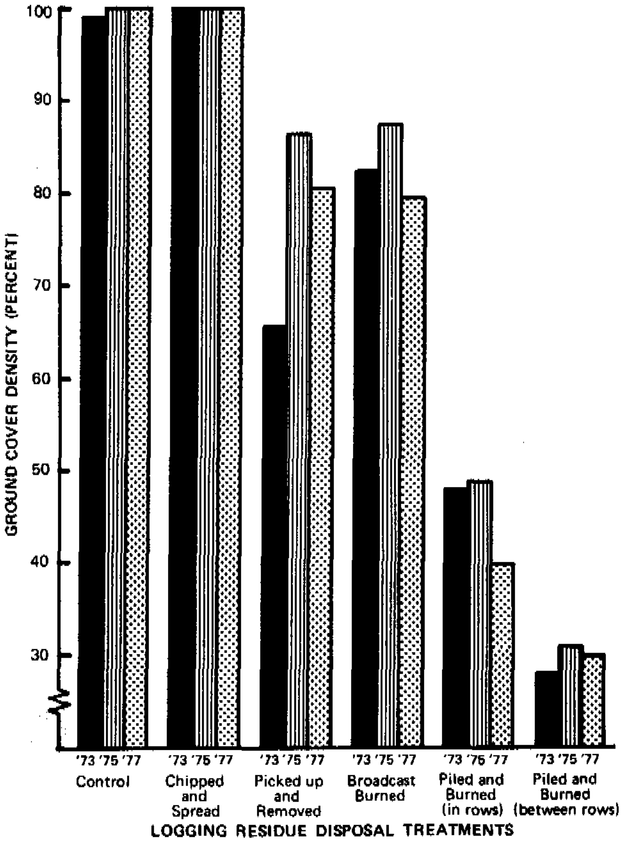

Figure 5.--Density of vegetative cover associated with various residue treatments on lodgepole pine clearcuts.

ABOVE-GROUND BIOMASS

The effects of logging and residue treatments on the production of above-ground biomass of grasses and forbs in 1977 are shown in figure 6. In the unlogged control areas, the production of herbaceous biomass averaged about 310 pounds per acre. On sites where residue was chipped and respread, herbaceous regrowth was restricted to only about one-eighth of that on the control areas.

The greatest production, 980 pounds per acre, was measured on sites where logging residue was picked up, removed for chipping, but not respread. Not only were these areas opened to sunlight by clearcutting, but the existing understory vegetation was not damaged by machinery or fire. These sites retained the most potential for increasing the production of herbaceous biomass.

On sites that were broadcast burned, herbaceous biomass production averaged 800 pounds per acre. Apparently the quantities of residue left following logging were not sufficiently concentrated to support the hot fires that greatly damage herbaceous vegetation.

Average production of herbaceous biomass where logging residue was windrowed and burned was about 400 pounds per acre, almost as low as in the relatively unproductive control areas. This low production rate reflects the destruction of a substantial portion of herbaceous plants by high fire intensities developed during burning of the windrows.

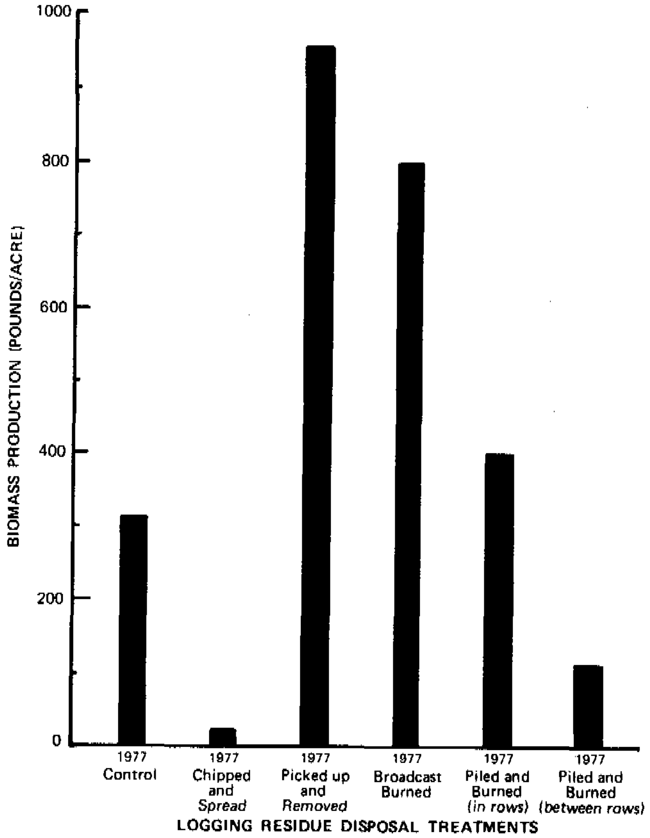

Figure 6.--Above-ground biomass production resulting from residue treatments on lodgepole pine clearcuts.

Excluding the blocks where residue was chipped and respread, the lowest biomass production, 125 pounds per acre, occurred between windrows. A substantial portion of herbaceous plants and large areas of surface soil were removed from these areas by dozer blades, drastically curtailing the potential for regrowth.

Effects on Surface Hydrology and Soil Stability

SURFACE RUNOFF

The effects of the residue treatments on surface runoff are shown in figure 7. In 1973, the smallest amounts of surface runoff occurred on sites where logging residue had been chipped and respread. Largest amounts of runoff occurred between windrows where residues, as well as some vegetation and soil, had been removed by bull dozing.

In 1975, the relation between disposal treatments and surface runoff were essentially similar to those in 1973.

By 1977, the smallest amounts of surface runoff occurred on broadcast-burned sites. Almost as small were the amounts from sites where the residue had been chipped and respread. In both instances, the amount of runoff was about one-half the amount produced by the unlogged control areas, showing that broadcast-burned and chipped-and-spread areas provide better surface runoff control than do similar unlogged areas.

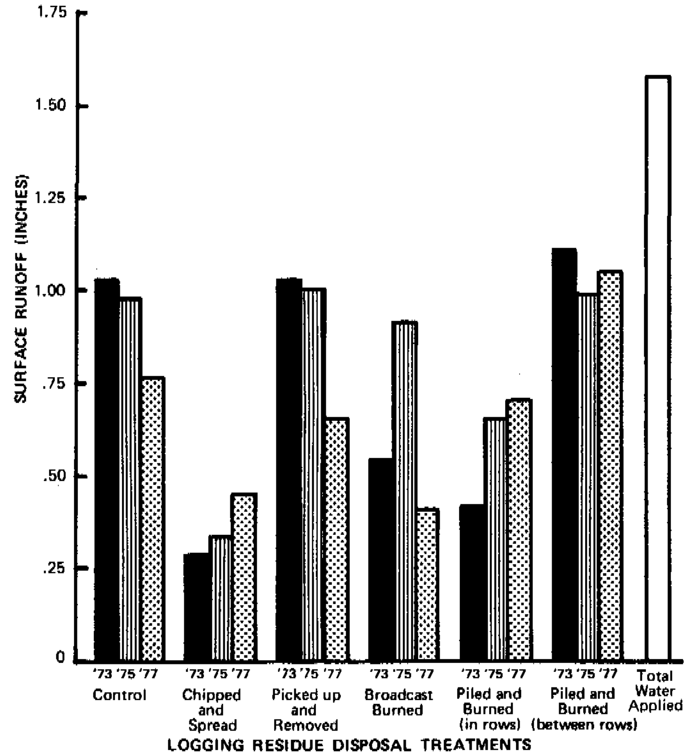

Figure 7.--Surface runoff associated with various residue treatments on lodgepole pine clearcuts during 30 minutes of infiltrometer rainfall at 3.25 inches per hour.

The largest amounts of surface runoff in 1977 occurred between windrows and is probably attributable to partial baring of the soil by bull dozing.

SOIL EROSION

The effects of the residue treatments on soil erosion are shown in figure 8. In each year of measurement, less than 40 pounds per acre of soil were eroded where residues were chipped and respread. These amounts were even less than those eroded on unlogged control areas.

The largest amounts of soil erosion--in excess of 1200 pounds per acre--occurred between windrows. By 1977, almost as much erosion per unit area occurred from the windrowed sites themselves. On clearcut sites--with the exception of areas on which chips were respread--the most effective erosion control was provided where residues were broadcast burned. Almost as good control was provided by sites where logging residue had been picked up for chipping without spreading the chips back on the sites. Poorest erosion control was obtained on sites where logging residues were dozer piled and burned.

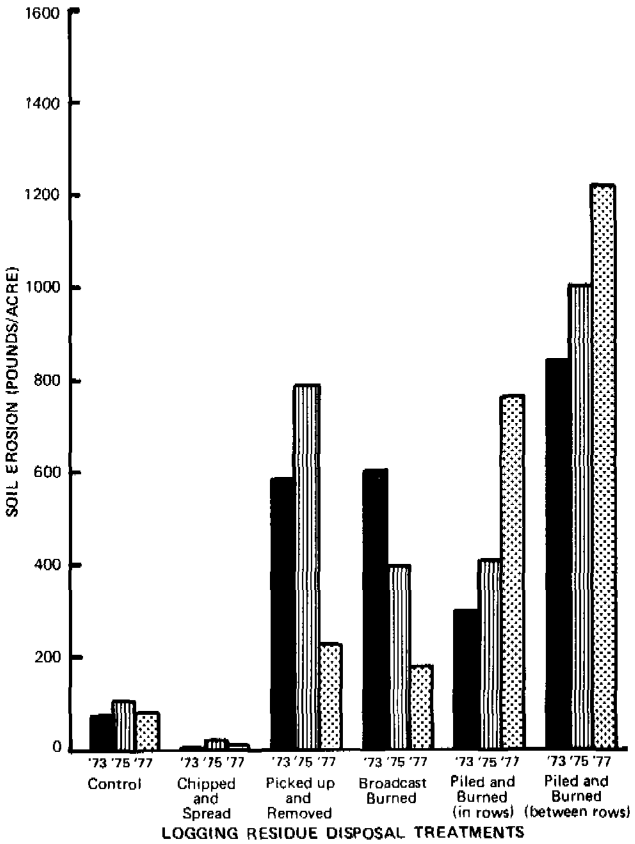

Figure 8.--Soil erosion losses associated with various residue treatments on lodgepole pine clearcuts during 30 minutes of infiltrometer rainfall at 3.25 inches per hour.

CONCLUSIONS

The results of this study show that the residue disposal treatments employed on these tracts produced changes in surface soil and vegetative characteristics--changes that sometimes enhanced and sometimes impaired the hydrologic performance and soil stability behavior of the lodgepole pine sites. In general, the recovery of impaired watershed protection conditions does not occur rapidly given the high altitudes and the short growing seasons that characterize these forests. Furthermore, recovery of impaired conditions appears somewhat slower on sites where the vegetation and soil mantle have been drastically disturbed by mechanized equipment than on similar sites where residue disposal did not disturb the forest floor.

The most effective residue treatment in terms of surface runoff and erosion control is the chipping and respreading of the residue as a protective mulch. This particular treatment, however, has serious disadvantages--the almost complete suppression of vegetation and the elimination of natural lodgepole pine reproduction.

The most adverse soil and vegetative characteristics, the poorest surface runoff and erosion control, and the slowest recovery rates were encountered where residue was dozer piled and burned.

One of the least detrimental residue disposal treatments in terms of watershed condition, performance, and speed of recovery is complete removal of residue for chipping and subsequent use of chipped material elsewhere. The practicality of this treatment, however, is contingent upon the existence of an economically feasible market for chips or other small timber products. Finally, the most effective and economical residue treatment in terms of protection to soil and vegetal characteristics, control of surface runoff and erosion, and rapidity in watershed recovery following logging is broadcast burning.

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THE IMPACTS OF UTILIZATION ON NUTRIENT CYCLING

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ABSTRACT

Studies of the impacts of fire and logging in western Montana have shown that only the hottest fires are likely to have long-lasting nutrient losses. Fires with surface soil temperatures of about 572° F (300°C) can be used indefinitely on a 50-year rotation with no significant loss of long-term productivity on the richer forest soils. A method of estimating the nutrient storage capacity of soil can be used to help select management treatments that avoid excessive losses of biologically essential nutrients from fire or fertilization. Harvest of wood and bark in clearcuts on two forests did not remove more nutrients than could be returned through precipitation in 70-100 years. Intensive harvest s should not remove more nutrients in fiber than can be returned from precipitation, soil solution available nutrients, pollen and normal decay in 70 years time. This means that only wood, bark, and branches can be harvested safely. Harvest should not be subsidized by the nutrients released from weathering during a particular rotation or the site will never improve in productive capabilities. Results are not pertinent to nitrogen or phosphorous.

KEYWORDS: Douglas-fir, fire, intensive harvest, logging, nutrient depletion.

INTRODUCTION

In the early days, the main concern of foresters was how to get the logs out of the forest. As time went on, they realized the importance of achieving good spacing and species composition for maximum growth of reproduction. Today, added to these silvicultural concerns, is a growing realization of the importance of protecting the site for future rotations and sustained yields. In the southeast, intensive harvest for pulp wood is a reality. In the Rocky Mountains, we are beginning to think about greater efficiency in the use of energy and resources with each rotation. We are asking questions like, "How much fiber can we remove from a site before we damage the ability of a soil to support a comparable forest in the same rotation time?", or "How frequently can we burn and at what temperatures before irreparable damage is done?"

Questions like these have been the stimulus of my research over the past seven years. This paper will summarize the highlights of that research and provide what answers we have. It is not intended as a survey of the recent literature, but rather takes some newly formed theories and develops these into useful managerial tools through the use of extensive field and laboratory measurements.

Three main studies form the basis of this report:

1. Studies of the effects of different intensities of fire on nutrient cycling on soil derived from quartzitic argillite at the Lubrecht Experimental Forest near Missoula in western Montana, and nutrient retention by forest soils.

2. Studies of the influence of clearcutting, shelterwood and group selection cutting with 4 levels of slash disposal on andeptic cryoboralfs on the Coram Experimental Forest near Glacier National Park.

3. The impact of fire and logging on nutrient cycling and soil deterioration at the Lubrecht Experimental Forest.

All three areas are covered by Douglas-fir and western larch.

THE INFLUENCE OF FIRE ON NUTRIENT CYCLING

This study began as a simple exploration of the changes in soil chemistry wrought by different fuel loadings and different burn intensities at different times of year. The forest is at 1,464 m elevation on coarse textured, shallow quartzitic argillites with low cation exchange capabilities 2.4 - 9 meq/100 g. The habitat type (Pfister et al. 1977) is a north slope maturing PSME/VACA (*Pseudotsuga menziesii/Vaccinium caespitosum*) type with relatively steep topography (35-42%), heavy snowfall (1.5 m or 5 feet), and moderate precipitation (466 mm, 18.3 inches). The forest had been undisturbed for 70 years (previous logging) and had 2-11 kg/m^2 of old rotten residual fuels.

During the study, certain phenomena involving nutrient depletion and soil deterioration which I had studied over the past 12 years began to jell into a series of hypotheses. The first involved "direct nutrient cycling" or the transfer of nutrients in the tropics on extremely poor soils from dead organic matter via mycorrhizal fungi almost completely bypassing the soil (Stark 1969). This hypothesis has since been tested for the tropics (Herrera et al. 1978), but is of little importance to the Rocky Mountains since on young soils nutrients appear to be transferred largely indirectly or from the dead organic litter to the soil solution, and thence to roots or mycorrhizae. The importance of direct nutrient cycling here is that it led to the second hypothesis.

The second one involved the concept of the "Biological Life of a Soil." This term refers to the length of time on the geologic time scale over which a soil is chemically able to support merchantable trees, regardless of climate. This concept acknowledges that a soil can wear out, and that excessive harvest or too frequent fires can accelerate the rate of "wearing out." The logical question for a nutrient cycling ecologist now working in western Montana was, "Can these fire treatments being applied on these soils cause an acceleration of the decline in the long-term productive capabilities of the soil?" The data being collected on the loss of nutrients below the root zone in the soil water on 20 treatments and 5 controls, and precipitation as well as a host of other related measurements were ideal for answering this question (Steele 1975). About the same time, a third idea appeared in the author's mind, that of "nutrient shock." Nutrient shock is the temporary deficiency of one or more biologically essential nutrients in available form in the soil. The biological life theory deals with a permanent loss of available and unavailable (total) nutrients. Nutrient shock is the condition which could occur on nutrient-poor young, thin, or poorly developed soils which had had the vegetation destroyed by too frequent or intense fires, or by logging. This was a phenomenon which could occur on the relatively young soils of the Rocky Mountains. It has been observed by the author in Nevada (unpublished).

The results of the study are summarized in fig. 1. Fires were classified by surface soil temperatures as light (<180° C or 356° F), medium (180-300° C or 356-572° F) or hot (>300° C or >572° F). No significant nutrient losses occurred with fires less than 180° C, nor with those ranging from 180-300° C. The nutrient losses which did occur were largely replaced by precipitation in 1-2 years time. Those fires greater than 300° C and particularly those greater than 500° C (932° F) caused accelerated nutrient losses below the root zone for 2-5 years. In all of the hot fires the only two elements lost in excess of what was being returned annually in precipitation were Ca and Mg. Nitrogen was also lost in solution and in smoke, but nutrient losses in smoke were not quantified in this early study. Nutrient losses below the root zone in the unburned control soils were 20.8 meq/m^2 of surface area, compared to 21.2 meq/m^2 for precipitation input. Control nutrient loss just equalled the annual return of calcium from precipitation. Magnesium showed a slight deficit on control plots (more routinely lost then added).

By applying the reasoning of the Biological Life of the Soil, we were able to measure the total nutrient content over a meter square (3 ft^3) of surface area to the depth of the root zone (50 cm, 19.7 inches). This constitutes the "working capital" in the bank, plus interest (annual additions from weathering). We were also able to measure how much added nutrient loss occurred for the hottest fires (over the level of loss by the controls). This was money expended from the bank account for 2-5 years after each fire over every 50-year fire rotation. A 50-year fire frequency was selected in the absence of natural or man-controlled fire frequencies for the sake of calculation. Precipitation inputs cancelled out control losses.

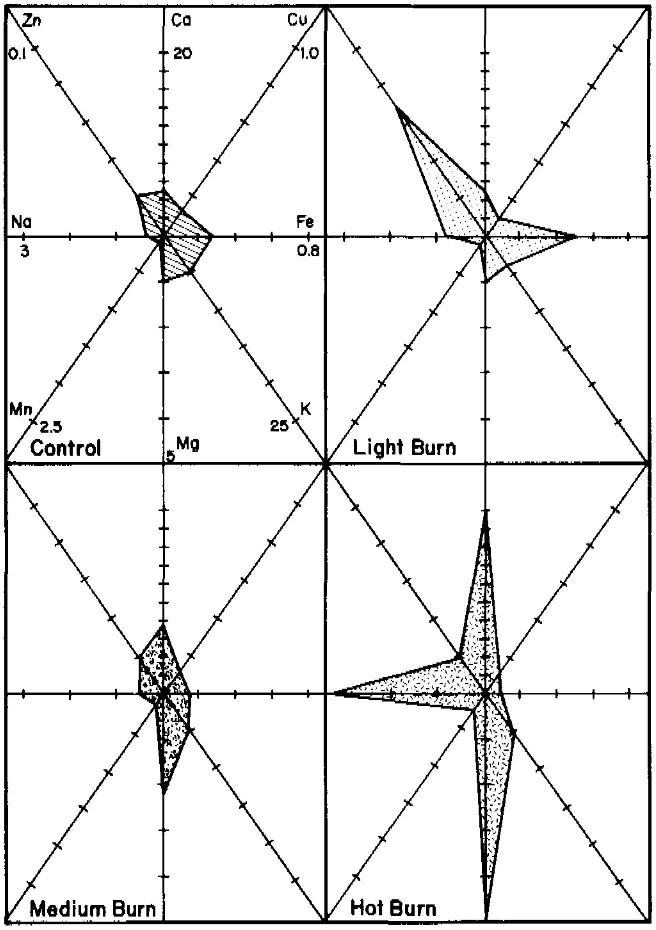

Figure 1.--Measured concentrations (mg./l.) of selected elements in soil water under untreated (control) conditions, and following prescribed burning treatments.

The total calcium in the 0.6 m^3 root zone weighted by the volume of rocks versus the volume of soil (<2 mm) proved to be 75,824 meq/0.6 m^3. Losses from hot burns the first year post-burn were 46.5 meq/0.6 m^3 and the second year they were 23 meq/0.6 m^3. By the third year, all but 2 of the hottest burns had nutrient losses approximately equal to that below the root zone of the controls. Thus 46.5 meq/0.6 m^3 year 1 + 23 meq/0.6 m^3 fire under standing timber (not a wild fire) "costs" in terms of nutrients if the fire is >300° C (572° F) and occurs only once very 50 years. The seriousness of this loss to the long-term productive capabilities of this soil can be evaluated by dividing the total calcium content of the 0.6 m^3 of soil by the 50-year loss from burning of this type. This gives a figure of 1,092. That figure x 50 years gives 54,600 years, or the length of the remaining Biological Life of the Soil. This means, that theoretically, this soil can support 1 fire with temperatures >300° C every 50 years for 50,000 years before all of the available and unavailable calcium per gram of soil would drop below that needed to support a merchantable tree, and would signify the true end of the Biological Life of the Soil. Recent data show that it takes at least 10,160 meq Ca/0.6 m^3 of available soil or recyclable Ca to grow a 70 foot Douglas-fir to 16" dbh in 70 years. Change the fire frequency, or add logging, and the remaining Biological Life changes. Perform the same calculations for Mg, and the Biological Life is reduced to 33,000 years. If you measure these nutrient losses under tropical conditions on depleted white sands, you find only 75 to 275 years of tree growing power left. This is significant.

What is the significance of 54,000 years? In that time span, there will be geologic change, speciation, glaciation, climatic change, migration and a host of other dynamic events which no land manager can anticipate. We cannot manage forest much beyond 1 or 2 rotations, so that a remaining Biological Life of 50,000 years, although statistically significant, is of no concern to a land manager except where the remaining life is less than 200 years on some poor tropical soils. Measurement on site of the surface downslope movement of solids using land weirs showed that it would take about 50,000 years to erode away the present root zone through microerosion associated with 50-year burns on this coarse-textured soil.

Nutrient shock or temporary nutrient depletion is a more realistic concern on these Montana soils than is the loss of long-term productive capabilities. The soils studied are low in total calcium, and relative to the total Ca content, calcium losses below the root zone of the maturing forest are quite high. The north slope is cold and decay is slow. Too much burning, or too much harvest could deplete the soil-plant system of its readily available calcium producing nutrient shock, or temporary loss of the ability of this soil to grow trees. Nutrient shock can be recognized by low available levels of 1 or more biologically essential nutrients in the soil, and stunted seedlings or brush fields. It does occur in the Rocky Mountains and should be a major concern to land managers in planning harvest and regeneration strategies. There should be at least 8,000-10,000 meq/m^2 of calcium to grow the next forest, and 3 x that much to avoid drawing on nutrients released through weathering. Understanding how much nutrient one soil can store after fire was not enough.

Out of this study came a study of the nutrient retention capabilities of a wide range of texturally different soils. It was the intention of this study to develop a system to predict how much of each nutrient in ash could be held by the root zone before massive nutrient losses would occur below the root zone. Such losses in a mature forest below the root zone are permanent and irreversible. A land manager who is uncertain of the ability of a soil to hold biologically essential nutrients should be able, with 1-6 simple measurements to predict how many total cations in meq/m^2 of surface area can be added through ash (or fertilizer) before substantive losses will occur. If the storage capacity of the soil is low, and the available or total nutrient storage is low, the land manager may want to select fuel loadings, air temperatures, fuel moisture, and wind conditions which will affect a 50% fuel reduction or other appropriate fuel reduction to avoid overloading the soil. Alternatively, this method will allow the land manager to select an appropriate fertilizer level to avoid excessive cost and losses to ground water or streams (Stark, in press).

This study on nutrient retention is just in completion. The storage capacity for most of 8 cations can be predicted with R^2 values of 0.7 to 0.9 using 1 to 6 independent variables. Total cation storage can be predicted with R^2 of 0.69-0.96 and % standard error of the Y of 12.5-28.7 % for 28 soils. With the perfection of the prediction of fire behavior in different fuel types, weather conditions, and fuel moisture contents, it will soon be possible to couple these two approaches and use fire in a more dependable and ecologically sound manner.

THE INFLUENCE OF FIRE AND LOGGING ON NUTRIENT CYCLING

These studies in Douglas-fir/western larch forests at 1,219 m (4,000 ft.) elevation on slopes of >40% were designed to determine if logging and slash disposal would result in nutrient losses below the root zone or to the stream, and through harvest. Several habitat types occurred in the areas, but the predominant one was PSME/VACA (Pfister, et al. 1977). The soils are 40-50 cm (15.7-19.6 in) deep, often underlain by low-quality limestone or argillite, and in places they are andeptic. The annual precipitation is 763 mm (30 in), with approximately one-half coming as snow.

The silvicultural treatments applied were clearcutting, shelterwood, and group selection cuts. Within each replicate of these were four levels of slash disposal: 1. slash left in place; 2. slash removed; 3. slash burned-low intensity burn; 4. slash burned-medium-low intensity burn (Barger, this proceedings).

Abbott Creek is an intermittent creek which begins in the study area and then goes below ground to emerge below the treated areas. None of the treatments applied produced significant changes in stream water chemistry, and only minor increases in Na content for a few days. These results are not definitive because of the peculiar nature of the stream, but other studies have shown little stream pollution from logging and light burns away from the riparian zone. The burns in this study had to be done in unusually wet fall weather so that no significant nutrient losses occurred on any of the treatments from fire.

Clearcutting represents the most severe case of nutrient removal from harvest. Table 1 shows that under 0.25 percent of the total soil root zone nutrients were removed in the boles as a result of clearcutting. Table 2 shows that harvest removes under 15% of the immediately available nutrients except for Zn. The parent material is low in Zn, and hence, available zinc is low. The removal of wood and bark takes away low levels of all nutrients, but proportionally large amounts of zinc. This would have no immediate impact on regeneration or seedling growth because the soil still has its normal complement of available Zn and it will be at least 20 years before the regeneration begins to make heavy demands on the soil for zinc. The zinc in the wood and bark has accumulated there over 70 to 100 years at a slow rate. About 60% of that zinc left in heavy slash will be returned through decay in the next 70 years.

This study, along with others (Carlisle 1975) has shown that the nutrients removed through the conventional harvest of wood and bark will be restored to the soil in 70 to 100 years through precipitation, even after clearcutting. The nutrient levels in the precipitation at Coram are a bit higher than in other areas because of the ions added to the atmosphere from a nearby aluminum plant.

If more fiber is removed beyond the usual level, the nutrient depletion could be more serious, especially on a young, poor soil.

THE IMPACT OF FIRE AND LOGGING ON NUTRIENT CYCLING AND SOIL DETERIORATION

If we have to resort to heavier utilization to provide fiber for supplementing energy shortages through burning pelletized slash in generators for electricity or for some other reasons, how much can we safely remove from the forest? How much nutrient must be left to grow the next forest?

To answer these questions, we must first lay some ground rules. We cannot accurately measure weathering rates, but we know that weathering is occurring. It would seem unwise ecologically to depend on weathering to provide any portion of the nutrients to grow the next forest. If we depend on the nutrients released from weathering to grow the next forest, then the soil portion of "site" will never improve or mature. Since we have largely young soils, we can anticipate gradual improvement in the quality of these soils with each rotation if the nutrients released through weathering are left behind when we harvest. Changes brought about by weathering will not only improve nutrient availability for the next rotation, but will also increase the water and nutrient storage capacities of the soil.

Table 1.--Percent of total quantity[1] of each element removed from a 1 m^2 surface area through timber harvesting, on the basis of $g/0.5\ m^3$ feeder root zone, relative to total root zone.

Silvicultural Practice[2]	Tr	Ca	Cu	Fe	K	Mg	Mn	N	Na	PO_4	Zn	Equivalent % of total Cations removed
		Percent										
Shelterwood 1	2	1.2	1.2	0.004	0.11	0.17	0.33	2.6	0.01	0.76	0.19	0.17
	4	0.4	0.5	0.002	0.04	0.14	0.10	1.2	0.004	0.43	0.25	0.07
	1	0.9	0.5	0.002	0.05	0.09	0.17	2.4	0.02	0.25	0.19	0.12
	3	0.6	0.7	0.003	0.05	0.07	0.13	1.7	0.006	0.59	0.12	0.08
Group Selection 1	2	1.1	1.1	0.001	0.12	0.15	0.23	2.7	0.01	1.20	0.20	0.16
	4	0.6	0.8	0.002	0.07	0.14	0.16	2.1	0.007	0.63	0.10	0.09
	1	0.5	0.6	0.002	0.05	0.06	0.11	1.6	0.006	0.53	0.09	0.08
	3	0.9	0.9	0.003	0.08	0.10	0.18	2.2	0.008	0.67	0.12	0.12
Clearcut 1	2	0.4	0.5	0.001	0.04	0.12	0.10	4.5	0.004	0.21	0.06	0.06
	4	1.3	2.0	0.004	0.09	0.23	0.42	5.1	0.02	0.57	0.26	0.18
	1	0.4	0.4	0.001	0.03	0.04	0.08	4.2	0.004	0.43	0.08	0.05
	3	0.3	0.3	0.001	0.03	0.03	0.08	1.4	0.004	0.36	0.05	0.05
Shelterwood 2	2	0.2	0.3	0.001	0.02	0.02	0.05	1.2	0.002	0.26	0.05	0.03
	4	0.4	0.4	0.001	0.03	0.03	0.08	1.3	0.003	0.38	0.06	0.05
	1	0.4	0.4	0.001	0.03	0.04	0.08	4.2	0.004	0.43	0.08	0.05
	3	0.3	0.3	0.001	0.03	0.03	0.08	1.4	0.004	0.36	0.05	0.05
Group Selection 2	2	1.2	1.2	0.003	0.09	0.12	0.26	3.0	0.01	0.87	0.20	0.16
	4	0.8	0.7	0.002	0.07	0.08	0.16	2.2	0.007	0.71	0.11	0.11
	1	1.7	2.9	0.005	0.11	0.13	0.25	4.5	0.02	0.95	0.18	0.21
	3	0.7	0.7	0.002	0.07	0.08	0.04	2.0	0.006	0.59	0.09	0.10
Clearcut 2	2	0.9	0.9	0.002	0.09	0.09	0.14	2.3	0.008	0.50	0.12	0.12
	4	0.6	0.7	0.002	0.07	0.07	0.16	1.9	0.007	0.52	0.10	0.09
	1	1.1	0.9	0.003	0.09	0.09	0.22	2.6	0.009	0.74	0.14	0.15
	3	0.6	1.4	0.002	0.06	0.05	0.13	1.6	0.005	0.42	0.07	0.08

[1] Total quantity of an element refers to all of the element present in the root zone in soil and rock, in both available and unavailable forms; represents total nutrient potentially available through weathering.

[2] For treatment descriptions, refer to Barger, this proceedings. Treatments are arrayed least to most severe: 2, 4, 1, 3.

Table 2.--Percent of total quantity[1] of each element removed from a 1 m^2 surface area through timber harvesting, on the basis of g/0.5 m^3 feeder root zone, relative to total root zone.

		Percent									
Silvicultural Practice[2]	Tr	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn	Equivalent % of Available Cations Removed
Shelterwood 1	2	8.6	13.5	4.7	14.1	11.6	9.9	5.7	1.25	62.7	9.5
	4	3.1	5.7	1.9	5.7	9.7	2.9	2.3	0.71	80.1	4.0
	1	6.3	11.5	6.6	7.0	6.5	5.1	8.3	0.41	62.6	6.4
	3	4.3	7.9	3.4	6.9	4.6	3.9	3.1	0.96	40.3	4.6
Group Selection 1	2	7.8	12.8	1.4	16.1	10.5	6.9	5.3	1.98	64.7	9.0
	4	3.9	9.2	2.4	9.3	5.9	4.9	3.8	1.03	33.6	4.9
	1	3.9	6.9	2.0	6.8	4.4	3.4	3.0	0.88	29.6	4.3
	3	6.1	10.5	3.0	11.0	6.9	5.6	4.3	1.10	39.6	6.8
Clearcut 1	2	2.7	5.3	1.2	5.2	3.2	2.9	2.1	0.34	19.1	3.0
	4	9.1	23.5	4.7	10.5	15.8	12.8	7.9	0.94	84.3	10.1
	1	12.1	17.3	3.9	27.4	11.2	9.2	6.8	2.01	91.7	13.9
	3	5.8	13.9	2.8	9.8	8.8	7.5	5.5	0.58	48.2	6.6
Shelterwood 2	2	1.7	2.9	1.1	2.6	1.6	1.6	1.21	0.43	15.3	1.9
	4	2.5	4.1	1.5	3.9	2.4	2.4	1.7	0.63	20.7	2.8
	1	2.6	4.5	1.6	4.1	2.5	2.6	1.9	0.71	24.7	2.9
	3	2.3	3.6	1.7	3.7	2.3	2.5	1.9	0.59	14.8	2.6
Group Selection 2	2	8.3	14.2	4.0	11.4	8.2	7.9	5.6	1.43	65.4	8.9
	4	5.4	8.9	2.5	8.2	5.6	4.9	3.8	1.16	35.9	5.9
	1	11.7	34.2	5.9	13.4	9.3	7.7	9.2	1.57	59.0	11.8
	3	5.2	8.0	2.3	7.8	5.3	1.1	3.3	0.96	29.8	5.5
Clearcut 2	2	6.3	9.6	2.6	10.1	6.1	4.4	3.9	0.82	38.4	6.9
	4	4.6	8.1	2.4	8.1	4.6	4.9	3.4	0.86	31.9	5.2
	1	8.0	11.2	3.1	10.8	6.3	6.5	4.6	1.21	44.4	8.3
	3	4.3	16.5	1.8	6.6	3.8	3.9	2.8	0.68	23.2	4.6

[1] Available quantity of an element refers to the ammonium acetate extractable quantity of the element present in the root zone; represents nutrient available in the soil at one point in time to provide immediate support for tree growth.

[2] For treatment descriptions, refer to Barger, this proceedings. Treatments are arrayed least to most severe: 2, 4, 1, 3.

The basic ground rules are that harvest cannot remove any portion of the fraction of nutrients made available through weathering during the last rotation. Harvest should not seriously reduce the available soil nutrients.

We can assume from previous studies (Stark 1977) that if we did not touch a forest, the trees would mature, gradually die and fall down, succession and weathering would occur, and there would always be adequate nutrients to grow the next seral stage until the soil neared the end of its Biological Life and "wore out." If we remove only the wood and bark, the Coram and recent Lubrecht studies showed that precipitation would restore most of the biologically essential nutrients in 70-100 years (Stark, 1979 in press). But what if we removed the boles for lumber and the slash for hog fuel or pelletized fuel? In some of the southeastern forests, even roots of small trees are being harvested.

To determine the nutrient impact of whole tree removal, we have to know how much of each biologically essential nutrient is needed to grow a tree. The normal forest shrub-herb component will grow whether we want it to or not. Often shrubs such as *Ceanothus velutinus* (Dougl., tobacco brush) are important to trees because they harbor nitrogen fixing bacteria. Shrubs and herbs provide feed for wildlife detracting from the possible heavy browsing impact of tree seedlings. So we really must know how much of each biologically essential nutrient is needed to grow a tree plus its natural shrub and herb components. We also need to know how much of each element is needed for animals and the soil fauna and flora. These latter measurements could not be made within the scope of a 2-year study, but they ultimately must be added to the total.

If we could examine an area roughly 39 x 39 inches (100 x 100 cm) from the top of the canopy to the forest floor and on to the depth of the root zone, to include all forest components in their proper proportion, we could see how much calcium it takes to grow a forest. I mention calcium only because it is an element often in short supply. Ten biologically essential elements have been examined in this way by collecting 25 to 50 samples of each forest component by species (foliage, branches 0-1/4", 1/4-1", 1-3", >3" sound, >3" rotten, litter, duff, shrubs, herbs, roots, pollen, bulk precipitation and thrufall, soil) and then measuring the amounts of each material occurring on a hectare. The concentration of each material and element per hectare was divided by 10,000 to relate this to the amount of element per m^2 as mg/m^2. Mean figures were used but final data will include maximum and minimum figures for all forest components to characterize range. These data were further converted to meq/m^2 by dividing by the equivalent weights of each element studied (except for N and P). These ions exist in many forms and cannot be readily converted to equivalents.

Figure 2 shows how the forest components break down for calcium as meq/m^2 over 70 years time (rotation). Since we are considering future rotations and management, I have taken the liberty to assume 300 to 400 trees per acre as ideal stocking, with 30% ponderosa pine, 30% western larch, and 40% Douglas-fir, planted with proper spacing. This is not the same as the original forest which was all-aged and poorly spaced. To replace the original forest with its thousands of suppressed, bud-worm damaged Douglas-fir seedings seems wasteful. Instead, we will aim for a better forest in 70 years with Douglas-fir and ponderosa pines approaching 15-16 inches (40.6 cm) and western larch reaching 12-13 inches (33 cm) in 70 years. The trees would be 70-90 feet tall. This may be overoptimistic for the site, but determining the best method for estimating the true productive capabilities of a site is the next challenge.

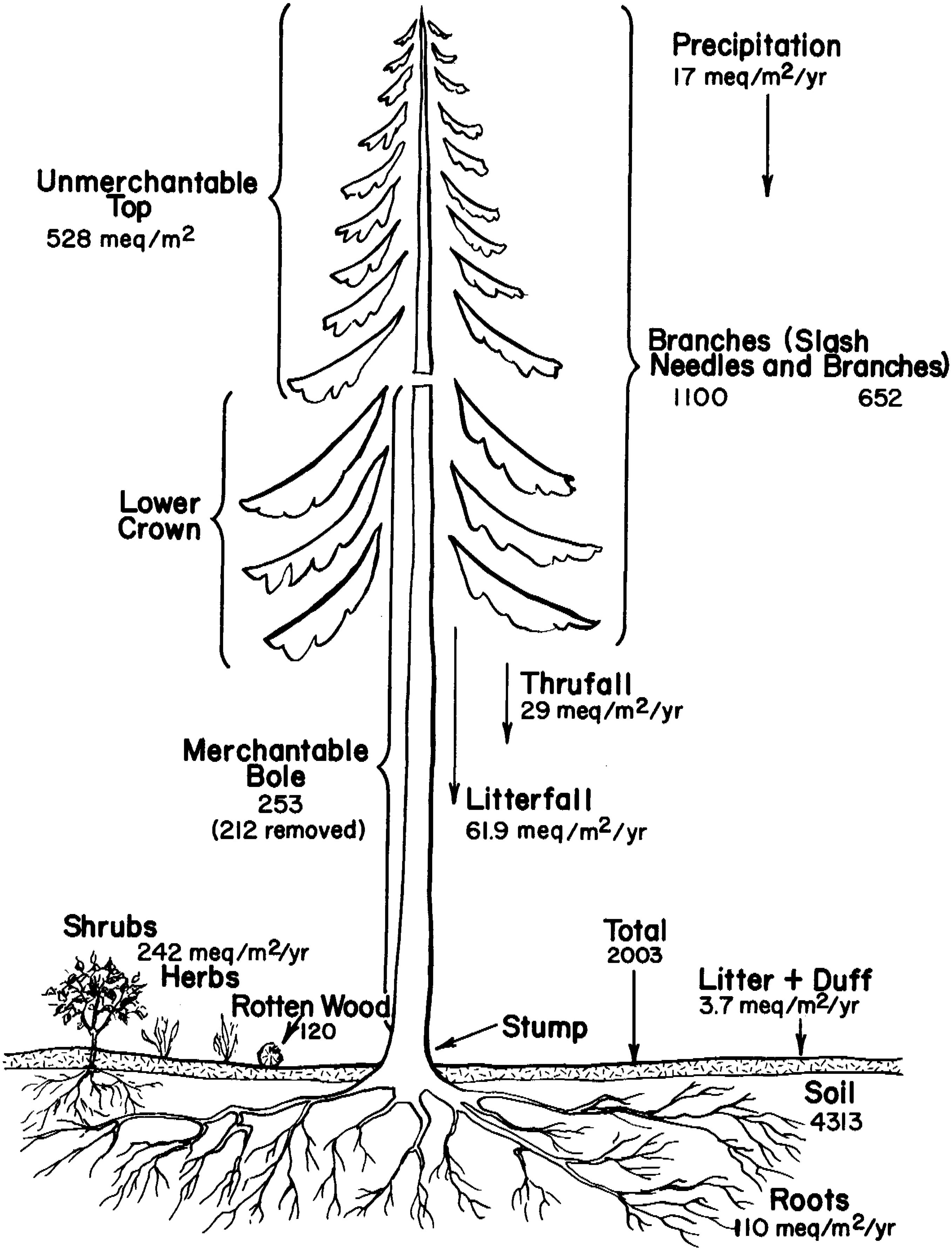

Figure 2.--Calcium distribution in a Douglas-fir forest ecosystem, 70 to 90 year old trees. All above-ground quantities not otherwise identified are meq/m^2; soil quantity refers to meq/0.5 m^3.

Some recycling, like litterfall, assumes so much measured litterfall for each ten years over 70 years time and complete nutrient release in 4-6 years for needles. Thrufall and precipitation are proportioned so that the first 20 years of growth would receive mostly bulk precipitation (with equal spacing), and the last 50 years the forest would receive mainly thrufall. Tree interception and nutrient release from foliage is small in the first 20 years. Root calcium content is based on the measurement of many size classes of roots for calcium, and determining mature root biomass as 34-44% of the crown weight (Fogel and Hunt 1978, Ovington 1962, Rodin and Bazilevich 1965, Whittaker and Woodwill 1968). Shrubs and herbs were analyzed together from 1/10 m^2 clip plots since no large shrubs occurred in this forest. Only 20% of the wood >3" on the forest floor will decay in 70 years (Quick, personal communication). All data on wood includes the nutrients in bark as well. Pollen data are from limited studies (1 year) of spring pollen rain. The nutrients in the feeder root zone were determined by weak acid extraction as a 1 point in time measure of available ions. Since the root zone for the m^2 averages 0.6 m deep (or alternatively 1 m deep maximum), and the roots cannot access every gram of the total root zone, available soil nutrients are viewed as only 20% accessible from the total root zone. We do not know how large a soil volume can be extracted by mycorrhizal fungi, but these organisms are most abundant in the upper 30 cm. Root growth over 70 years time probably does not allow the roots access to nutrients from more than 20% of the total root zone volume. Soil microorganisms are not included, but are a main recycling agent in soil. Nutrient losses from fire are dealt with separately.

If the merchantable trunk is removed, the system loses 253 meq Ca/m^2 each 70 years. Precipitation alone would return enough Ca to grow more wood (1,189 meq/m^2/70 years). The soil would make available 16,100 meq/m^2 (1 point in time without weathering inputs). Decay of the foliage, slash, litter, duff, shrubs, herbs, and ground wood would add about 13,188 meq Ca/m^2/70 years. This is corrected for an estimated 220 meq/m^2/70 years calcium loss by natural leaching below the root zone. From this short term study, we cannot tell how long it will take the soil water nutrient levels to return to normal after clearcutting (no fire) but the estimates are 2-4 years. The shrubs and herbs, because of the many primordia and reproductive structures in a small space, have more total Ca/m^2 than does the wood and bark. All other elements studied would be replaced by precipitation after conventional removal of boles.

If we assume the other extreme of total harvest of all organic matter, we would lose over 10,160 meq Ca/m^2/70 years and precipitation alone cannot replace this loss. In the absence of the decay of litter, shrubs, and slash with the most intensive utilization, the only nutrients available to grow the next forest would have to come from precipitation (and thrufall), the soil available nutrients (not recent weathering), and litterfall (5% of down fuels, 10% shrubs, herbs) over 70 years. These would return about 24,000 meq/m^2 in 70 years (corrected for leaching losses), or barely enough to safely cover the loss of 10,160 meq/m^2 through total organic removal. Although nearly 2 x as much calcium would appear to be left as would be needed to grow an entire forest, there could be periods of depletion (nutrient shock) for rapidly growing saplings because these would have to survive on the nutrients immediately available in the soil and precipitation inputs until the shrubs, litter, duff, and other forest decay components had become reestablished, grown, died, and provided a recycling source. The microbial populations would have to be reestablished too. The time needed to begin significant recycling from reestablished shrubs and litter is estimated at about 40 years, even though small amounts of annual litterfall and decay would occur. On a totally denuded site, the soil temperatures and moisture conditions would be unfavorable for decay until the trees were large enough to provide some shade if they could grow at all. The removal of litter, duff, and downed logs would take away most of the substrate needed for nitrogen fixers and would almost certainly create a nitrogen deficiency during the early years of growth. This is essentially the conditions which exist on many road cuts where total removal of vegetation has occurred. These results do not take into account the input of biologically fixed nutrients such as nitrogen, but only those weathered from rock.

Removal of roots through intensive utilization would disrupt the soil and on this generally level, heavy clay-silt soil, would not stimulate serious erosion. But if as little as a 5% slope were present, and a lighter textured soil, complete organic removal could mean certain loss of the fertile top soil from erosion, making regrowth of the original forest even more difficult.

Obviously, complete fiber removal is not ecologically sound or economically feasible. How much should we remove? The data suggest that we can safely remove trunks, branchwood (585 meq/m^2/70 years), but probably no foliage before we need be concerned about the next rotation. For a site to grow a forest on a continuing basis, there must be enough of each nutrient available to allow harvest, and enough present for growing the next entire rotation at the time of harvest. That means there must be 2-3 x the amount of Ca (and other ions) needed to grow a complete forest.

Remember that this is a relatively rich, young forest soil (table 2). Intensive utilization on a much poorer soil could interfere with the next rotation. Theoretically, harvest intensity should not exceed the regular nutrient additions from precipitation--thrufall, and decay (9,000-12,000 meq/^{2}). If this level is exceeded, growth may be subsidized by weathering.

It is critical that there be the same or a greater level of available nutrients in the soil at the end of each rotation. Thus, harvest cannot appreciably reduce the levels of available nutrients present at the beginning of that rotation, or there could be insufficient nutrients to grow the next rotation (nutrient shock). Weathering would provide greater levels of nutrients than originally were present if the forest had grown entirely on the nutrients recycled from decay and added from precipitation and thrufall. The entire weight of the root system is thought to turn over 1 to 2 times in 100 years, but little is known beyond the fact that feeder roots are very short-lived.

It takes an average of 145 meq of available Ca/m^2 per year to grow this forest ecosystem. Obviously, this will be less when the forest is young and more as it gets older. If at any time during the rotation, the site cannot supply the calcium needed for growth, then too much available nutrient has been removed, or inadequate water is present to transport the nutrients. It is essential to remember that the more nutrients removed in small-sized, nutrient rich ecosystem components, the less there will be left behind to decay. Because foliage releases large amounts of nutrients relatively rapidly, it seems unwise to remove much of the foliage which can provide nutrients needed for early tree growth.

Another way to look at the effects of nutrient loss on cycling is through the losses in soil water. In terms of available nutrients, sodium, zinc, and copper are not abundant in this soil. Heavy textured soils restrict the losses of large amounts of nutrients. In spite of this, there was insufficient Na, and marginal amounts of Cu and Zn left in the soil in available form after intensive harvest to grow the next rotation. This means that removal of more than boles and possible branches can bring about nutrient shock, or temporary available nutrient depletion. Adequate Ca, Fe, Mg, and Mn remained in the soil to allow similar types of harvest on a 70-year rotation with no threat to growth. But the fact that 1 or more ions could be limiting to future growth with intensive harvest (beyond wood removal) is significant to management.

The value of the data obtained from this study is that we now know the range of nutrients in all components of this forest type. If we measure the available soil nutrients and a few other parameters from other forests of the same type on different soils, we should be able to estimate how much fiber can be removed safely from those sites, and how much nutrient will be released and lost as a result of burning. Knowledge of the total and available soil nutrient content will help us judge whether nutrient shock is likely to occur from any combination of treatments. Since mainly poor soils are of concern the task of finding these soils and marking them as "chemically fragile" is the next problem.

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HARVESTING AND SITE TREATMENT INFLUENCES ON THE NUTRIENT STATUS OF LODGEPOLE PINE FORESTS IN WESTERN WYOMING

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ABSTRACT

Four 8 ha units were clearcut harvested. Post-harvest slash treatments on conventionally harvested units included broadcast burning and piling and burning; near-complete harvested units received no treatment or were mulched with chips from unmerchantable material. Samples of the soil, the soil solution, and lodgepole pine seedlings were taken during the five growing seasons after treatment. Clearcutting and slash treatments produced significant changes in the chemical composition of the soil solution, the surface organic soil horizon, and the surface mineral soil. Most of these changes were greatest under the burned piles of slash. However, the phenol content of the soil solution was highest under the chip mulch, where seedling growth was the poorest. The concentration of nutrients in pine seedlings varied little among treatments, despite remarkably different amounts of growth and vigor.

KEYWORDS: Pinus contorta, slash disposal, prescribed burning, chipping, soil fertility, nutrient budgets, biomass, mulching, tree regeneration, soil chemistry, nutrient composition, soil solution, phenol.

INTRODUCTION

Several forest types, including lodgepole pine (Pinus contorta), are commonly harvested by clearcutting to insure regeneration of the harvested seral species. The practice is silviculturally sound, but it often leaves large quantities of unsightly debris. This debris is a fire hazard, may affect tree regeneration, and is a barrier to subsequent uses of the forest. Because of the problems attendant with logging slash, a cooperative study between the USDA Forest Service and U.S. Plywood-Champion Paper Company commenced in 1971 in western Wyoming.[1] This study assessed the economic and environmental feasibility of employing either of two levels of utilization coupled with four debris disposal methods following clearcutting old-growth lodgepole pine in the Union Pass area on the Bridger-Teton

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[1] The use of trade, firm, or corporation names does not constitute an official endorsement of or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

National Forest. This paper summarizes the effects of treatments over the first 5 years on the nutrient status and associated chemical characteristics of regenerating tree seedlings, the soil, and the soil solution.

SITE DESCRIPTION

The Union Pass area in western Wyoming is a gently rolling, extensively glaciated, high plateau approximately 3000 m in elevation. It is covered with a mosaic of large meadows and coniferous forests.

Slopes on the study area range from 5 to 25 percent, and elevations from 2800 to 2900 m. The forest stands are predominantly lodgepole pine, mostly overmature and becoming decadent (fig. 1). As classified by Reed (1969), the stands belong to the Picea engelmannii/Vaccinium scoparium habitat type.

Figure 1.--The old-growth lodgepole pine forest near Union Pass in western Wyoming, with a large volume of dead and down trees.

Prior to harvest the study area had a live volume of 363 to 501 m^3 per ha (5,182 to 7,167 ft^3/ac) and standing dead volume of 71 to 78 m^3 per ha (1,014 to 1,120 ft^3/ac) all cruised to a top diamter of 15 cm (6 in). Lodgepole pine comprised 75 to 90 percent of that volume, with the remainder being Engelmann spruce (Picea engelmannii), subalpine fir (Abies lasiocarpa) and limber pine (Pinus flexilis). The addition of smaller trees and dead and down material to the above values increased total preharvest volume of 663 to 757 m^3 per ha (9,480 to 10,825 ft^3/acre) (Gardner and Hann 1972).

The soils on the study site have developed in glacial till. The surface organic horizon in the forest, made up largely of decaying pine needles and twigs, is 2 to 3 cm thick. Below this, the surface mineral soil typically is loam with a platy structure. This grades into sandy to gravelly loam, with coarse fragments (> 2 mm in diameter) making up as much as half the volume below a depth of 1/2 m. The soils classify as Mollic Cryoboralfs and Mollic Cryochrepts.[2] Many roots are found in the upper 30 to 40 cm of mineral soil. Mottled and grey coloration, indicating a lack of aeration and sometimes water saturated conditions, frequently are found below depths of 1 m.

METHODS

Four units of approximately 8 hectares (20 ac) each were selected for clearcutting in 1971 (fig. 2). Two units were harvested using methods conventional in this region--trees were felled, limbed, cut to a 15 cm diameter top, and then tree-length skidded to landings with crawler tractors. The other two units were harvested using a mechanical feller-buncher; rubber-tired skidders hauled entire trees to landings, where the sawlogs were cut out and the remainder was chipped. All standing live and dead trees to 8 cm (about 3 in) in diameter, and all down logs to 15 cm diameter, were removed from these two "near complete" units.

After harvest, each unit was divided into quarters and alternative treatments applied to the logging debris. On each of the conventionally logged areas the debris was left as it fell for broadcast burning on two quadrants or piled with dozer blades into windrows on the remaining two quadrants. These windrows, where debris was concentrated on about 18 percent of the area, were burned a year later, in the fall of 1972. The broadcast slash was burned in June 1973. The "near complete" logged units were relatively free of coarse logging slash. The quadrants on these were either left untouched, or were mulched with a layer of woodchips equivalent in volume to the amount of nonmerchantable material that had been removed. Mulching with chips to an average depth of 10 cm was completed in the spring of 1973.

To study tree regeneration, the quadrants on all units were divided into thirds. In June 1973, one-third of each quadrant was planted to 2-0 lodgepole pine, one-third was spot seeded to lodgepole pine, and one-third was left to regenerate naturally.

In addition to the four study units, a fifth, conventionally logged, nearby unit was used for comparing soil solution chemistry under and between burned piles of logging debris. This unit was clearcut in 1973 and piled and burned in summer and autumn of 1974. Soil solution samplers were installed there in spring 1975.

Except for the fifth unit, data from the study area were gathered during five growing seasons after completion of all treatments.

Five planted trees and five seeded trees were sacrificed from each quadrant of each unit in 1977. Each tree was dissected into five components: (1) needles of current year, (2) needles of prior years, (3) terminals of current year, (4) remainder of above-ground portion of tree, and (5) roots. These were oven-dried and weighed, then analyzed quantitatively for contents of nitrogen, phosphorus, potassium, calcium, magnesium, sodium, zinc, iron, ash, and, in the case of planted stock only, boron. Similar, but less detailed, sampling and analyses of lodgepole pine regeneration were made in 1975, after three growing seasons. All chemical

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[2] Personal communication with A. R. Southard, Utah State Univ., Logan.

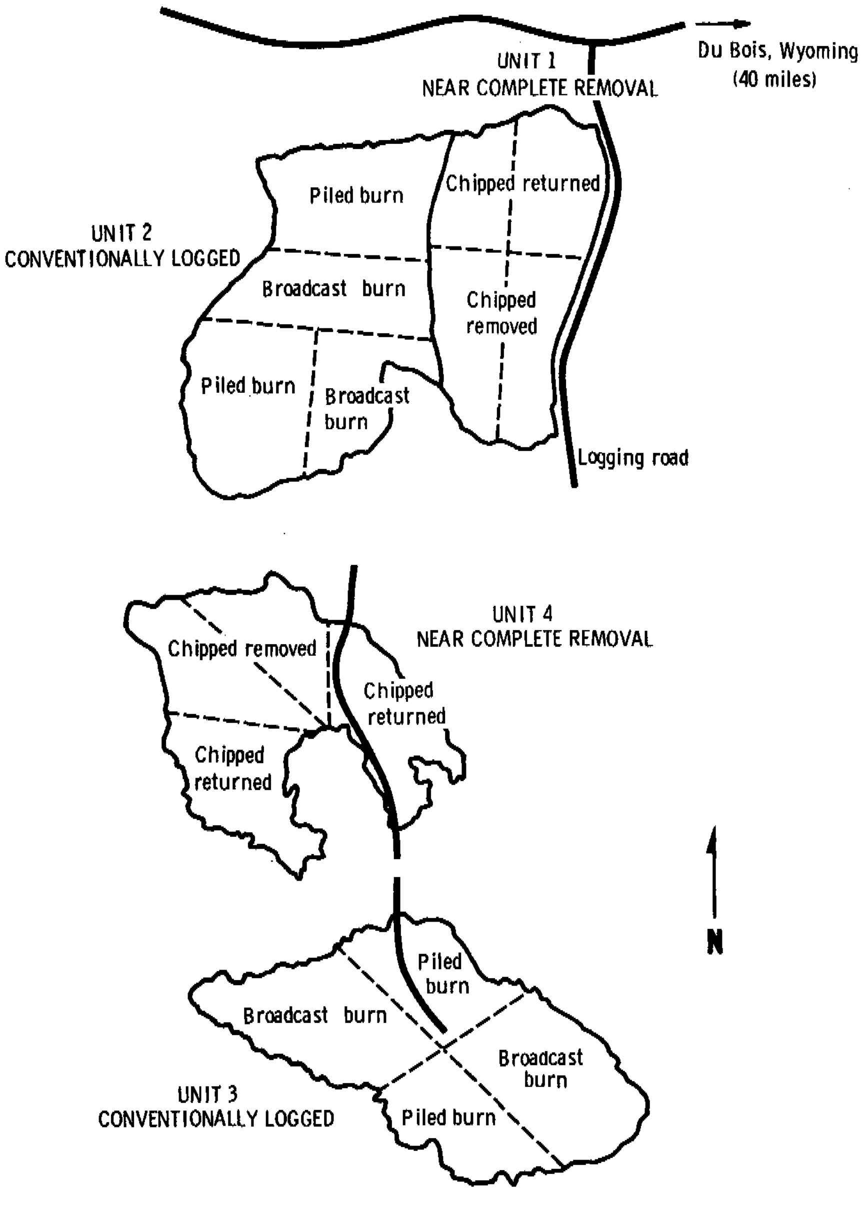

Figure 2.--Layout of treatments on the four clearcut units, each approximately 8 hectares.

analyses were conducted using commonly accepted techniques at the Soil Plant and Water Laboratory, Utah State University, Logan, Utah.

Samples of the organic, or ash, surface soil horizon, and the 0-5 cm and 5-15 cm depths of mineral soil, were taken at the initiation of treatments in 1972 and 1973 and again, in 1977. A sample from each depth was taken from every quadrant of all four units, with material from 20 or more random locations constituting each sample. Four samples from each depth also were taken from the undisturbed forest between Units #3 and #4 (fig. 2).

The surface organic or ash samples were analyzed for pH and total contents of nitrogen, phosphorus, potassium, calcium, magnesium, and, in 1977 only, sodium. Most of the mineral soil samples were analyzed for all of the above plus organic matter content, cation exchange capacity, available phosphorus, and total extractable (water soluble plus exchangeable) potassium, calcium, and magnesium. In addition, the 1977 mineral soil samples were analyzed for available sodium, boron, zinc, and iron.

With the use of ceramic cup extractors, the soil solution at depths of 60 and 120 cm (about 2 and 4 ft) was withdrawn under vacuum at several locations and times each growing season within all treatments, including the undisturbed forest, from 1972 through 1977. The samples were analyzed quantitatively for sodium, potassium, calcium, magnesium, nitrate, phosphate, total phenols, electrical conductivity, and pH.

RESULTS

Quantity of Debris

Harvesting and slash disposal left markedly different conditions on these units. Gardner and Hann (1972) and Benson (1974) reported the quantities removed. The quantity and nature of the biomass remaining is of particular interest now. The amounts of litter and debris less than 3 cm in diameter present on the soil surface after treatment were:

	Litter weight Kg/ha	Litter depth Cm
Undisturbed forest	35,494	2.6
Broadcast burned	34,995	1.8
Piled-burned (under piles)	31,985	1.7
Piled-burned (between piles)	33,222	1.3
Chipped-removed	42,213	2.4
Chipped-returned	180,582	11.7

More than 20 samples were used to arrive at each of the tabulated values. Within each group of 20 there was enough variation to mask any differences in weights that may have existed among most treatments. However, one treatment, the return of chips to the forest floor, was highly significantly different than the others.

In a post-logging inventory of these units, Brown (1974) found that near complete utilization produced almost as much fine debris (< 8 cm diameter) as did conventional logging; but, on the near-complete units there was only 1/5 as much larger diameter debris. The conventionally logged areas had 2.6 times more needles in the debris on the forest floor than did near-complete units.

Trees

Figures 3 and 4 show the oven-dry weights by components, of planted and seeded lodgepole pine harvested in August 1977 from each of the four treatments. Obviously, the chips-returned treatment produced the smallest trees, and the piled-burned treatment yielded the largest.

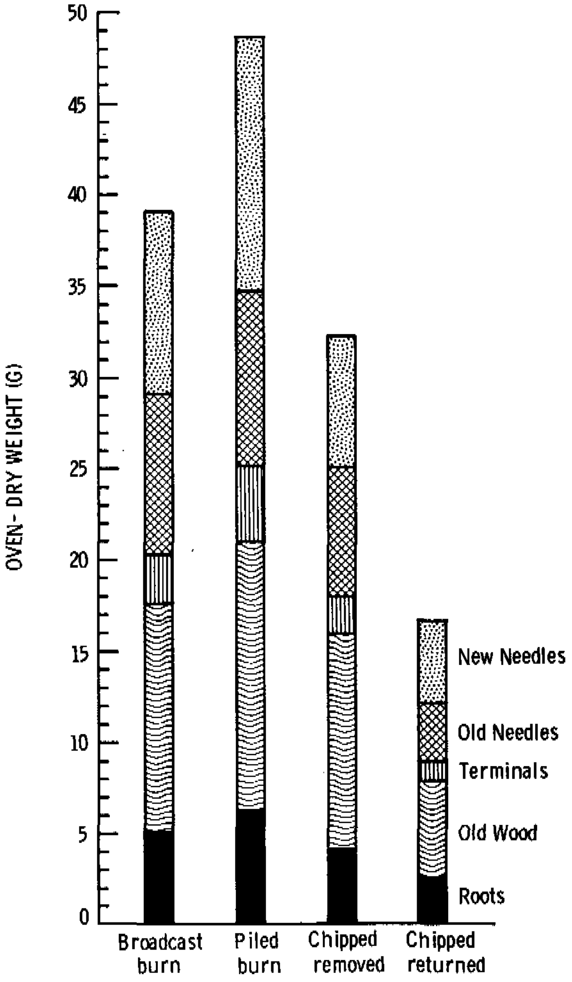

Figure 3.--Weights, by component, of typical lodgepole pine 5 years after planting on each treatment.

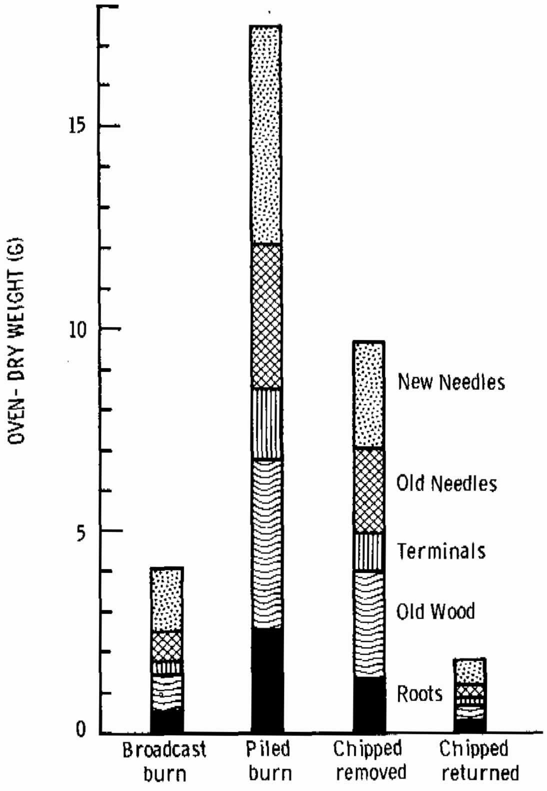

Figure 4.--Weights, by component, of typical lodgepole pine 5 years after developing from seed on each treatment.

In 1977, five growing seasons after planting and seeding, the surviving seedling densities per hectare were:[8]

	Planted	Spot seeded
Broadcast burned	1,505	914
Piled-burned	1,522	815
Chipped-removed	1,021	519
Chipped-returned	848	395

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[8] Data courtesy of W. C. Schmidt, Forest Service, Bozeman, Mont. A density of only one seedling per seed spot is assumed in this tabulation.

Weights of typical trees on these treatments are multiplied by the appropriate values in this tabluation to produce the biomass estimates per hectare shown in table 1.

Table 1.--Biomass in 1977 of planted and seeded lodgepole pine

	Broadcast burned	Piled burned	Chipped removed	Chipped returned
	------------------Kg/ha			------------------
Planted				
Above ground	48.3	61.2	26.9	11.2
Roots	7.3	8.8	4.4	2.1
Total	55.6	70.0	31.3	13.3
Seeded				
Above ground	2.7	11.4	4.0	0.5
Roots	0.7	2.0	0.6	0.1
Total	3.1	13.4	4.6	0.6

Nutrient and ash concentrations in the planted lodgepole pine are shown in table 2. Except for iron, the concentrations did not statistically differ with respect to treatment. Far less iron was found in the new needles from the chipped-removed and chipped-returned sites than from the broadcast burned and piled-burned treatment areas. A similar, but less marked, relationship held true for the iron contents of the other above-ground tree components. In contrast, the opposite occurred in the roots; the iron content of roots on the near-complete (chipped) units was more than twice that found on the conventionally harvested units.

Only four samples, of five trees each, make up each of the observations in table 2. As a result, the slightest variation within treatments masks any differences among them. The data indicate no marked nutrient deficiencies, supporting field observations of healthy stock on all but the chipped-returned treatment.

Multiplying nutrient concentrations by the weights of typical trees on these treatments produced results that show marked differences among treatments in the amount of some nutrients taken up by the developing tree biomass (table 3). But, this directly reflects the size and vigor of these trees, not their nutritional well-being. Gram for gram they all may be equally well nourished.

Soils

ORGANIC SURFACE

The nutrient content of the surface organic layer (Ao), including that of all chips and debris less than 3 cm in diameter, is shown in table 4. Over the 5-year post-treatment timespan, nitrogen and calcium contents generally increased, and potassium and magnesium contents decreased. Even though chips had lower concentrations of most elements than the usual forest litter, the large volume of chips on the chipped-returned site, in addition to the residual litter underneath, resulted in a larger quantity of every nutrient on this treatment than on any other. After 5 years, total nitrogen was least under burned piles, largely because it was volatilized when the organic material on the soil surface was burned. Phosphorus content of the forest litter seems to have been unaffected by treatment. The

Table 2.--Nutrient and ash content of 2-0 lodgepole pine five growing seasons after planting

Tree component and treatment	N	P	K	Ca	Mg	Fe	B	Ash
	Percent					p/m	p/m	pct
New needles								
Broadcast burned	1.26	0.15	0.66	0.15	0.11	110	16	2.4
Piled-burned	1.41	.17	.58	.14	.11	322	8	2.5
Chipped-removed	1.38	.16	.60	.15	.10	61	39	2.3
Chipped-returned	1.34	.18	.64	.14	.10	56	21	2.4
Old needles								
Broadcast burned	1.09	.11	.44	.26	.09	172	18	2.4
Piled-burned	1.24	.12	.43	.26	.09	228	22	2.7
Chipped-removed	1.26	.12	.45	.24	.09	123	20	2.5
Chipped-returned	1.34	.12	.48	.22	.09	112	30	2.5
Terminal shoots								
Broadcast burned	1.05	.13	.63	.11	.10	185	9	2.4
Piled-burned	0.90	.14	.57	.10	.11	210	16	2.5
Chipped-removed	0.86	.14	.59	.12	.10	128	15	2.6
Chipped-returned	1.10	.18	.65	.10	.11	112	21	2.6
Old wood								
Broadcast burned	0.46	.08	.34	.12	.09	302	14	2.1
Piled-burned	0.54	.09	.38	.12	.10	292	11	2.3
Chipped-removed	0.59	.09	.38	.14	.10	132	16	2.0
Chipped-returned	0.64	.10	.44	.12	.10	131	24	2.0
Roots								
Broadcast burned	0.42	.10	.38	.15	.15	1335	26	6.2
Piled-burned	0.44	.10	.37	.11	.13	1122	22	5.4
Chipped-removed	0.44	.10	.38	.18	.15	2732	15	6.2
Chipped-returned	0.62	.13	.44	.20	.18	2382	25	6.8

piled-burned treatments were lowest in potassium content, perhaps because the fine, nutrient-rich debris (leaves and twigs) was scraped away or burned, and because vegetative recovery was slowest on this treatment.

Table 3.--Nutrients and ash in biomass per hectare of surviving 2-0 lodgepole pine, five growing seasons after planting.

Treatment and tree component	N	P	K	Ca	Mg	Ash
	------------Grams/hectare------------					
Broadcast burned						
Needles	316	36	149	54	27	643
Wood, bark, buds	120	19	84	25	20	463
Roots	32	7	28	11	11	451
Total	468	62	261	90	58	1557
Piled-burned						
Needles	388	38	147	88	30	850
Wood, bark, buds	170	28	113	32	28	644
Roots	39	9	33	10	11	476
Total	597	75	293	130	69	1970
Chipped-removed						
Needles	185	20	74	27	13	337
Wood, bark, buds	81	12	53	18	13	268
Roots	20	4	17	8	7	275
Total	286	36	144	53	33	880
Chipped-returned						
Needles	83	10	35	11	6	152
Wood, bark, buds	36	6	24	6	5	105
Roots	13	3	9	4	4	141
Total	132	19	68	21	15	398

pH

The pH of each layer of soil sampled in 1977, 5 years after treatment, is illustrated in figure 5. Mineral soil pH under all but one of the treatments was essentially the same, averaging 5.2. Under the burned piles it was markedly higher--6.4 in the 0-5 cm depth and 5.7 in the 5-15 cm depth. The pH of the organic surface horizon was less uniform. It was 5.8 and 6.4 in the ash-litter-duff mixture on the broadcast burned and piled-burned treatments, respectively, still reflecting the changed physical conditions and the release of cations triggered by burning 5 years earlier. In contrast, the slowly decomposing chip mulch had a pH of 4.6, more acidic than the underlying mineral soil.

The year after burning, in 1973, the pH under the burned piles was 7.2, 6.5, and 5.3 in the Ao, 0-5, and 5-15 cm soil depths, respectively. In the areas broadcast burned 2 months before sampling, pH was 6.2, 4.8, and 5.0 at the same depths. Burning immediately changes the pH of the organic surface layer. Leaching of soluble material from that layer by subsequent precipitation later raises the pH of the mineral soil beneath. Those changes were present a year after burning and have remained for several years. Other treatments did not significantly change mineral soil pH.

Table 4.--Nutrient content of the surface organic (Ao) horizon

Nutrient	Year	Treatment					
		Undisturbed forest	Broadcast burned	Piled burned (under)	Piled burned (between)	Chipped removed	Chipped returned
		Kilograms/hectare					
Nitrogen	1972-'73	462	349	129	346	306	---
	1977	504	446	288	305	458	569
Phosphorus	1972-'73	34	56	52	32	41	---
	1977	39	38	32	27	38	78
Potassium	1972-'73	96	118	120	79	132	---
	1977	68	66	51	50	73	166
Calcium	1972-'73	175	318	347	129	188	---
	1977	335	419	359	220	299	457
Magnesium	1972-'73	61	105	108	90	98	---
	1977	82	84	64	61	77	185
Sodium	1972-'73	---	---	---	---	---	---
	1977	5	4	4	3	4	11

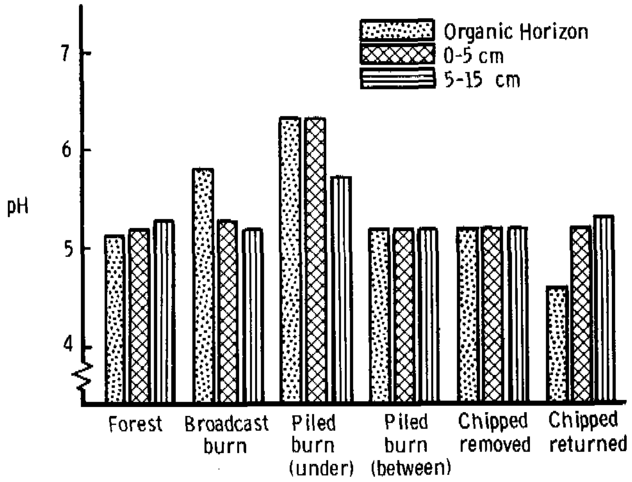

Figure 5.--Soil pH some 5 years after treatment.

MINERAL SOIL

Total nutrient content

The total amount within the soil, plus small increments in precipitation, make up the entire supply of many essential nutrient elements. The total nutrient content of mineral soil reflects its mineralogical composition and the composition of its organic component. Total supplies of most nutrient elements are essentially stable, and were relatively constant across all treatments in this study. Total nutrient contents of four essential elements in the surface 15 cm of these soils, averaged across all treatments and years, in kilograms per hectare were:

Phosphorus	915
Potassium	5 136
Calcium	4 529
Magnesium	8 003

Nitrogen presents a special case, since most of it is tied up in the organic fraction. As the content of organic matter varies, so will the content of total nitrogen. Total nitrogen supply in 1977 was as follows:

	Depths		
	0-5 cm	5-15 cm	Total
	----------Kg/ha----------		
Forest	962	1 040	2 002
Broadcast burned	1 359	1 313	2 672
Piled-burned (under)	1 050	1 288	2 338
Piled-burned (between)	1 179	1 221	2 400
Chipped-returned	1 044	1 180	2 224

Per unit of depth, there was almost twice as much nitrogen in the surface 5 cm of mineral soil than in the next 5-15 cm layer.

Organic matter content

The content of organic matter in the surface 5 cm of the undisturbed forest soil ranged between 5 and 6 percent. In the 5-15 cm layer it declined to half this concentration. The organic fraction of the surface 5 cm under each of the treatments were:

	1972-1973	1977
	-----Percent-----	
Forest	6.0	5.2
Broadcast burned	7.2	5.9
Piled-burned (under)	6.9	4.1
Piled-burned (between)	7.1	4.6
Chipped-removed	6.6	5.9
Chipped-returned	7.1	8.6

Logging, broke up the fine organic debris in the A_0 horizon and incorporated it into the mineral soil beneath, likely causing the initial increase in organic matter content in 1972-1973. Burning and decomposition of this increment (and of the residual organic material in the surface 5 cm) no doubt produced the decline shown in 1977 on most treatments. During this timespan new plant growth added little organic matter to the soil on these clearcut sites; hence, the decrease could be expected.

Available nutrients

Table 5 shows the amounts of available nutrient elements (except sodium) extracted from the 1977 soil samples. Total extractable sodium was the same for all sites--approximately 0.1 meq per 100 g of soil at both depths.

Available phosphorus was almost twice as abundant in the surface soils 5 years after logging than it was in the undisturbed forest. The largest quantity was found under chip mulch, followed by the soil under burned piles. In contrast, the soils between burned piles did not differ significantly from those of the forest.

Table 5 expresses potassium, calcium, and magnesium cations in the form of milliequivalent weights of the total extractable amounts per 100 g of soil. The total extractable amount is the sum of the exchangeable content plus the water soluble content. Exchangeable cations comprised 90 percent or more of the total extractable cations in these soils.

Extractable potassium was greatest in 1977 at both depths under the burned piles of debris. Otherwise, the amounts of this element did not differ significantly among treatments. There was about 20 percent more potassium in the surface 5 cm of soil than in the 5-15 cm depth.

Logging increased slightly the amounts of extractable calcium in soils. In 1977 the surface 5 cm of soil under the burned piles contained almost twice the calcium concentration of the undisturbed forest, this amount--14.6 meq per 100 g--was significantly greater than all others. The highest amount of calcium in the next 10 cm layer also were found under this treatment. Levels of extractable magnesium, a similar divalent cation, followed the same pattern. There was only

Table 5.--Concentrations of available nutrients in mineral soil in 1977

	Available	Extractable			Available		
Depth and treatment	phosphorus	Potassium	Calcium	Magnesium	Boron	Zinc	Iron
0-5 cm:	p/m	Meq/100 g			p/m		
Forest	31.2	0.50	7.55	1.42	1.65	4.08	230.
Broadcast burned	50.8	0.58	9.95	1.98	1.58	7.12	206.
Piled-burned, under	60.8	0.68	14.60	2.05	1.62	12.25	302.
Piled-burned, between	48.8	0.50	7.18	1.62	1.05	4.45	219.
Chipped-removed	59.2	0.58	8.80	1.82	1.82	3.88	241.
Chipped-returned	67.5	0.55	8.22	1.72	1.78	4.08	446.
5-15 cm:							
Forest	34.8	0.42	4.68	0.98	0.85	1.55	256.
Broadcast burned	49.2	0.40	5.40	1.25	0.65	2.20	266.
Piled-burned, under	56.2	0.60	6.78	1.62	1.50	4.95	305.
Piled-burned, between	48.0	0.40	5.72	1.25	1.22	7.32	280.
Chipped-removed	55.5	0.45	6.02	1.35	0.95	2.10	284.
Chipped-returned	62.2	0.45	6.10	1.40	0.90	2.60	445.

about a fifth as much extractable magnesium in these soils as there was calcium, however, despite the fact that the total amount of magnesium is twice that of calcium. The concentrations of the extractable forms of both elements were a fourth to a third greater in the surface 5 cm of mineral soil than they were below that depth.

The amounts of available boron showed no particular pattern with respect to treatments or depths. Boron concentration appeared to be slightly less in the deeper soil layer, however.

Zinc, in the 0-5 cm layer, was two to three times more concentrated under the burned debris piles than on any other treatment, a highly significant difference. Higher zinc concentrations, though not statistically significant, also occurred on the broadcast burned sites. Lesser concentrations of this element occurred in the 5-15 cm layer, although the same pattern seemed to hold true.

Iron was significantly concentrated in both layers of soil under the chip mulch--twice as concentrated as in the undisturbed forest. The next greatest concentration occurred under the burned piles. Both soil layers had about equal concentrations of this relatively abundant element.

Cation exchange capacity

The quantity of available metallic nutrients retained by soil depends upon the soil's cation exchange capacity, which, in turn, depends upon the nature and amount of clay and the amount of organic matter in the soil. Most of the cation exchange capacity of these soils is in the clay fraction--a parameter not likely to be altered much by the imposed treatments. The cation exchange capacity of the surface 5 cm averaged 18.63 meq and that of the 5-15 cm layer averaged 15.27 meq per 100 g of soil.

The four cations quantitatively analyzed in 1977 (potassium, sodium, calcium, and magnesium) occupied a bit less than half the average exchange capacity in the undisturbed forest, about half of this average under four of the treatments, and nearly three-fourths of it under the burned piles.

Soil Solutions

From 1972 through 1977 more than 600 samples of soil solutions from 44 tubes under the six treatments were analyzed. The average concentrations of each element for this period are summarized in table 6. Not all treatments were in effect for this entire time. Only two treatments--forest and chipped-removed--produced records for all 6 years; piled-burned (under) data cover 3 years; conventional clearcut only 1 year; all others produced 5 years of data.

Potassium concentrations increased under the chip mulch and under both burning treatments (broadcast and beneath piles). This increase was most permanent, lasting up to 5 years, under the chip mulch, whereas the effects diminished rapidly after 2 years under the broadcast burn. Sodium increases due to treatment were greatest beneath burned piles.

Slightly higher concentrations of magnesium were observed on the treated sites, especially under chipped-returned and the burns. The duration of these effects was similar to that of potassium. Calcium levels increased and persisted under all treatments. Clearcutting alone appeared to be the primary cause for the increase of both calcium and magnesium, with the chip mulch and the ash concentration under burned piles contributing additional amounts under these two treatments.

Table 6.--Average concentrations of nutrients in soil solutions

	Treatment					
Nutrient	Forest	Broadcast burned	Piled burned (under)	Piled burned (between)	Chipped removed	Chipped returned
	Mg/l					
Nitrate-nitrogen	0.1	1.5	4.4	1.2	1.0	0.9
Potassium	0.6	1.6	2.0	1.0	1.0	1.6
Calcium	2.6	5.3	11.9	4.2	4.2	6.8
Magnesium	0.7	1.4	3.3	1.1	1.1	1.6
Sodium	1.4	1.1	2.2	1.0	2.0	1.2

All residue disposal methods produced increased concentrations of nitrate-nitrogen. The percent increase varied from 2- to 100-fold, over that found in soil solutions under the undisturbed forest. Ten soil solution samples, eight of which were taken from beneath burned piles, exceeded the maximum concentration of 10 mg/l established for public water supplies.

Total phenol concentrations during the first year ranged from practically none under undisturbed conditions to 0.622 mg/l under chipped-returned and to 0.188 mg/l under the chipped-removed treatment. Thereafter phenol concentrations declined markedly, reaching pre-treatment values by 1975. The phenols came from a breakdown and leaching of fresh organic debris--from the chip mulch and from the needles and fine debris incorporated into the surface mineral soil on the "near complete" utilization units.

DISCUSSION AND CONCLUSIONS

Growth rates of both planted and seeded lodgepole pine differed markedly among the four clearcutting and slash disposal treatments. Hopefully, quantitative analysis of soil and plant tissue would help explain some of this variation. But, despite gathering a wealth of data that describe the trees and the sites upon which they were growing, this primary objective was not met. There were no statistically valid differences in nutrient concentrations within these trees that explain their different growth rates. Admittedly, iron concentration in the above-ground portion, especially in new foliage, was greatest on the piled-burned sites and least on the chipped-returned sites. This correlates directly with tree growth. However, even the lowest iron concentrations appear to be more than adequate for satisfactory conifer nutrition (Leaf 1973).

Logging and slash disposal directly affect the surface (A_0) organic horizon of forest soils. Most obvious are physical effects such as the disturbance of this layer and its partial incorporation into the mineral soil beneath. Logging usually adds fine debris to the A_0 horizon. On one of the treatments in this study there was an even greater addition by mulching with chips. Broadcast burning, in contrast, often removes part or all of this horizon, and always deposits a layer of ash on the surface. Use of dozers to pile logging debris has the greatest physical impact on the surface organic layer--often completely removing it and always exacerbating the physical disturbance from logging.

The immediate physical changes in the surface organic layer, the removal of the forest overstory, and microclimatic changes at and near the soil surface, all contribute to chemical and physical alteration of both the surface organic horizon and the mineral soil beneath. This is true for a period of years or even decades after clearcutting and slash disposal. Many of the changes cited in this study were recorded at the end of 5 years--long enough after treatment to miss any immediate and transitory effects, but late enough for more subtle and long-term effects to have emerged. For example, the data in table 4 show an increase in potassium in the A_0 horizon during the first year after treatment. The increased amount of this readily soluble element, however, was largely gone after 5 years. During this time span, many of the losses or changes in the surface organic horizon exhibited their influence on measurable parameters in the mineral soil. For example, the potassium content of mineral soil had increased under most treatments by 1977 (table 5).

The mineral soil, immediately after logging and slash disposal, is less severely impacted than is the surface organic layer. Nevertheless, the mineral soil may be physically altered. Porosity, bulk density, organic matter content, and related hydrologic characteristics are often immediately changed (Packer and Williams 1976, and *this volume*). Chemical changes in the mineral soil are most pronounced after thorough leaching by rainfall or snowmelt water. This water dissolves the soluble components in the logging slash, the ash layer (if fire was employed after logging), and the surface organic soil horizon. The water then moves these solutes into the mineral soil, where they are precipitated and picked up by the ion exchange system, or where they otherwise alter the chemical characteristics of mineral soil horizons.

The pH of acid soils rises when enough cations are leached from surface materials. This alteration lasted 5 years only under burned piles of slash on the studied sites (fig. 5). Only here was there a sufficient spike of soluble cations to have a lasting and measurable effect. It is possible, however, that the lower pH of the slowly decomposing wood chip mulch will result in a decrease in mineral soil pH on these sites in future years.

The organic matter content of the surface mineral soil increased during the logging operation. Afterwards the lack of annual additions through litter-fall caused a decline on most treated sites. It is uncertain at this point in time if organic matter contents will continue to decrease on these treated sites due to decay rates exceeding the input of plant remains, or if relative stability has been reached. In general, the content of total nitrogen and, to a lesser extent, phosphorus will parallel that of organic matter content because almost all of the nitrogen and about half of the phosphorus are part of organic compounds.

In terms of plant nutrition, the content of available nutrients perhaps was the most important parameter measured in these soils. It must be kept in mind, however, that the laboratory techniques used to measure available nutrients provide only approximations of what is available for uptake by plant roots. They sometimes are poor approximations, particularly for forest tree nutrition.

The treatments--especially the piling and burning of slash--are the implied cause for significant differences in available nutrients on these sites in 1977. Clearcutting and most slash disposal treatments usually increased available nutrients. An exception occurred between burned piles, where dozer operations frequently removed the nutrient-rich surface soil and pushed it into the slash piles. These piles of logging debris occupied about 18 percent of the clearcut area. Hence, piling caused a five-fold concentration of nutrients held in the slash and surface debris on these sites. Burning then transformed the nutrients into relatively soluble forms that leached into the mineral soil.

Mulching with wood chips may further increase available nutrients in the surface mineral soil. Except for increasing available phosphorus and iron, mulching with chips seemed to have produced no real differences in nutrient concentration 5 years after treatment. The chips are decaying very slowly; as a result, they are not releasing structural elements very rapidly. In addition, the mulch alters the soil microclimate, potentially altering the amount of some available nutrients as well.

None of the measured nutrients needed for tree nutrition appeared to be lacking. This is borne out by the treated site with the lowest available nutrient quantity (between piles) producing the largest tree seedlings.

The chemical composition of soil solutions within the rooting zone represents a measure of water soluble nutrients, those that are very readily available for use by plants. As with available nutrients in the soil, clearcutting alone seemed to increase nutrient concentrations in soil solutions. Some slash disposal treatments, especially burning, added to this increase.

Available nitrogen was not quantified in the soil samples because it is known to vary too much through the growing season to make a one-time measurement very meaningful. However, one of the most available forms of nitrogen, nitrate, was determined in the soil solution samples. Obviously, there was a marked increase due to forest harvest, coupled with an additional increase due to burning. These increases could represent an increase in nitrification rates, and a reduction in nitrate uptake by plants on these treated sites. The latter would explain, at least partly, the fact that nitrogen levels were almost ten times greater on all treatments than in the undisturbed forest. The former would account for even greater nitrate quantities after burning.

Substances found in the soil solution within the rooting zone may still be present in this solution after it moves below the zone tapped by plants. Then, if these substances are in sufficient concentration, they may become pollutants of ground water or of interflow to streams and lakes. In this respect, the increased nitrate concentration under burned piles is a potential pollutant. Of the nutrients measured in soil solutions, only nitrate was concentrated enough to be of concern, and then in only a few samples from the burned treatments. Considerable dilution of these nitrate concentrations is virtually certain by the time they reach the stream, however.

Fresh organic debris, especially the chip mulch, contributed phenols to the soil solution in sufficient concentration during the first couple years to be of concern. As a group, phenols are very toxic, and even in low concentrations they affect water odor and may taint the flesh of fish. Accordingly, maximum concentrations of 0.1 mg/l for fishery habitats and 0.001 mg/l for public water supplies have been established (EPA 1973). If large areas of a watershed were mulched with a thick layer of conifer wood chips, it is quite conceivable that pollution of percolating waters and streamflow with phenols would result. Unfortunately, this study design did not permit the tracing of phenol movement beyond a meter depth in the soil.

In summary, the nutrient status of surface soil layers, soil solution, and lodgepole pine seedlings was measured over a 5-year period after clearcutting and slash disposal. Generally, harvesting led to an increase in the nutrient content of both the soil and the soil solutions, probably because nutrient cycling was interrupted. Burning of logging debris after conventional clearcutting further increased some nutrients. Mulching with wood chips from unmerchantable material after "near-complete" harvesting caused some nutrient changes in the soil; but, perhaps more important, this mulch contributed a flush of phenols to the soil solution. The different amounts of survival, growth, and vigor of tree seedlings under various treatments apparently had nothing to do with differences in nutrient status. None of the measured plant nutrients appeared to be limiting tree growth.

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RESIDUE DECAY PROCESSES AND ASSOCIATED ENVIRONMENTAL FUNCTIONS IN NORTHERN ROCKY MOUNTAIN FORESTS

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ABSTRACT

Decaying and decayed wood has received little attention in its relationships to the properties and functions of forest soils, although it is recognized that decay of woody substrates in forested ecosystems constitutes a major pathway for carbon and nutrient recycling.

Results from our investigations indicate that brown-cubical decayed wood in soil is more functionally unique than previously thought. Wood in soil exhibits functions and characteristics that are similar to those of other soil components, but in some instances performs more efficiently. Wood in soil is an efficient medium for storing nutrients and water. It also provides a place for growth of tree roots and certain fungi that together form "mycorrhizae"... structures essential to tree establishment, survival, and growth in western forests. Decayed wood is an important site for the biological fixation of nitrogen gas from the atmosphere. Since soil wood is an important part of soil structure and function, it is necessary to determine how much residue (wood) can be removed for further utilization and product development without precipitating site deterioration. By assessing the impact of increasing levels of utilization <u>before</u> forest harvesting and utilization, long term site deterioration or damage may be avoided.

KEYWORDS: decay, lignin, fungi, bacteria, N_2-fixation, soil wood, mycorrhizae, psychrophiles, nutrient cycling

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[1] Maintained at Madison, Wisconsin in cooperation with the University of Wisconsin.

INTRODUCTION

The use and future needs of wood fiber in the forms of lumber, paper products, chemicals, and as a source of energy have been escalating at an alarming rate. To alleviate these demands, wood resources can be increased by (1) recycling, (2) accelerating timber production, (3) the replacing of wood and conventional wood usage by alternative materials, (4) intensifying silvicultural practices, (5) intensive utilization of forest residues, and (6) protection from biological and physical degradation.

Part of our purpose has been to assess the significant long-term implications, from short-term experimental approaches, of intensive residue (biomass/fiber) utilization. We are questioning how much fiber, in specified quantity, form, and distribution, can be removed from any given site by prescribed harvesting without precipitating short- or long-term deleterious consequences.

In addition to fiber removal by man, natural agents--notably decay and fire--play an integral role in reducing organic resources. While decay is usually viewed as a long-term process of biomass volume reduction, fire produces immediate and long-term environmental effects similar to those of near-complete biomass utilization. In any given forest ecosystem there is a finite amount of energy available for biomass production, and decay and fire maintain a balance between production and decomposition. Therefore, there is a need to define the optimum levels of the end products of decay in terms of site needs for existing or long-term site productivity and to integrate these needs into forest management.

THE ROLE OF BIODEGRADATION IN FOREST ECOSYSTEMS

Decay or biodegradation are caused by a variety of processes, organisms, and interactions between the two. Decomposition is an ongoing, everpresent process in living and dead plants. A myriad of microorganisms including auto- and heterotrophic fungi and bacteria, streptomycetes, protozoa, and invertebrates contribute individually or collectively toward decay. Climatic weathering and interactions of the substrate with existing flora also have significant impacts. The end products of biodegradation of woody substrates are carbon dioxide, water, and a stable (but biodegradable) complex of phenolic components derived from the lignin portions of woody plants and, in some instances, fungal melanines. A major influence of this organic matter, which is phenolic in nature, is the enhancement of soil structure and function. Therefore, the principal role of decay is the recycling of carbon in the ecosystem. During this recycling process, decaying organic matter influences the structure and function of the system and acts as a nutrient source. The rates of decomposition and nutrient release are functions of the environment.

THE NATURE OF CONIFEROUS AND ANGIOSPERMOUS WOODY SUBSTRATA

To understand the processes of decay and its functional end products, an understanding of the compositions of woody material of angiosperms (hardwoods) and gymnosperms (softwoods) is necessary. Also, their major geographic and climatic distribution appear to be of fundamental importance.

The hardwood or angiospermous timber type is confined to eastern and north-central United States. There are exceptions however, where elevation or other significant site factors exist and coniferous or gymnospermous trees become the predominant type. In contrast, the western forest--whether in the Intermountain, Cascade, or Coast Ranges--is predominantly gymnospermous or coniferous. In terms of climatic distribution, hardwood forests predominate east of the 15+ inch precipitation isobar, while, to the west of that isobar, coniferous forests are prevalent. These forests are associated with high and low humidities, respectively.

Structurally, wood is comprised of three major polymeric substances: lignin, cellulose, and hemicelluloses. Although the cellulosic portions of hardwoods and conifers are similar, there are differences in the quantity and type of lignin content. Lignin is a generic name for the complex aromatic polymers that are major components of vascular tissues (stems) of terrestrial plants (Kirk and Fenn 1980). Woods of conifers are 24 to 30 percent lignin (table 1), while hardwood is 19 to 25 percent lignin. Also, there is a fundamental difference in the chemical structure of lignins of hardwoods and conifers (fig. 1). Conifer lignin is formed principally from gauiacyl moieties and is called "guaiacyl" lignin. In contrast, most hardwood lignins in addition to guaicyl, contain large proportions of syringyl moieties and are termed "syringyl" lignins.

Table 1.--Composition of ash-free wood and bark (pct).

	Softwoods[1]		Hardwoods	
	Wood	Bark	Wood	Bark
Lignin[2]	24-30	45-55	19-25	40-50
Carbohydrate	66-72	30-48	74-80	32-45
Other	2.2-9.6	Up to 25	2.2-5.6	Up to 20

[1] Mixture of the lignin and suberized phlobaphene.
[2] Based on extractive-free material.

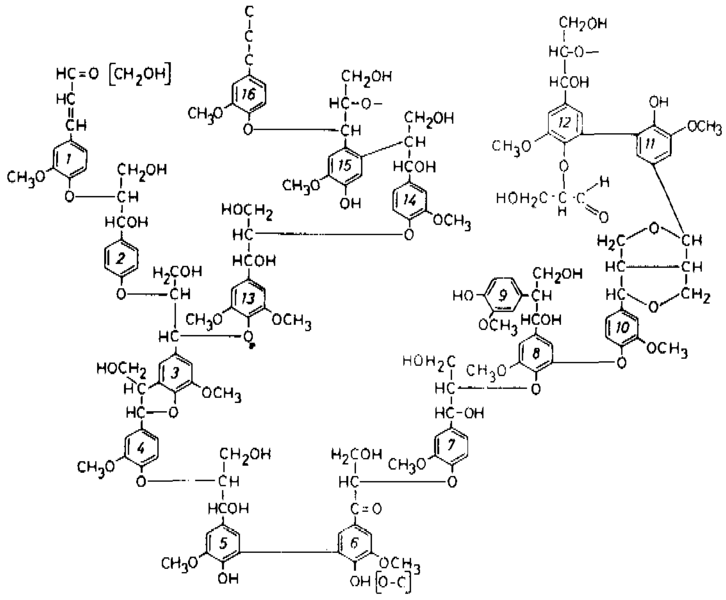

Figure 1.-- Proposed structure of lignin polymer depicting interunit linkages found in angiospermous and gymnospermous lignins (Kirk and Fen 1980).

DECAY SYSTEMS

Types of decay in the major groups of woody plants are of two major kinds: white rots and brown rots. Typically, white-rot fungi depolymerize cellulose and hemicellulose at similar rates and lignin at a similar or somewhat faster rate. Brown-rot fungi depolymerize cellulose and hemicellulose and leave the lignin essentially unchanged, though there is demethylation of the polymer and the accumulation of lignin degradation products (Highley and Kirk 1980).

There are also indications that the extractive content of heartwood and sapwood, particularly in coniferous substrata, exerts a limiting or selective influence on the activities of both brown-rot and white-rot fungi. In coniferous residues, initial sapwood decay appears to be of the white-rot type, which eventually shifts to brown-rot. Heartwood is usually decayed by the brown-rot fungi. The present understanding of the distribution is not a clear one.

In the intermountain regions of the western United States, the principal decay process for large-dimensional dead coniferous woody materials is the brown-rot type. The end products are apparently a function of the interaction between lignin-type, temperature-moisture (T-M) regimes, and associated decay microorganisms (fig. 2).

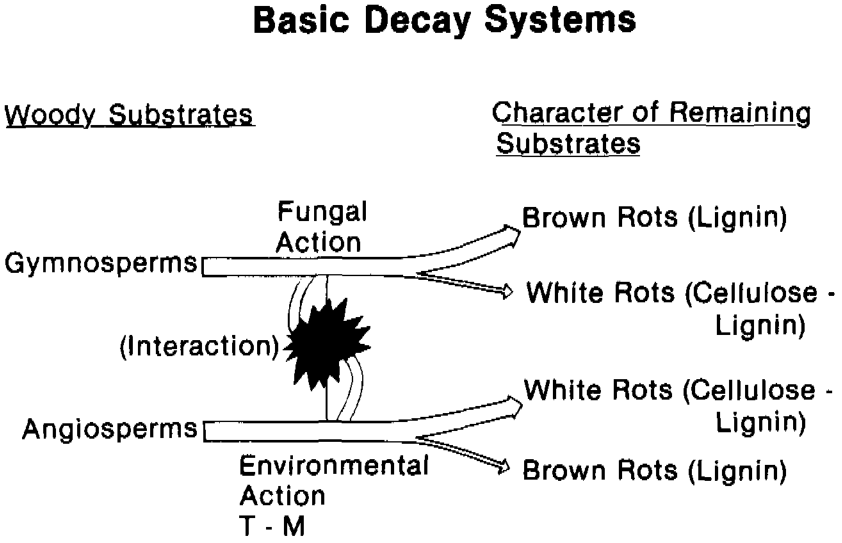

Figure 2.-- Major decay pathways in angiosperms and gymnosperms.

Principal Environmental Parameters Associated With Decay

Moisture and temperature regimes are the two primary controlling factors in wood decay processes. The effects of both are critical to the survival of decay fungi at two points in their life-cycles: spore germination and vegetative growth. The temperature and moisture requirements are not the same--spore germination and initial substrate colonization operate within narrower limits than the vegetative growth associated with decay processes. Because of the differences between these two stages, spore germination and initial substrate penetration would be a greater limiting factor to decay.

TEMPERATURE

Most decay fungi are mesophiles and are unable to grow vegetatively above 40°C. They have temperature optima between 25-30°C. Jensen (1967) indicated that minor fluctuations in temperature stimulated growth. For many fungi, minimum temperatures for growth are below 0°C (Pechmann 1966). Apparently, fungi are able to extend the vegetative fungal body to a considerable degree in woody tissues during the winter. In fact, exposure to cold may cause or stimulate growth when temperatures become optimal (Pechmann 1966).

Temperature extremes and moisture deficits have been reported as decay limiting by Hubert (1920), Spaulding and Hansborough (1944), and Childs and Clark (1953). Lohman (1962, 1965) indicated that unfavorable temperature-moisture regimes in lodgepole pine (*Pinus contorta* Dougl.) slash were the principal limiting factors to the onset and continuation of decay. Higher temperatures in the wood's upper 5 cm favored, by selection, *Phlebia phlebioides* (Jack and Deard.) Donk and *Gloeophyllum seapiarium*, (Wulf. ex Fr.) Karst., whereas *Haematosterium sanguinolentum* (Alb. and Schw. ex Fr.) Pouz. and *Coniophora puteana* (Shum. ex Fr.) Karst., with low temperature optima, were recovered at depths in wood greater than 5 cm. Lohman (1962, 1965) attributed the presence of low-temperature fungi in upper parts of slash to the occurrence of wet and moist periods. Aho (1974) reported that few heat-tolerant fungi are normally found in the middle and lower portions of slash piles.

Data (fig. 3) collected by Hungerford (1980) also demonstrate that residue surface temperatures approach levels that would limit biological activity, particularly spore germination and initial colonization. In contrast, internal temperatures were lower and well within the range of temperatures required for decay activity. Temperatures at the surface of the underside of selected residues also were conducive to fungal activity. Furthermore, the amelioration of higher soil temperatures at or near the surface by soil-wood was also noticed.

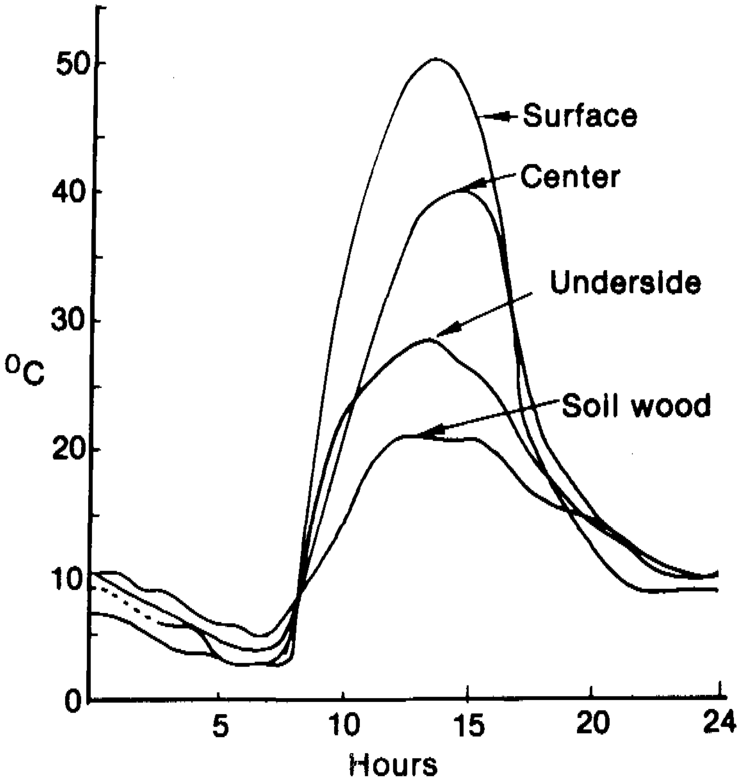

Figure 3.-- Relationship of temperatures of suspended residues and decayed wood partially buried in the soil.

Natural inoculation of residues may occur in two ways: through spores and through vegetative hyphal growth. Spore inoculation may occur on any surface; inoculation by vegetative hyphae usually will occur only from soil or wood on the undersides of residue. Initial decay in conifer residue occurs on the underside in contact with soil and is usually of the white-rot type. Decay on the upper surface or the sides is usually of the brown-rot type. Aho (1974) states that decay progresses faster in residues in contact with the soil.

MOISTURE CONTENT

Moisture availability is a primary controlling factor in decay. Pechmann and others (1967) reported that substrates with moisture contents below 30 percent or above 120 percent were not colonized by most fungi, particularly decay fungi. Etheridge (1958) noted that moisture content of heartwood is dependent on species and site and generally is less than sapwood moisture contents, although there are exceptions. Etheridge (1958) also noted that even minor changes in moisture content had significant effects on decay rates. Wood in contact with the soil readily absorbs moisture from it. Other factors also contribute to increased residue moisture content and increased decay: shading, north-facing slopes, elevation, compaction/stratification of wood residues, amount of soil organic matter, and temperature.

As decay progresses, pore volume of the woody substrate increases, facilitating the total amount of moisture that potentially could be present (fig. 4). Figure 5 reflects the effect of pore volume in terms of moisture holding capacity on the Coram site between the control and clearcut-intensive utilization treatment. The data indicate the soil-wood moisture contents are not affected by treatment and, as a result, woody residues in this form would alleviate moisture stress in clearcut areas.

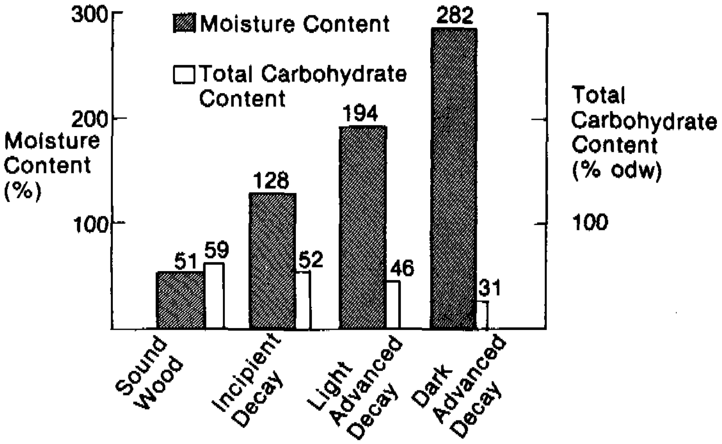

Figure 4.-- Relationship between moisture content and decay progression in brown-rotted Douglas-fir. Decay associated with Fomitopsis pinicola. (Coram Experimental Forest, September 1977. All moisture content values significantly different from each other: pF 0.01).

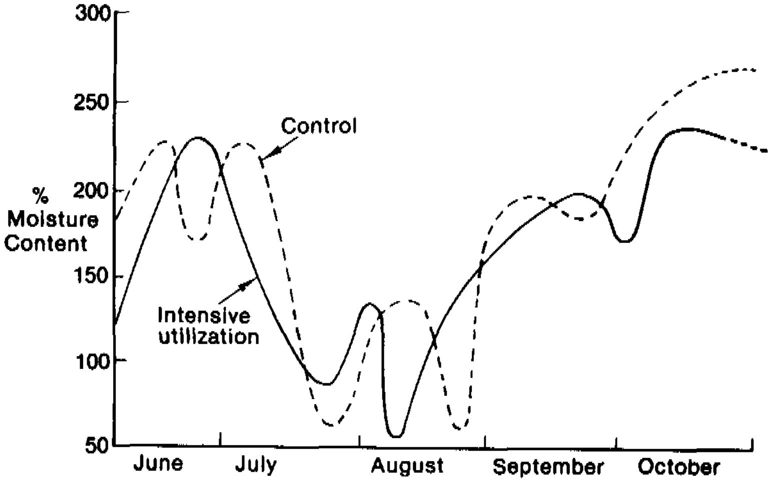

Figure 5.-- Seasonal variation of moisture content in soilwood.

HYDROGEN ION CONCENTRATION

Wood pH is controlled primarily by the presence of acetic and formic acids. Acidity (pH) in sound conifer wood varies between 2.7 to 8.8. Brown-rot fungi apparently can withstand acid conditions better than white-rot fungi (Henningson 1967). Highley (1976) reported that fungal cellulases and hemicellulases of brown-rot fungi were more tolerant of lower pH's than white-rot fungi. Furthermore, brown-rot fungi lower the pH during the decay process through oxalic acid production (Takao 1965). Also, white-rot fungi utilize acetic acid. Our pH measurements on brown-rotted wood agree with these observations. Decaying and decayed brown-rotted wood, in or on soil profiles, is significantly more acidic than other soil components. The acidity of this substrate appears to have significant implications for forest management, particularly regeneration.

Microorganisms Associated With Residue Decay

Analysis of the microbial flora associated with residue decay on the Coram Experimental Forest, in Montana has provided some insight into occurrence of decay fungi and also into the associations that exist between decay fungi, yeasts, bacteria, and non-hymenomycetes. The information assembled to date is provocative in the sense that it suggests that organism association (and possible interaction) may be important in the brown-rot process producing brown-cubical decayed wood. The interactions may also provide insight into decay mechanisms.

On the Coram site, brown-rot fungi isolated from woody residues were more numerous than white-rot fungi (ratio ca 5:3). *Poria placcenta* (Fr.) Cooke and *Gloeophyllum seapiarium* (Wulf. ex Fr.) Karst., both brown rotters, were more consistently associated with larger diameter material (4" diam. or greater). *Poria cinerascens* (Bres.) Sacc. and Syd., and *Aleurodiscus lividocoeruleus* (Karst.) Lemke, both white rotters, were more prevalent in small dimension (up to 2" diam.) material. These observations reinforce the view that the conifer lignin type and the increase in extractive content in larger, older materials favors brown rot fungi.

PROPERTIES AND FUNCTIONS OF BROWN-CUBICAL DECAYED WOOD

After studying red spruce (*Picea rubens* Sang.) and yellow birch (*Betula alleghaniensis* (Britt.) sites in the Adirondack Mountains, McFee and Stone (1966) reported that woody residues made up 26 percent of the total humus layer and that 30 percent of a 24-foot transect approximately one-foot deep was comprised of woody tissues. They estimated that these "masses" of brown-cubical decayed wood remain in the soil profile for more than 100 years.

Decaying wood has been implicated in the process and success of tree regeneration by a number of authors (Barr 1930; Day 1963; Day and Duffy 1963). All have noted the close association between regeneration and decaying wood. Mork (1927) suggested that spruce regenerated on this substrate because of the abundance of mycorrhizae (fungal inoculum). Day (1963) and Day and Duffy (1963) have provided substantive evidence to show that residues with a high moisture content in the intermountain regions of southern British Columbia influenced white spruce regeneration. This does not preclude the possible presence and effect of mycorrhizae in such residues. Barr (1930) also associated higher moisture contents of residues with improved regeneration.

Harvey and others (1976), while studying the relationships between mycorrhizae and brown-cubical decayed wood, reported significant differences in the numbers of mycorrhizal root tips between sampling points with brown-cubical decayed wood and those without (nonresidue soil profiles). Their data indicated that woody residues in this form were a favorable part of the soil profile for mycorrhizal development (figs. 6, 7). They also showed that this substrate comprised up to 15 percent of the volume of the top 38 cm of a western Montana forest soil and attributed the favorable mycorrhizal response to the water-holding capacity of brown-cubical decayed wood. Furthermore, the spatial distribution of brown-cubical decayed wood is also of interest. Table 2 summarizes the probability that at least "x" amounts of residue will be found in any 100-foot transect.

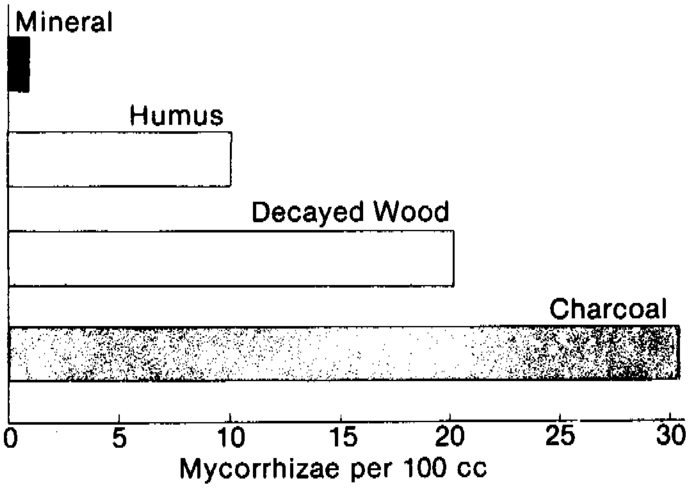

Figure 6.-- Numbers of mycorrhizal root tips per 100 cc of organic substrate.

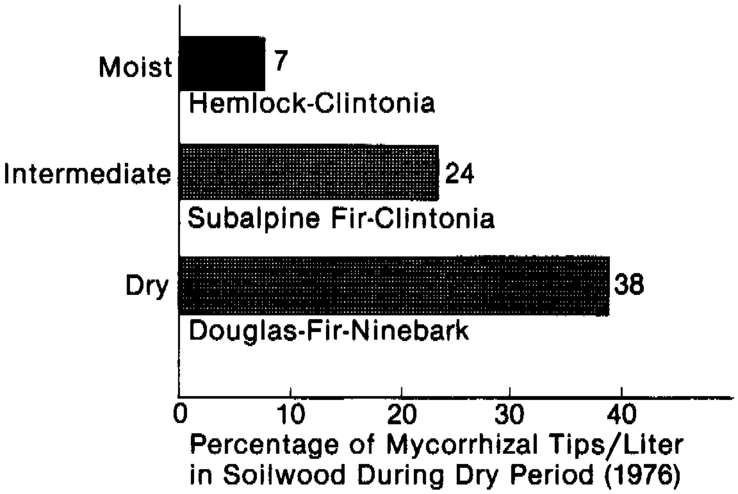

Figure 7.-- Percentage of mycorrhizal tips (liter) in brown-cubical decayed soilwood, August, 1976.

Table 2.--Probability (P) of encountering linear feet (x) of brown-cubical decayed wood in 100-foot transects, Coram Experimental Forest, Montana.

	Linear-feet (x) of BCD						
	5	10	15	20	25	30	40
Probability (at least x)	0.970	0.865	0.644	0.367	0.111	0.0026	0.000

Decaying logs have been suggested as potentially important sites for dinitrogen fixation. Cowling and Merrill (1966) suggested that nitrogen-fixing bacteria may provide an additional source of nitrogen required for the decay process. Cornaby and Waide (1973) have shown that dinitrogen fixation occurs in decaying chestnut (*Castanea dentata* (Marsh.) Borkh.) logs and Larsen and others (1978) presented data showing dinitrogen fixation in decaying wood of dead and down logs and live, standing conifers decayed by common wood-rotting fungi. The relationships between decay progression, nitrogen fixation rates, and nitrogen contents are presented in figure 8.

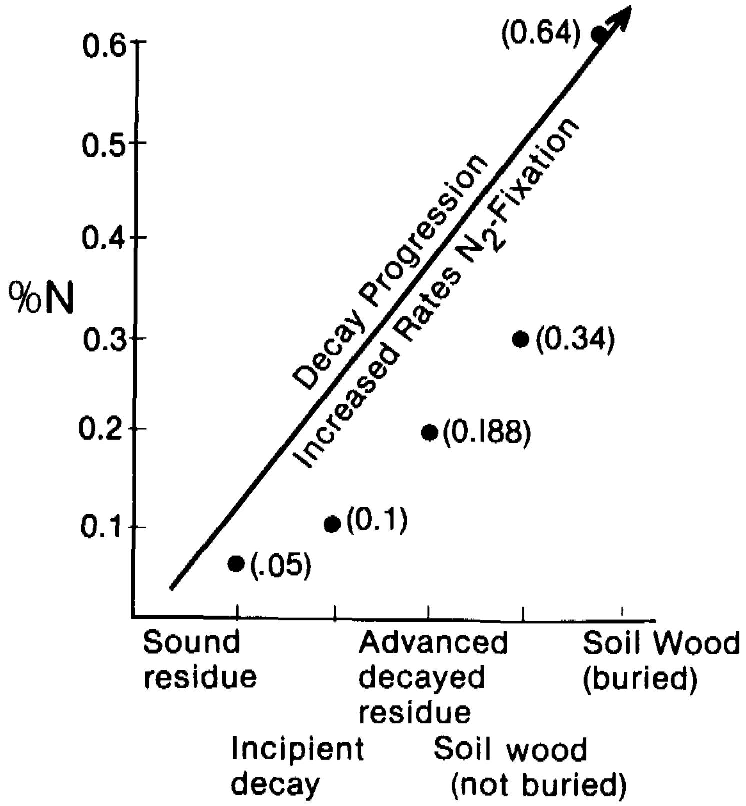

Figure 8.-- Nitrogen content of brown-rotted woody substrate in various stages of decay.

Recently Harvey and others (in process), through ^{14}C analysis, have shown that Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) residues persist for 500 years or longer, depending on the site and depth in soil. Our observations, though incomplete, indicate that brown-rotted Douglas-fir residue is the most persistent. We tentatively suggest that resistance to further decomposition is a function of extractives or extractive-like substances chemically bound to the lignin polymer in Douglas-fir--to a greater extent than other conifer species.

Appearance and characteristics of brown-cubical decayed wood

The substrate is readily characterized in the field by its dark brown to reddish-brown color and its texture is three-dimensionally checked, forming six-sided configurations (often referred to as cubical) (fig. 9).

Figure 9.-- Brown-rotted Douglas-fir showing fissures and checks in the substrate.

Recognizable brown-cubical decayed wood in the field is usually in the form of dead fallen trees or logging residues greater than 0.5 m in diameter or large enough to maintain a reasonable degree of recognizability through the processes of decay, weathering, and physical dispersion. Residues of lesser dimension are subject to spreading, dispersion, and downhill movement in steep terrain. Thus, the larger residues tend to collapse and spread during the deterioration process, appearing somewhat ellipsoidal in profile at the soil surface. Tables 3 and 4 summarize the more important properties and characteristics of soil wood. Rypáček and Rypáčkova (1975) note that humic substances isolated from wood decomposed by brown rot fungi exhibit properities similar to those of soil humus, and that differences are dependent on the degree of wood decomposition.

Table 3.--Summary of brown-cubical decayed soil wood properties and characteristics.

Volume	5-25 pct	0.5-0.8 KgN/ha/YR - N_2 Fixation
Persistence	500 +	12-fold increase in N compared to undecayed wood
Moisture	300 pct +	5-fold increase in P
CEC	45-90-MEQ per 100 gm	Appreciable macroelement content
Low pH	4-5.5	Lignin content 68 pct

Table 4.-- Mean percent lignin, ash and carbohydrate contents, based on odw of brown cubical decayed wood from Coram Experimental Forest, Montana, 1975.

Number samples	Ash content	Lignin content	Carbohydrate content
25	16.1 (S = 11.3)	68.4 (S = 4.7)	15.5 (S = 4.8)

"NONDECAY" ACTIVITIES

In addition to the two major kinds of decay associated with biodegradation of woody residues, other activities of fungi may be considered nondegradative in the sense that they are not responsible for major volume or weight reductions in residues. Ecologically, these fungi appear early in the biodegradative sequence of plant materials. They are the primary colonizers with the ability to metabolize the readily available low-molecular-weight carbon and nitrogen sources that are available in fresh residues. Fungal numbers gradually decrease with time, an increase in extractive content and, perhaps, increasing acidity of substrates. Their ability to rapidly form large amounts of biomass within short periods of time is noticeable in figures 10 and 11.

Figure 10.-- Fungus biomass of Athelia epiphylla associated with fresh residues. (Coram Experimental Forest, May 1975).

Figure 11.-- Growth of Athelia epiphylla under psychrophilic conditions associated with fresh residues. (Coram Experimental Forest, May 1975).

Observations indicate that organisms of this kind prefer habitats that are restrictive to most other organisms, thus providing a competitive advantage. The occurence of filamentous and nonfilamentous fungi, bacteria, etc. under psychrophilic and thermophilic conditions is well known.

Newly formed, small-dimension residues (leaves, twigs, and small branches up to 2 to 3 cm in diameter) are relatively high in available carbon, nitrogen, and macroelement nutrients. Initial colonization of these materials at the Lubrecht site was by *Athelia epiphylla* Pers. (figs. 11 and 12), while at Coram the prevalent fungi were (in order of frequency) *Athelia epiphylla, Leucogyrophana pseudomollusca* (Parm.) Parm., and *Corticium lepidum* Rom. Primary colonization occurred under psychrophilic conditions (fig. 11). Leaves were more frequently colonized than small woody materials. The impact of these fungi on small dimension materials may be expressed directly by changes in nutrient content of needles (table 5) and indirectly by observations on amounts of fungal biomass produced.

Table 5.--Apparent effect of the association of *Athelia epiphylla* on nutrient losses of over-wintered needles of subalpine fir, *Abies lasiocarpa* (Hook.) Nutt., Coram Experimental Forest, Montana, May, 1975.

A. epiphyllam	Ca	Mg	K	P	Ash	C	N	C/N
	--------PRM-------			-----------Pct-----------				
Present*	17,200	710	1,975	0.086	6.6	34.7	1.18	29:1
Absent	14,500	1,090	5,750	.14	6.1	44.88	1.18	38:1
Significance	ns**	ns	p=0.001	p=0.001	ns	ns	ns	p=0.01

*Values corrected for weight loss of affected foliage.
**Not significant.

DISCUSSION AND CONCLUSIONS

We have attempted to characterize one part of the organic resource of Rocky Mountain forests in some detail. The characteristics and amounts of wood in the soil are significant (Jurgensen and others 1980; Harvey and others 1980) in terms of their effects on soil quality and function. It is apparent from existing (or formerly existing) forest ecosystems that ecosystem perturbation, where biomass is removed either by fire or indiscriminate harvesting practices, may be directly reflected in the organic resources of the site, whether they be parent materials or end products.

Brown-cubical decayed wood on all investigated sites is interchangeably functional with humus, but the functional importance increases with the dryness of the site. Reasonable guidelines for biomass utilization can be established using biomass productivity estimates, estimates of decay rates, and assessments of optimal volumes of necessary soilwood (Harvey and others 1980). These guidelines, however, only address one form of residue, i.e. those large enough (0.2 to 0.5 meters) to emerge as recognizable and persistent brown-rotted wood in soil. Significant impacts, at present lacking adequate assessment, could occur by harvesting or premature burning small-dimensional materials. Deleterious effects on site nutrient resources would be observed because the nutrient capital in small-dimension materials is large.

In conclusion, the coniferous ecosystem has evoloved with and become adapted to and, in some ways, is dependent on brown rotted wood on and in soil profiles. Soilwood performs similar functions as humus layers and in some instances exceeds the abilities of humus. Forest managers should therefore view woody residues as a manageable entity within existing concepts of resource management objectives.

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MICROBIAL PROCESSES ASSOCIATED WITH NITROGEN CYCLING IN NORTHERN ROCKY MOUNTAIN FOREST SOILS

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ABSTRACT

The soil microflora is of critical importance for the cycling of nitrogen (N) in forest ecosystems. Forest management practices such as timber harvesting, residue removal and prescribed burning greatly affect the activity of these microorganisms. N fixation by free-living soil bacteria in the Northern Rocky Mountain region was reduced following harvesting. This was particularly true in the surface organic horizons and appeared related to low moisture levels on the surface of cleared sites. Decaying wood incorporated in the soil was a major site of N fixation. The establishment of N-fixing plants, such as Alnus, Ceanothus, Lupinus, and Astragalus on logged areas could more than compensate for the lower N fixation rates by soil bacteria. However, the occurrence of these plants are habitat-type related, and most of the sites studied did not have a significant N-fixing plant component. Increases in ammonium and nitrate concentrations occurred in the soil following logging, especially when the sites were burned. Such increases in available soil N levels could be beneficial for subsequent regeneration establishment and growth. However, both ammonium and nitrate concentrations returned to their original levels within several years after cutting. Higher nitrate concentrations after harvesting could increase leaching losses of N from the site. Changes in soil organic matter content must be considered when evaluating the effects of harvesting methods on soil N strata.

KEYWORDS: nitrogen fixation, nitrogen mineralization, ammonium, nitrate, timber harvesting, fire, litter

Nitrogen (N) is normally the soil nutrient most limiting the productivity of forest stands. Since nearly all N in forest soils is present as a component of various types of organic matter, the activity of the soil microflora is particularly important for N availability and subsequent uptake by tree roots. It is this biological decomposition of organic matter which make soil N levels more susceptible to modification by silvicultural practices than any other nutrient. Timber harvesting, residue removal and post-logging site preparation, such as burning and soil scarification, may directly modify the soil N status. Less conspicuous, but in many instances just as important, are the soil chemical and physical changes following these operations which effect the soil microorganisms active in the N cycle (Harvey and others, 1976).

Much has been written about the various aspects of the N cycle and how it may be altered by forest management activities. A comprehensive treatment of N relationships in forest soils is given in an excellent review by Wollum and Davey (1975). Rather than try to cover all facets of this complex subject, only the effects of timber harvesting on biological N fixation and mineralization of organic N in various northern Rocky Mountain forest ecosystems will be discussed. Five experimental sites were used in this study:

Idaho - Old growth western cedar - western hemlock stand (_Tsuga heterophylla/Pachistima_ habitat type[1]) located near the Priest River Experimental Forest, northern Idaho Panhandle.

Montana - 200-year old western hemlock stand (_Tsuga heterophylla/Clintonia uniflora_ habitat type), Coram Experimental Forest in northwestern Montana.

Montana - 250-year old Douglas-fir, western larch, subalpine fir stand (_Abies lasiocarpa/Clintonia uniflora_ habitat type) in the Coram Experimental Forest, northwestern Montana.

Montana - 250-year old Douglas-fir stand (_Pseudotsuga menziesii/Physocarpus malvaceus_ habitat type) in the Coram Experimental Forest, northwestern Montana.

Wyoming - Overmature 175-year old lodgepole pine stand (_Abies lasiocarpa/Vaccinium scoparium_ habitat type) located near Union Pass, northwestern Wyoming.

Detailed information on stand characteristics, soil properties and harvesting treatments on these sites are given in other papers of this symposium or have been published elsewhere (Harvey and others, 1979).

DINITROGEN FIXATION

Timber and/or residue removal results in a direct loss of N from a site. This N loss is further increased if prescribed fire is used for site preparation (Wells and others, 1979). Natural replacement of this soil N capital in the Intermountain West comes from small amounts of N (1-2 kg/ha/yr) present in rainfall (Tiedemann and others, 1978), and from the biological conversion or "fixation" of inert atmospheric N_2 into usable forms by select microorganisms free-living in the soil or present in plant roots. It is these biological N fixation processes which are affected by various forest management practices. Such N inputs by soil microorganisms are important for long term site productivity and should be considered when evaluating the environmental impact of timber removal.

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[1] Habitat type designation according to Pfister and others, (1977) or Daubenmire and Daubenmire (1968).

Nonsymbiotic N Fixation

Free-living N-fixing microorganisms, with the exception of the autotrophic blue-green algae, are dependent on a source of organic matter to satisfy both energy and carbon requirements. With this nutritional constraint, greater activity of the N-fixing microflora might be expected in soil substrates high in organic matter. Such a relationship was evident in all of the northern Rocky Mountain soils examined. In the example shown in Figure 1, the highest N fixation rates on this Douglas-fir/western larch site were associated with decaying logs. When decayed wood is eventually incorporated into the soil profile, it normally retains a higher N-fixing capacity than the surface litter, humus, or mineral soil. However, these N fixation values may be misleading when trying to estimate the relative contribution of each soil component to total N input. The actual amounts of N fixed depends on the weight/volume relationship of each soil fraction on the site.

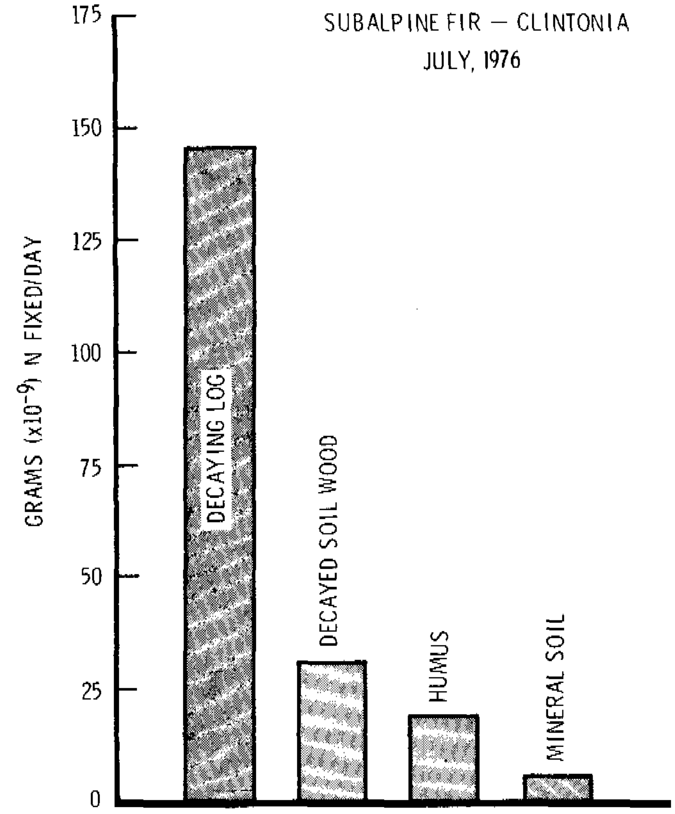


Figure 1.-- Amounts of N fixed in various forest floor and soil components (Montana).

Nonsymbiotic N fixation in Intermountain forest soils is also related to stand productivity. As the timber yield potential of a site increased, so did the N fixation rates (Figure 2). However, the drier and poorer the site, the greater the importance of decayed wood to overall soil N fixation capacity (Figure 3). It seems likely that at least some of the increased productivity of the higher quality sites is related to a greater N input from the N-fixing microflora.

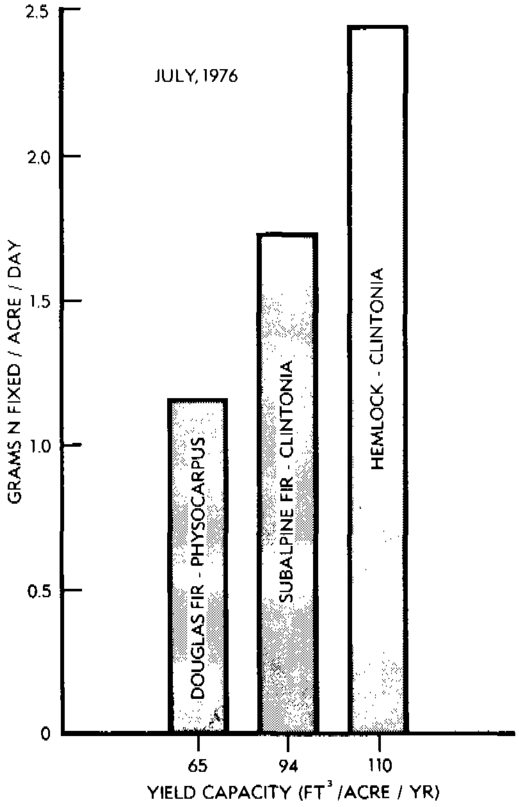
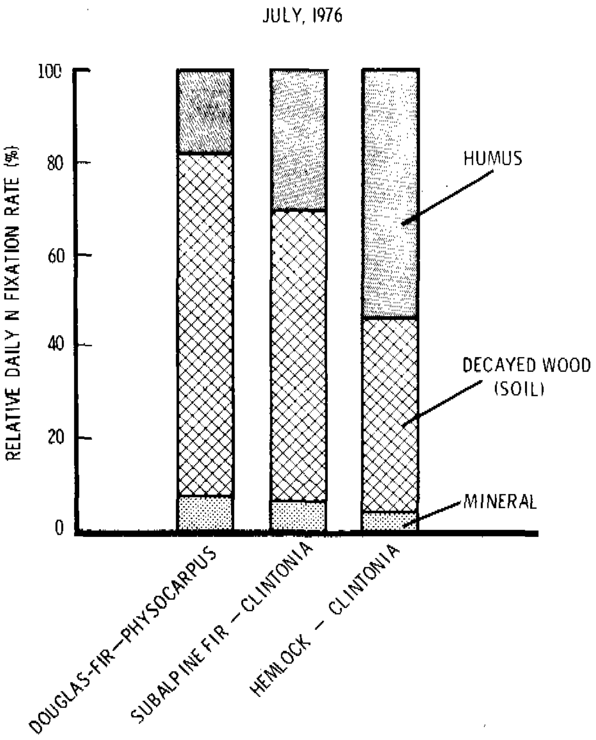


Figure 2.-- Relationship of forest site productivity to amounts of N fixed in the forest floor and top 5 cm of mineral soil (Montana).

Figure 3.-- Relative daily N fixation rate by soil component on three different habitat types (Montana).



In a previous paper (Jurgensen and others, 1979a), we speculated that timber harvesting would alter the soil chemical and physical properties to favor the activity of N-fixing microorganisms. Preliminary sampling in a Douglas-fir/western larch stand in northwestern Montana tended to substantiate this hypothesis. However, more intensive sampling throughout the growing season on several other sites indicated that N fixation rates were actually lower on harvested sites as compared to uncut controls, especially when a post-harvest fire treatment was used (Figure 4).

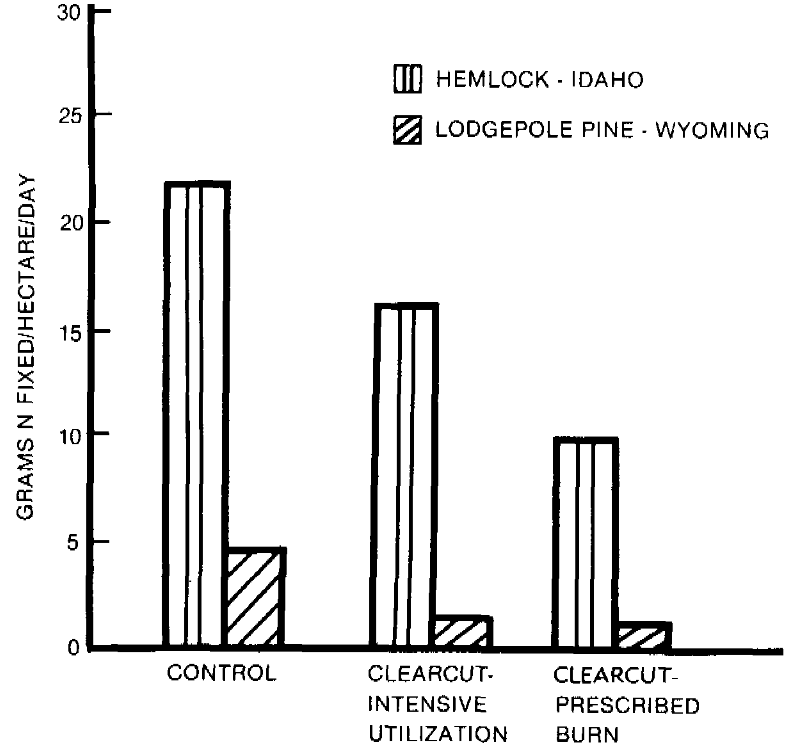


Figure 4.-- Effects of harvest treatment on N fixation in the surface 30 cm of forest floor and mineral soil (July).

All harvested sites and the controls showed a general lowering of N fixation rates in the summer months. This was due to a drying out of the surface soil layers during this period, especially on the exposed clearcut areas (Hungerford, 1980). The small amounts of N fixed in the O_2 horizon on the intensive utilization and burned site reflected these low soil moisture levels (Figure 5). A lowering of N fixation rates on these burned sites contrast with several other studies which indicated a stimulation of N-fixing microorganisms following fire (Wells and others, 1979). Differences in soil, timber type, climate, severity of burn, and method of measuring N fixation rates could account for such variable results.

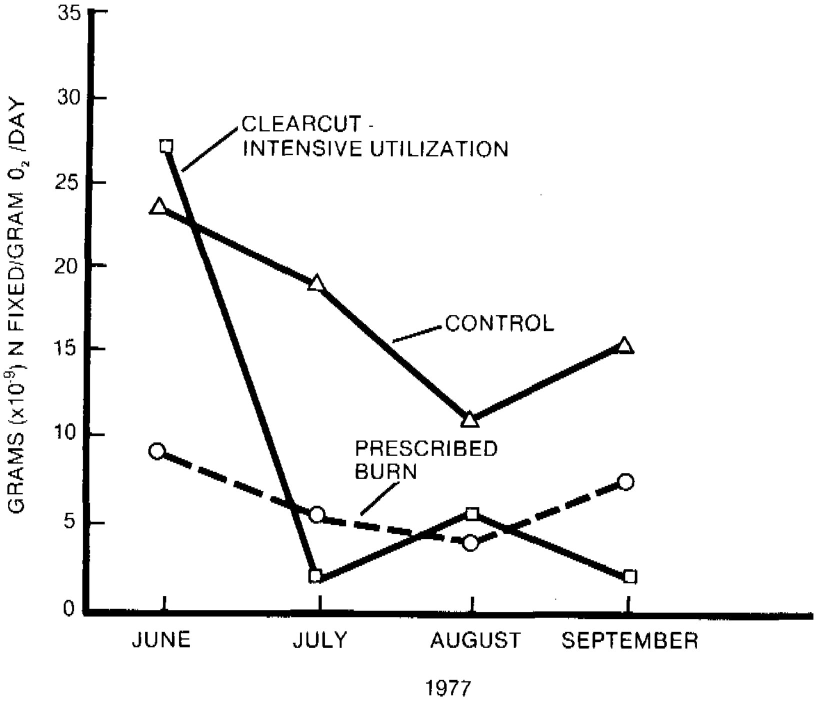


Figure 5.-- Effects of harvest treatment on N fixation in the humus layer (O_2) of a cedar-hemlock stand during the summer (Idaho).

Changes in nonsymbiotic N fixation rates due to timber removal also reflects differences in site productivity. The amounts of N fixed in a highly productive, northern Idaho cedar-hemlock soil were much greater than in a cold, high altitude lodgepole pine soil regardless of harvest treatment. Conservatively assuming that the N-fixing bacteria would be active for only 100 days/yr, N added to the cedar-hemlock soil would amount to slightly over 1 kg/ha/yr on the prescribed burned sites to nearly 2.3 kg/ha/yr in the uncut stands. However, as the stands on these cut and burned areas become reestablished, the N fixation rates would likely increase to preharvest levels. The length of the recovery period is unknown. While these N gains are small on an annual basis, the significance over a stand rotation of 100-150 years would be appreciable. In contrast, N added to the lodgepole pine soils would be much lower. Again assuming a 100 day activity period for the N-fixing microflora (a possible overestimation), less than .25 kg/ha/yr of N would be added to the burned sites, and only .5 kg/ha/yr in the undisturbed stands. N fixation rates should also increase as this site regenerates, but the recovery time would probably be longer than on the more favorable cedar-hemlock site.

More immediate N gains on poorer sites could be obtained by converting unused logging residues into chips. N fixation rates associated with wood chip decay were the highest found in any of the wood or soil substrates examined (Jurgensen and others, 1979b). The insulating properties of the chips and the heat and moisture generated during fermentative and decay processes would favor the activity of N-fixing organisms throughout the year (Larsen and others, 1980). While the economic or practical feasibility of conducting such chipping operations is questionable, it is one way by which logging residues could be more rapidly decomposed and overall site productivity improved.

Symbiotic N Fixation

The establishment of N-fixing plants such as Alnus, Ceanothus, Lupinus, or Astragalus on logged sites could more than compensate for the low N additions by the free-living soil bacteria. For example, Youngberg and Wollum (1976) reported that in a ten year period Ceanothus fixed over 1,000 kg N/ha in an Oregon Douglas-fir stand after harvesting and slash burning. Appreciable amounts of N are also added to forested sites by other N-fixing plants (Youngberg and Wollum, 1970).

Most of the forests in the northern Rocky Mountains do not have a significant N-fixing plant component in pole-size stands or larger (Jurgensen and others, 1979b). When these stands are logged, N-fixing plants may become established, but their development is habitat-type specific. For example, Ceanothus is favored on warm, dry Douglas-fir sites following logging and prescribed burning, while on cooler, wetter sites, much less development is found.[2] Stickney (1980) observed that Alnus was greatly reduced on several clearcut and burned subalpine fir sites in western Montana. However, Alnus is abundant on road cuts and other scarified sites in many subalpine fir habitat types. In the southeastern U. S. timber harvesting and prescribed burning frequently increases the legume component in the ground vegetation (Cushwa and others, 1966). In the generally drier Intermountain region, no such consistent post-harvest pattern of legume development is evident (Jurgensen and others, 1979b).

The use of N-fixing plants to replace N losses due to harvesting or fire offers considerable management potential. Youngberg and Wollum (1976) have recommended using Ceanothus for early seedling shade protection and soil N enrichment following logging operations in Oregon. Grier (1975) believes most of the N lost from a severe wildfire in Washington can be replaced by Ceanothus becoming established on the site. The use of legumes as a cover crop in southern pine stands following harvesting is being considered for site N additions and weed control (Haines and DeBell, 1979). Native and introduced legumes are an integral part of erosion control efforts on logged or burned sites (Monsen and Plummer, 1978). However, much more information is needed on the response of these plants to stand manipulation and the successional roles they play on disturbed sites.

N MINERALIZATION

Timber harvesting has pronounced effects on N transformations within a soil. Increases in ammonium (NH_4) and nitrate (NO_3) concentrations were found in the soil following clearcutting and prescribed burning on a subalpine fir site at the Coram Experimental Forest in western Montana. The patterns of N release from the humus (O_2) horizon for two years after logging is shown in Figure 6. Similar changes in available N levels were recorded for the mineral soil horizons but the amounts were much lower than found in the organic layer. Clearcutting and intensive residue removal increased NH_4 and NO_3 concentrations over those found in an uncut stand during the following growing season. These higher N values on the cleared sites could have resulted from both accelerated organic matter decomposition and a lack of vegetation to take up the N as it was mineralized. The greatest effect on available N levels occurred when the site was clearcut and burned. Such gains in available N after fire have also been reported for conifer sites in Idaho (Orme and Leege, 1976), Wyoming (Skujins, 1977), Oregon (Neal and others, 1965), Arizona (Campbell and others, 1977), and Europe (Tamm and Popovic, 1974; Viro, 1974).

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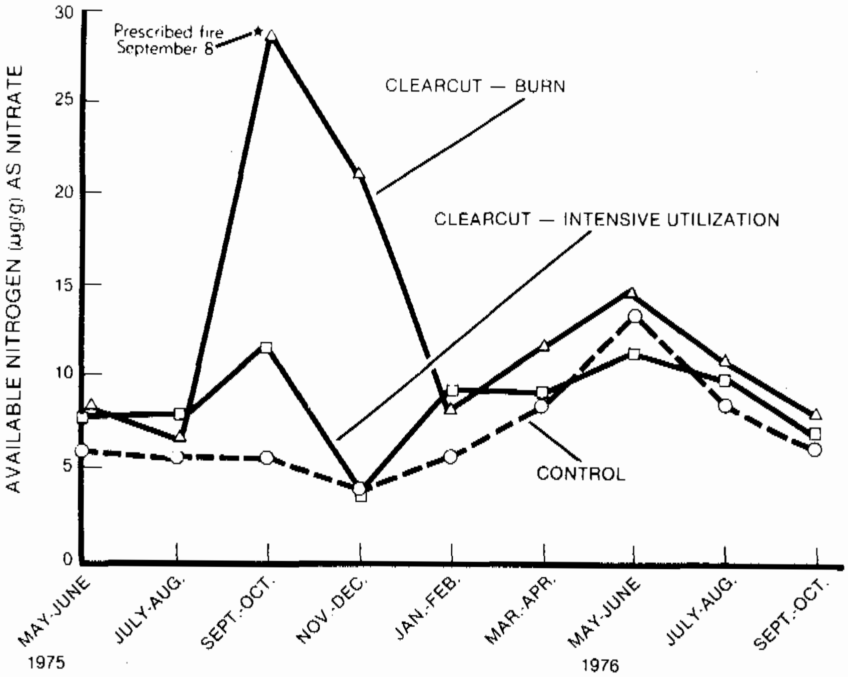
[2] Personnel Communication, S. F. Arno. U. S. F. S. Forestry Sciences Laboratory, Missoula, Montana.



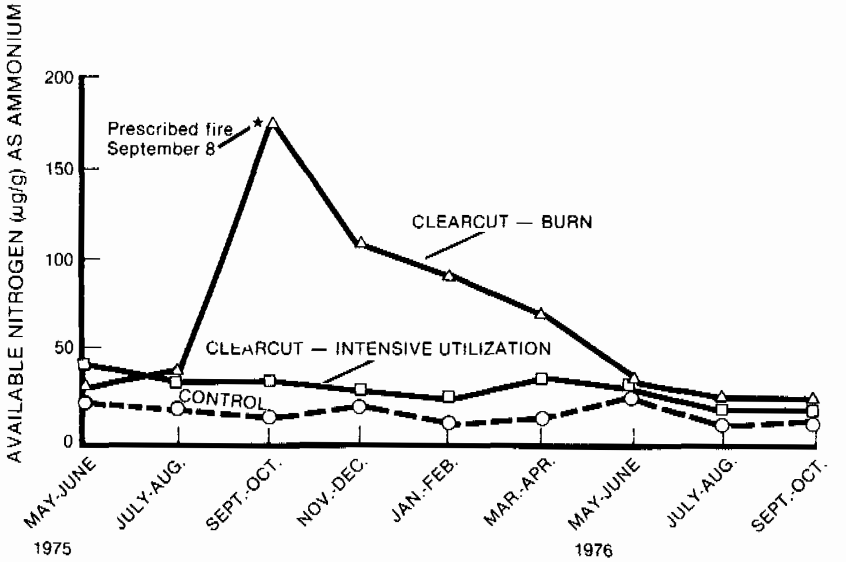


Figure 6.-- Effects of harvest treatment on ammonium and nitrate concentrations in the humus layer (O_2) of a Douglas-fir/western larch/subalpine fir stand (Montana).

A clearer picture of the N mineralization changes which occur in soil following fire was given by Mroz and others (1980) in a laboratory experiment using forest floor material from the Coram site (Figure 7). This study showed an immediate release of N when the organic layers were burned, a rapid immobilization of the available N within three days following the burn, and a gradual mineralization of the organic N to NH_4 in the succeeding five weeks. These N fluctuations are likely due to a rapid expansion of the soil microflora after the fire in response to increases in available carbon and NH_4 (Ahlgren, 1974). Microbial activity may also be stimulated by a release of mineral cations from the burned organic matter and a decrease in soil acidity (Wells and others, 1979). Soil reaction increased over one pH unit in the organic horizon of the burned site at Coram (Figure 8). A sampling of the areas four years after burning showed that the pH of the O_2 horizon had not yet returned to preburn levels.

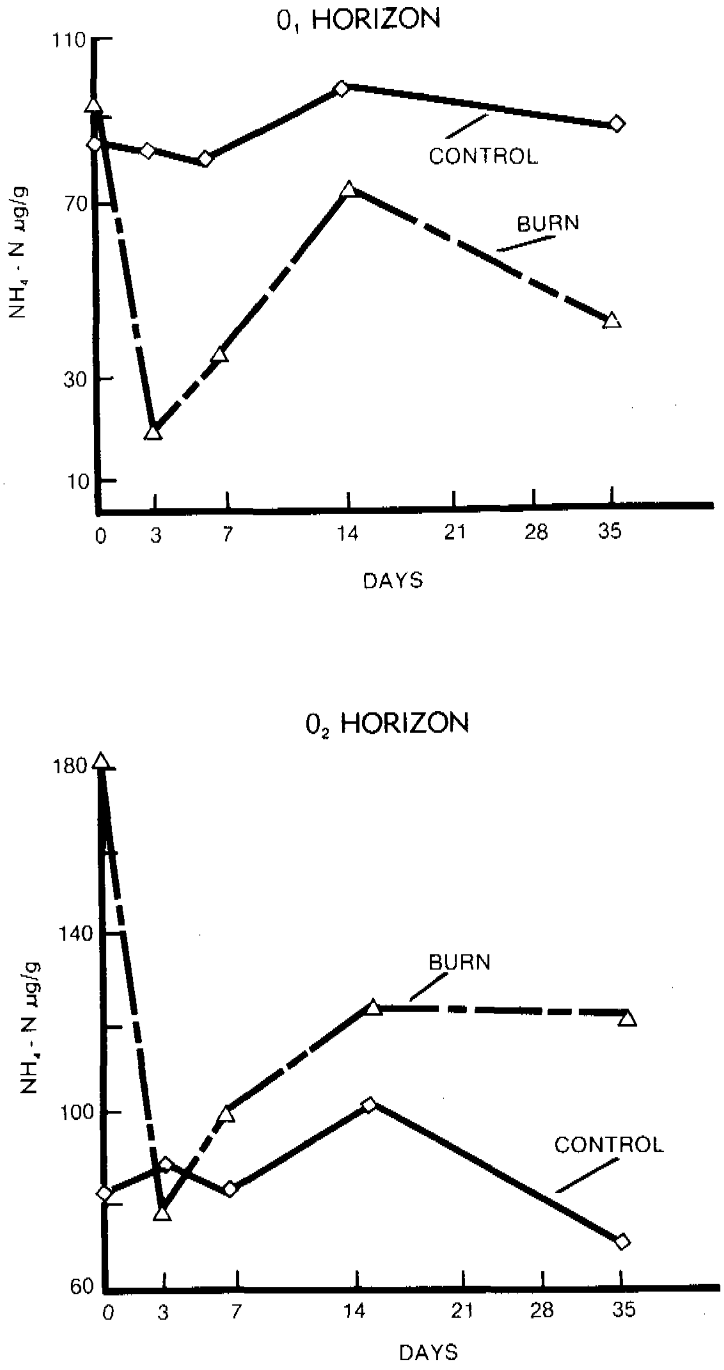


Figure 7.-- Ammonium concentrations in the forest floor layers of Douglas-fir/ western larch/subalpine fir stand following burning (Mroz and others, 1980).

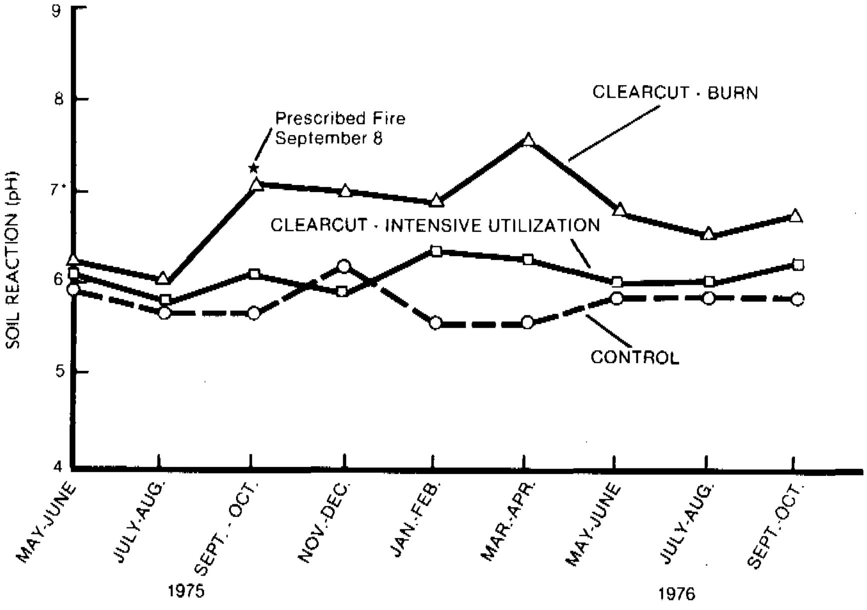


Figure 8.-- Effects of harvesting treatment on soil pH in a humus layer (O_2) of a Douglas-fir/western larch/subalpine fir stand (Montana).

The effects of post-harvest burning treatments on the levels of available N show a definite relationship to the soil component examined (Figure 9). These results from the Coram study show that before the prescribed fire, total amounts of NH_4 and NO_3 in the organic layers were approximately equal to that present in the surface 30 cm of mineral soil. After the fire, available N levels in the surface organic horizons and decayed wood increased to double the amount present in the mineral layer. Total N availability in the surface 30 cm of soil was highest in November-December, followed by a steady decrease during the winter and spring months to preburn levels (Figure 10).

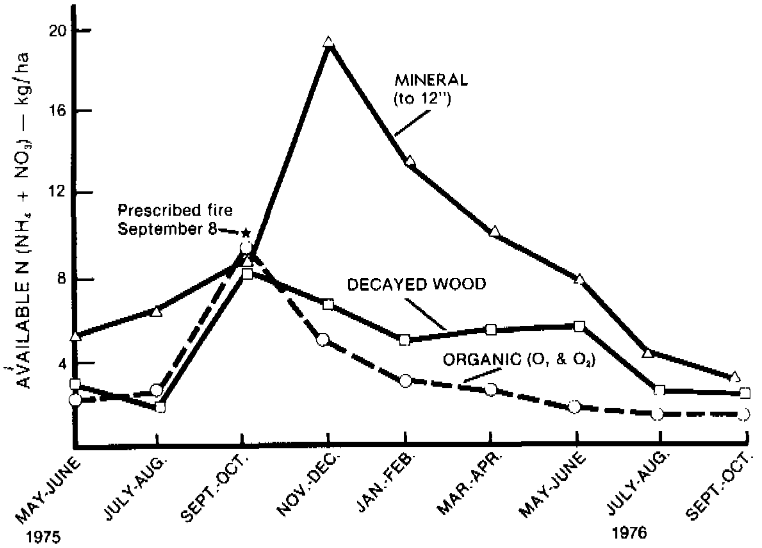


Figure 9.-- Nitrogen availability in various soil components after clearcutting and prescribed burning in a Douglas-fir/western larch/subalpine fir stand (Montana).

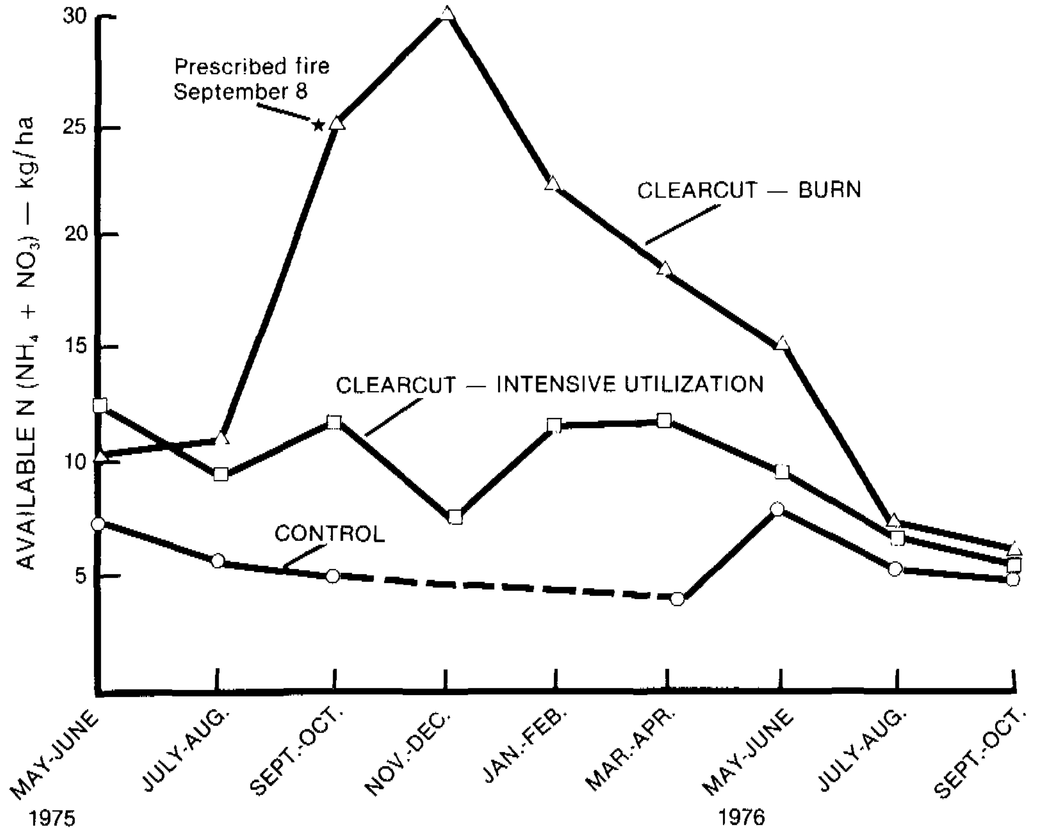


Figure 10.-- Effects of harvest treatment on available N content of the surface 30 cm of forest floor and mineral soil in a Douglas-fir/western larch/subalpine fir stand (Montana).

Immobilization and denitrification by the soil microflora as well as NH_4 and NO_3 leaching by snowpack melt would account for these winter and spring N losses. Appreciable losses of N have been reported from some eastern hardwood forests due to NO_3 leaching after timber harvesting (Hornbeck and others, 1975). While increased NO_3 losses have been reported following logging operations in the west, the amounts are usually too low to affect site productivity (Fredriksen and others, 1975).

Higher levels of available soil N following clearcutting (Figure 10) could be beneficial for subsequent regeneration establishment and growth on harvested sites. Total amounts of available N present in humus layers and in decayed wood are of special significance for tree uptake, since mycorrhizal root activity is concentrated in these soil strata (Harvey and others, 1980). However, the potential effects of this additional N would be of short duration. Available N levels in soil on both the intensive utilization and burned sites were comparable to uncut stands by the second year after harvesting.

CONCLUSIONS

The dynamics of N fixation and N mineralization in northern Rocky Mountain forest soils are strongly affected by timber harvesting. The impact of these operations was most evident on N transformations occurring in organic soil components. Changes in soil organic matter content must be considered when evaluating the effects of logging methods on soil N levels. However, the significance of such harvest-related N changes to overall site productivity in this region is unknown.

The caution given by Harvey and others (1980) in this symposium on applying mycorrhizae results from the Intermountain region to other forested ecosystems is equally valid for soil N relationships. Differences in climate, stand properties and soil type are only several of the variables which could alter the intensity and direction of microbiological processes occurring on a site.

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ECOLOGY OF ECTOMYCORRHIZAE IN NORTHERN ROCKY MOUNTAIN FORESTS

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ABSTRACT

Activity of ectomycorrhizal symbionts depends on the nature of the soil and vegetation, as controlled by climate and natural or man-caused disturbances over time. Organic materials in the form of litter, humus, decayed wood or charcoal that occur in layers or mixed in the mineral soil are key factors governing ectomycorrhizal activities in forest soils. Importance of these organic fractions to ectomycorrhizal activity can be predicted, based on their quantity and distribution in the forest floor, the season, and the relative position of the site along a temperature-moisture gradient. Organic materials are most important in the harshest soils. This appears to result directly from their ability to buffer wide variations of pH, moisture and temperature. Because the ectomycorrhizal association depends on host trees, manipulations of the stand also provides direct control of ectomycorrhizal activity.

KEYWORDS: harvesting, residues, fire, biological impact, soil quality, ectomycorrhizae.

INTRODUCTION

The strong positive effect of soil organic layers or organic amendments on abundance of ectomycorrhizae (Mikola 1973; Göbl 1967; Rayner 1936) and the dependence of conifers on this symbiotic association (Trappe and Fogel 1977) suggests a relationship between organic materials and soil quality. The ability of decayed wood to support ectomycorrhizae (Harvey and others 1976; Zak 1971;

McFee and Stone 1966; Trappe 1965; McMinn 1963) shows this material is an effective organic substrate in forest soils. This report describes the ability of various types of organic matter to support abundant, active ectomycorrhizal roots in soils from a broad range of forest ecosystems throughout the northern Rocky Mountains.

MATERIALS AND METHODS

Soil sampling methods and analytical procedures have been described in the authors' other published reports (Harvey and others 1979; 1978; 1976). To summarize, data on ectomycorrhizae are based on numbers of active associations (root tips) contained in measured volumes of various soil horizons from soil cores taken randomly throughout six experimental sites. Down woody residues were measured by the planar intersect method (Brown 1974). Soil moisture contents were determined gravimetrically by drying at $105^{\circ}C$ for 24 hours. Acidity was determined electrometrically, using a 1:2 mineral soil-water ratio or a 1:5 organic matter-water ratio.

Except where otherwise noted in the figure legends, the differences among treatments and sites, etc., on which we have based our conclusions were significant at least at the 0.05 probability level. Perhaps more important, these differences were generally evident throughout a wide variety of ecosystems from both paired samples and samples taken at different times and/or different places. Therefore, we feel the patterns and trends shown here provide a true picture of most northern Rocky Mountain soils.

In general, the term northern Rocky Mountains applies to ecosystems that can be described as "winter-moist" and "summer-dry". Winter snow accumulations are moderate, with very cold temperatures. Soil temperatures, except at the soil surface, would be described as moderate to cold. Any substantial variation from this pattern, even within the northern Rockies, will likely influence the relationships described. Thus, great caution should be used in applying these results to regions with deep snow accumulations, mild winter temperatures, or regions with heavy summer rainfall. Also, these data are representative of mature ecosystems. Young or regenerating stands have not been investigated and may have different characteristics.

Precise locations and the geographical, climatic and other features of the six experimental sites are described elsewhere in this symposium proceedings. Approximate locations and some characteristics are as follows:

Priest River - Cedar-Hemlock Site (TSHE/PAMY)* - approximately 20 miles northwest of the Priest River Experimental Forest in the northern Idaho Panhandle; northeast aspect; previously undisturbed by man.

Coram - Hemlock Site (TSHE/CLUN) - northwestern corner, Coram Experimental Forest in northwestern Montana; northwest aspect; previously undisturbed by man.

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*Habitat type designations (Pfister and others 1977).

Coram - Subalpine fir Site (ABLA/CLUN) - northern edge, Coram Experimental Forest in northwestern Montana; east aspect; previously undisturbed by man.

Coram - Douglas-fir Site (PSME/PHMA) - southwestern corner, Coram Experimental Forest in northwestern Montana; south aspect; previously undisturbed by man.

Lubrecht - Douglas-fir Site (PSME/VACA) - University of Montana's Lubrecht Experimental Forest in west central Montana; level to undulating; extensive history of logging.

Teton - Subalpine fir Site (ABLA/VASC) - near Union Pass in northwestern Wyoming; north aspect; previously undisturbed by man.

Five of these experimental sites were sampled regularly throughout the growing season of either 1975, 1976, or 1977. Sampling intensity varied among some of these sites. Sampling criteria were established to provide the largest possible data base for an intermediate site ("intermediate" being defined with regard to temperature and moisture) representative of the greatest possible proportion of commercial forest acreage in the northern Rocky Mountains (Subalpine fir habitat group). The other sites were sampled less intensely (table 1). One site (Teton) was sampled only once, July 6, 1978.

Table 1.--Approximate acres USFS, R-1 lands representative of various habitat series or of each experimental site (by habitat series) and the number of soil cores taken from each.

Habitat group	Site Location	Million Acres	Percent R-1 Forests	Cores
Limber pine	-	89	1	0
Ponderosa pine	-	384	2	0
Douglas-fir	Coram, D. fir (PSME/PHMA)[1]			150
	Lubrecht, D. fir (PSEM/VACA)	3,774	23	150
Spruce	-	211	1	0
Grand fir	-	1,560	9	0
Cedar hemlock	Coram, hemlock (TSHE/CLUN)			150
	Priest River, cedar hemlock (TSHE/PAMY)	2,521	15	150
Subalpine fir	Coram, subalpine fir (ABLA/CLUN)			450
	Teton, subalpine fir (ABLN/VASC)[2]	7,159	43	50
Whitebark pine	-	269	2	0
Lodgepole pine	-	45	<1	0

[1] Habitat type designation.

[2] Samples taken July 6, 1978

RESULTS AND DISCUSSION

To understand how interrelationships between various types of soil organic matter, a given site, and ectomycorrhizal activity interrelate, it is useful to examine 1) biophysical data indicative of the relative ability of the experimental sites to produce organic matter and 2) physical (fire) and biological (decay) forces responsible for regulating soil organic matter accumulation and type.

Effect of Environment on Organic Matter Accumulation

Temperature and moisture are physical factors which most limit the growth of both forest trees and the microorganisms on which they depend. Figure 1 compares the estimated ordination of the six experimental sites along temperature and moisture gradients characteristic of the northern Rocky Mountain area. To summarize, the Teton site is cold, with intermediate moisture; the Lubrecht site is warm and dry; the Priest River site is warm and moist; and the other sites are intermediate with regard to both temperature and moisture. The sites' estimated yield capabilities generally reflect their positions along these temperature and moisture gradients (fig. 2).

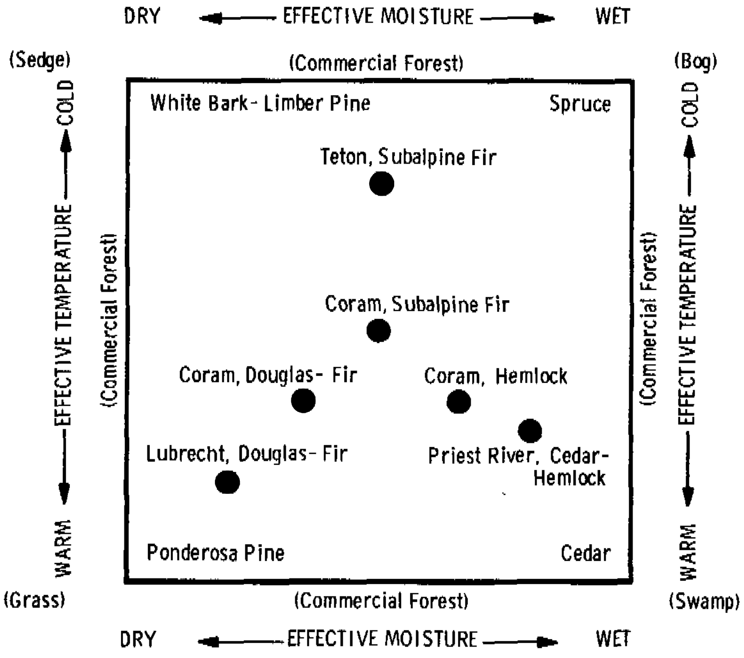


Figure 1.-- Ordination of the experimental sites along temperature and moisture gradients representative of the northern Rocky Mountains. Positions are estimates based in part on actual soil temperature and moisture data.

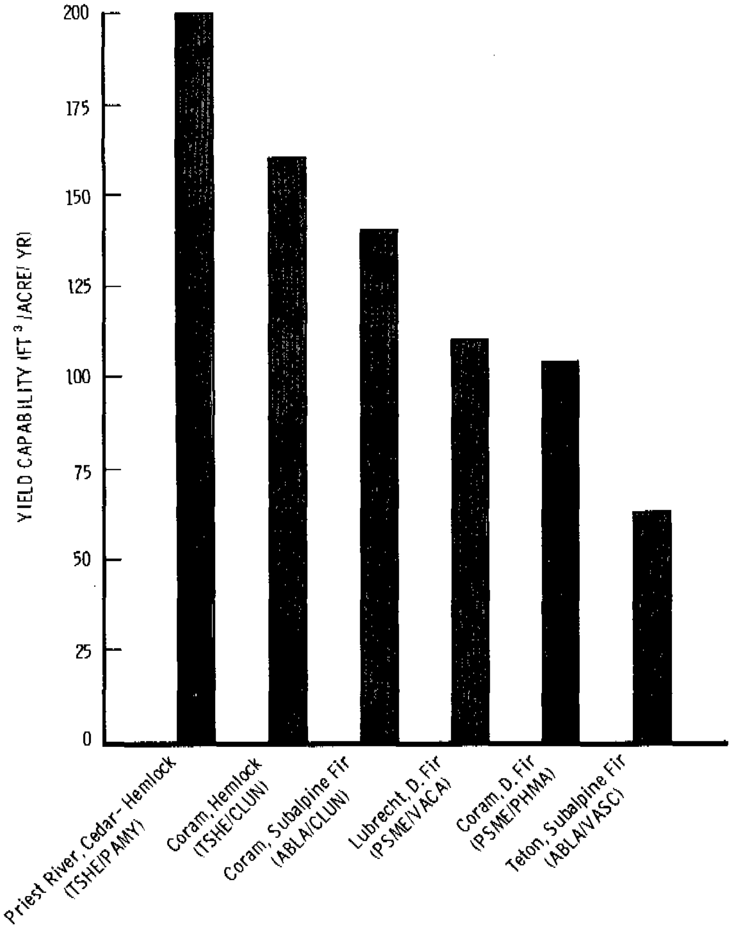


Figure 2.-- Relative yield capability estimates of the experimental sites based on Pfister and others (1977) and R.A. Graham (personal communication).

Recycling of accumulated organic matter is regulated by temperature and moisture gradients as reflected in the rapidity of the decay process and fire frequency. In recent years fire protection and timber harvesting also have influenced organic matter accumulation. Figure 3 compares accumulations of soil organic matter on the experimental sites. These measurements show substantial accumulations on warm, moist, productive sites, and good reserves on intermediate, productive sites. The lowest organic reserves appear on the cold Teton site and the relatively productive but dry Lubrecht site, which also has a prolonged harvesting history. How much, if any, effect past logging at Lubrecht may have had on the accumulation of soil organic matter, particularly wood, is not known. However, the disproportionately small amount of wood compared to soil humus may indicate that harvesting had significant effects. The relatively large accumulations of tree stem residues not incorporated into the soil on the Teton site (Benson and others 1980) indicates the decay process is extremely slow and that large fuel accumulations and associated severe fires may be responsible for the low soil organic matter accumulations.

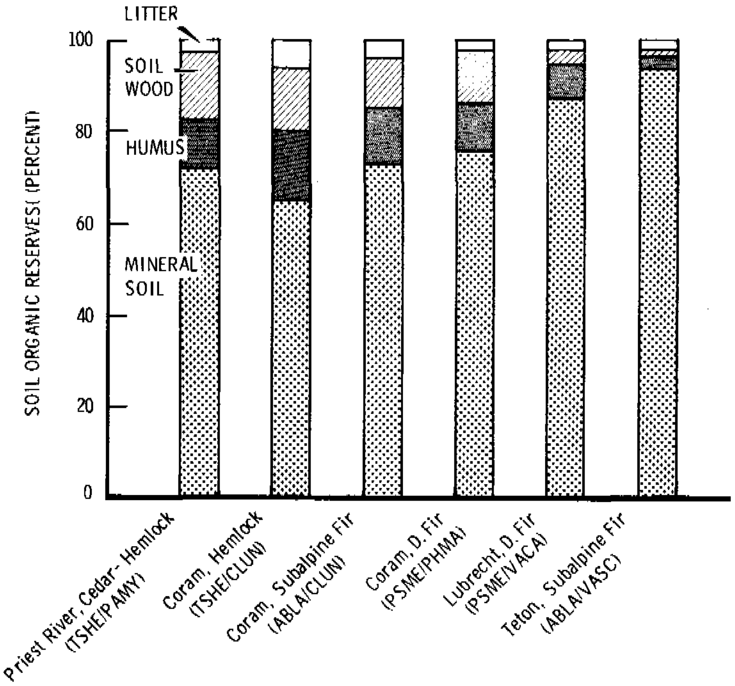


Figure 3.-- Soil organic matter type and percent occurrence in soil cores.

The natural balance between fire and decay, as a regulatory process for organic matter accumulations on these sites, is documented by the relative proportion of decay in woody residue (fig. 4), and by the incidence of charcoal in the soil samples (figs. 5 and 6). As we might expect, decay was highest in warm moist environments, lowest in cold or dry sites. Conversely, charcoal was most abundant in cold or dry systems and least abundant on warm-moist sites.

This pattern indicates that productive ecosystems regulate organic matter accumulation by means of those processes having the fewest external constraints. Thus, the cold Teton site is temperature-decay limited and fire dominated, while the Priest River site is moisture-decay dominated and fire limited. Under intermediate conditions, the balance between processes is more complex. For example, since the decay process breaks down organic matter to CO_2 and water, presumably moisture may be less limiting to the production of soil-wood than temperature. In general, high residue accumulations appear to be characteristic of cool ecosystems. More research is needed to adequately define this area of residue ecology.

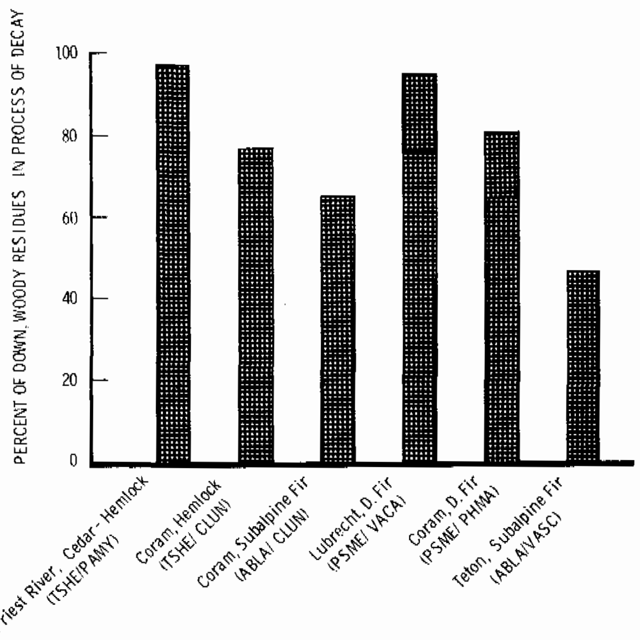


Figure 4.-- Woody residue in process of decay, determined by planar intersect method (Brown 1974), from the six experimental sites. These materials were in the form of dead down tree stems 3 in or larger in diameter. They have not decayed sufficiently to function as soil.

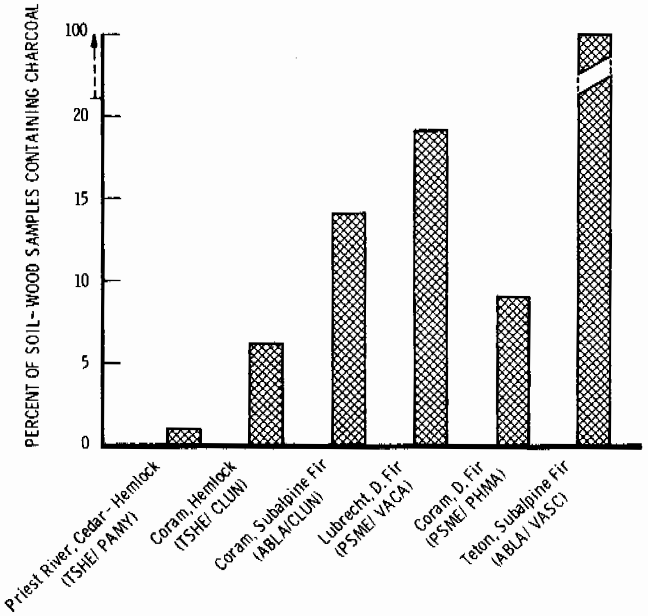


Figure 5.-- Percentage of soil-wood samples containing incorporated charcoal. The broken bar for the Teton subalpine fir site (in this figure and in several others) indicates that the data from this site are based on a smaller sample than for the other sites and represent only a single point in time. Therefore, although indicative, the data from the Teton site is not directly comparable to that from the other sites.

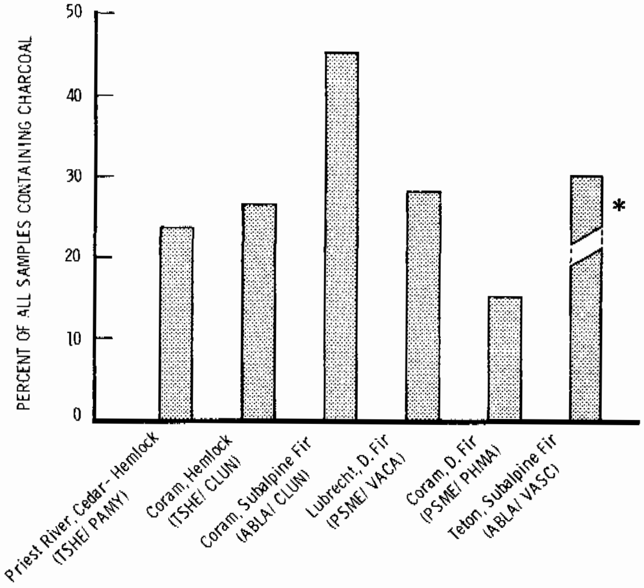


Figure 6.-- Percentage of all soil samples containing incorporated charcoal.

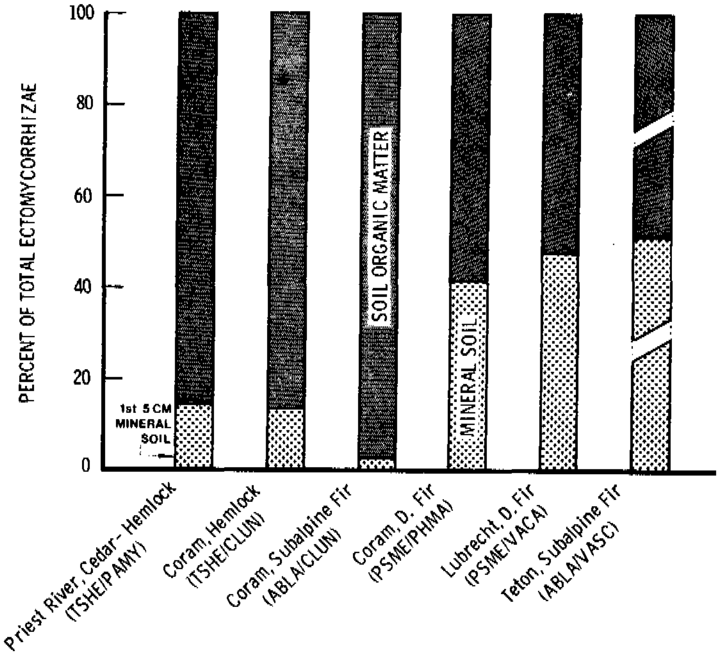


Figure 7.-- Percentage of annual ectomycorrhizal activity measured in shallow mineral soil and in organic matter of all types.

Effect of Organic Matter on Ectomycorrhizal Activity

Soil organic matter is usually the dominant substrate supporting ectomycorrhizae in northern Rocky Mountain forest soils. The degree of organic matter dominance over mineral soil varies among sites (fig. 7). The total amount of active ectomycorrhizal root tips over a growing season also varies among sites. The quantity of ectomycorrhizal root tips in soil samples generally reflects the relative productivity of the ecosystem (fig. 8). The Teton samples were taken on a single date equivalent to the spring peak in activity of the Coram site (fig. 9), and are not comparable to seasonal data from the other sites.

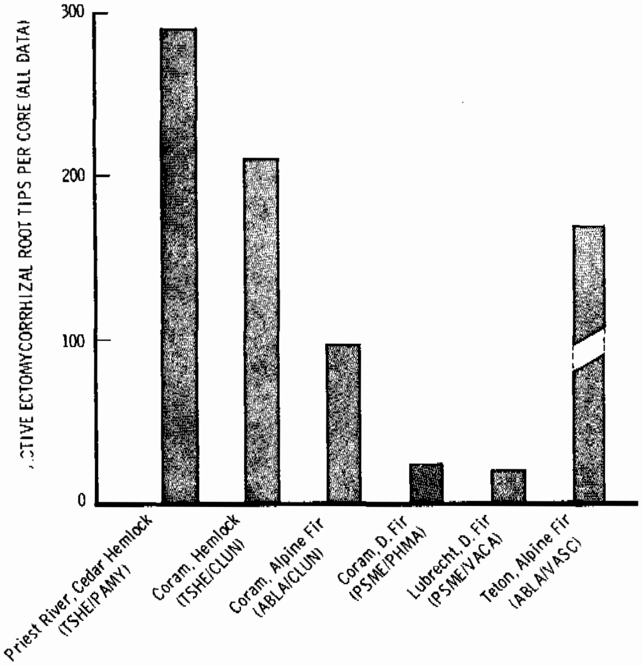
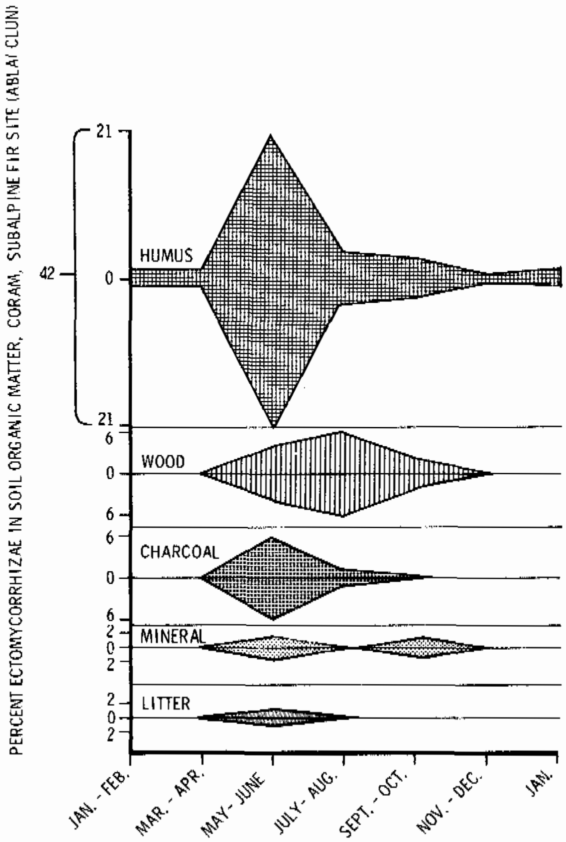


Figure 8.-- Average numbers of active ectomycorrhizal root tips per core sample from each of the six experimental sites.

Figure 9.-- Percentage of total ectomycorrhizae contained in each type of soil organic matter through the course of a growing season--Coram subalpine fir site.



Effects of Seasonal Changes on the Distribution of Ectomycorrhizae Among Soil Fractions

Seasonal changes affected both quantity and the distribution of ectomycorrhizal root tips among the various soil organic matter components (fig. 9). The greatest numbers occurred during the spring, when they were concentrated in soil humus. Smaller numbers occurred during the rest of the growing season. Most were concentrated in the soil-wood during the dry season of the year on the Coram subalpine fir site (Harvey and others 1978). Similarly, the relative number of ectomycorrhizal root tips in soil-wood from the six experimental sites were much greater on the dry sites than on the moister ones (fig. 10). Thus, a greater proportion of the relatively small amounts of ectomycorrhizal tips on harsh, dry sites (fig. 8) were concentrated in the soil wood. This is a strong indication that soil-wood influences productivity on dry sites (Harvey and others 1979).

Although these data emphasize the importance of soil-wood on dry sites, a substantial proportion of ectomycorrhizal activity occurred in this substrate even on the very moist sites. When data from all sites and all seasons were analyzed together, soil wood proved to be the most important substrate for ectomycorrhizae in the northern Rocky Mountains, followed by soil humus, and then the first 2 in (5 cm) of mineral soil. The latter was a transitional layer between the humus and the mineral soil base, and had relatively high organic matter content (8-12 percent as determined by loss-on-ignition).

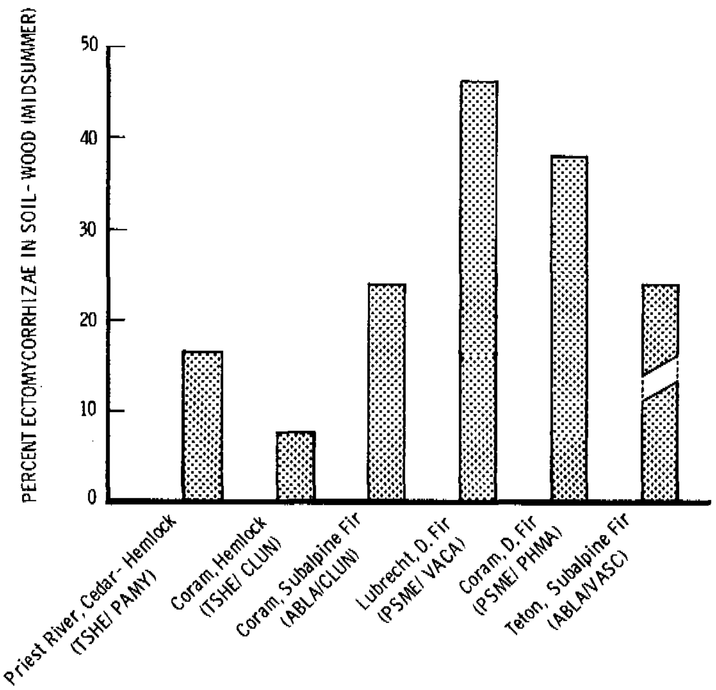


Figure 10.-- Percentage of ectomycorrhizae in soil-wood samples during the summer dry season on the six experimental sites.

Effect of Soil Components on Ectomycorrhizae

The distribution of ectomycorrhizal root tips among the various soil components appears to be primarily a function of moisture content (compare figs. 11 and 12). However, size of organic materials also has an important effect. The organic component must have sufficient volume to express an individual characteristic, such as moisture content, or provide a buffering effect with wide fluctuations of temperature and moisture (Larsen and others 1980). An acid soil reaction is usually favorable to the formation of mycorrhizae (Theodorou and Bowen 1969; Richards 1961). The relatively low pH of soil wood may be an additional factor underlying the importance of this substance to ectomycorrhizal activity in northern Rocky Mountain soils (fig. 13).

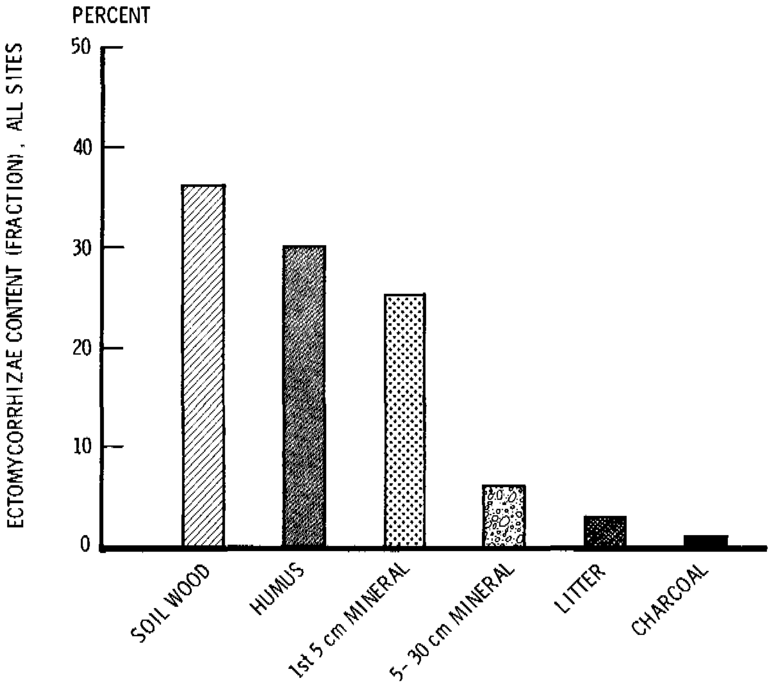


Figure 11.-- Percentage of ectomycorrhizae in each soil fraction. Determined from all soil sample data from all sites.

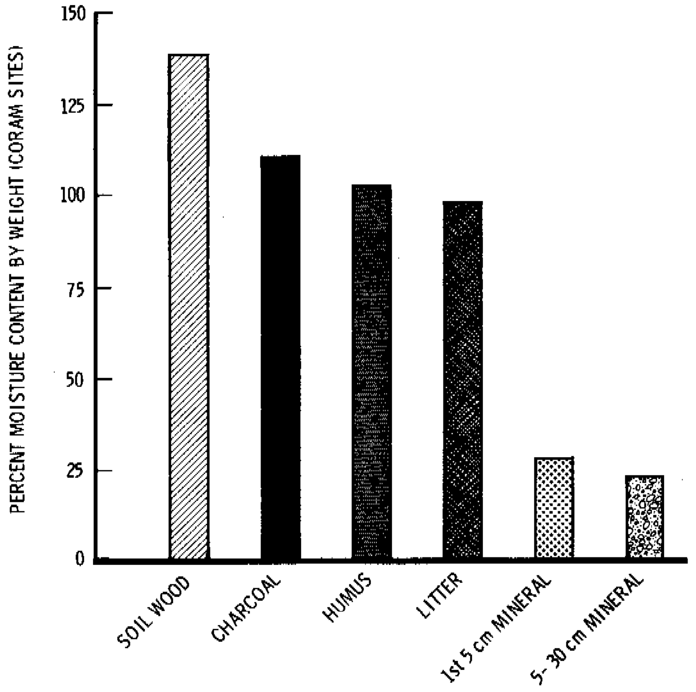


Figure 12.-- Percentage moisture content by weight in each soil fraction--Coram sites only.

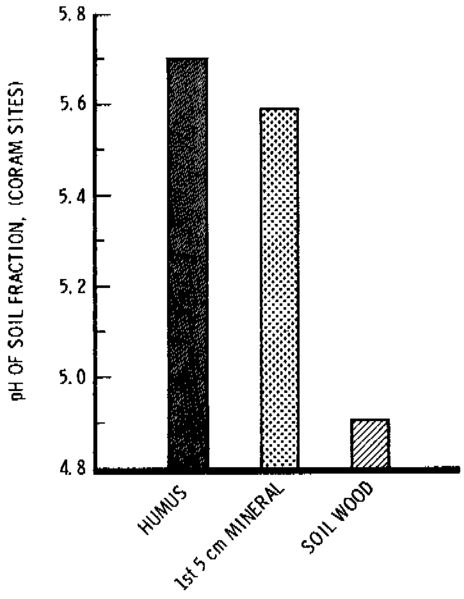


Figure 13.-- Reaction (pH) of representative soil fractions--Coram sites only.

Effect of Organic Matter Quantity on Ectomycorrhizae

The relative percentage of a soil profile that was occupied by organic matter affected the numbers of active ectomycorrhizal root tips found in that profile. The governing variable appeared to be moisture content of the organic matter resulting from the prevailing climate. For example, large quantities of organic matter were less related to numbers of ectomycorrhizal tips in spring than in summer or fall (fig. 14). Similarly, large volumes of organic matter were less important in moist sites than in dry sites (fig. 15). Large quantities of wood appeared to be more effective in sustaining ectomycorrhizal activity than large quantities of humus (fig. 16). However, in no case did quantities greater than 45 percent of any type of organic matter (top 12 inches [30 cm] of soil) result in higher numbers of ectomycorrhizal tips (figs. 14, 15 and 16).

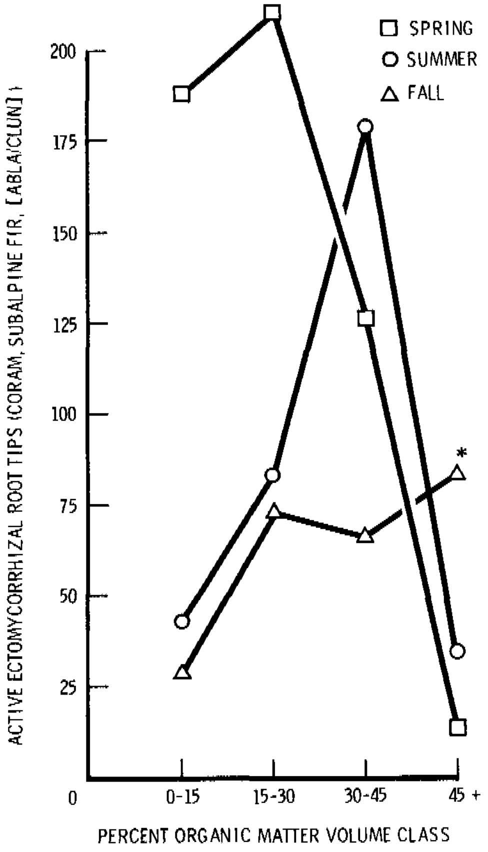


*Figure 14.-- Average numbers of active ectomycorrhizal root tips in samples representative of various organic matter content classes, data from throughout the growing season. *Difference from 30%-45% class not significant.*

Figure 15.-- Percentage of ectomycorrhizae in samples representative of various organic matter classes--Coram sites only.

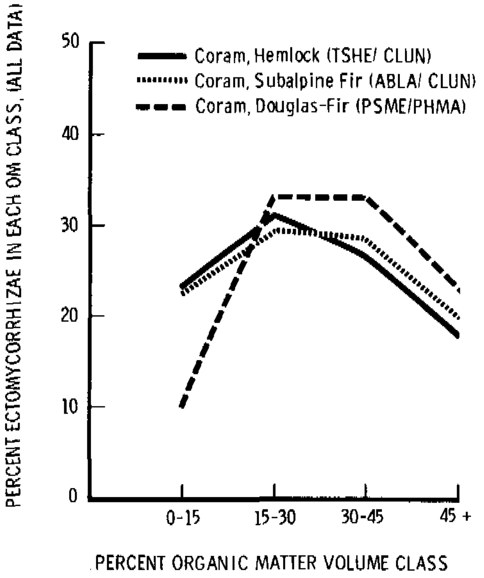
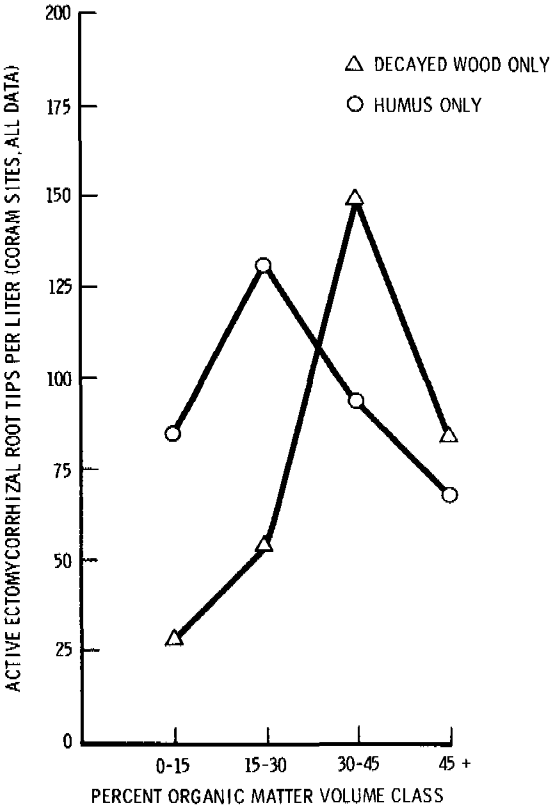


Figure 16.-- Average numbers of active ectomycorrhizal root tips (per liter) in soil-wood and humus samples representative of various organic matter classes--Coram sites only.



PARTIAL CUT

Since ectomycorrhizal fungi are obligate symbionts (Hacskaylo 1973), a reduction in live tree roots resulting from tree harvest would be expected to reduce numbers of active ectomycorrhizae. Such was the case two years after a 50 percent overstory removal on the Coram subalpine fir site. Further, when this overstory removal was followed by a broadcast burn one year later, an additional reduction occurred (fig. 17).

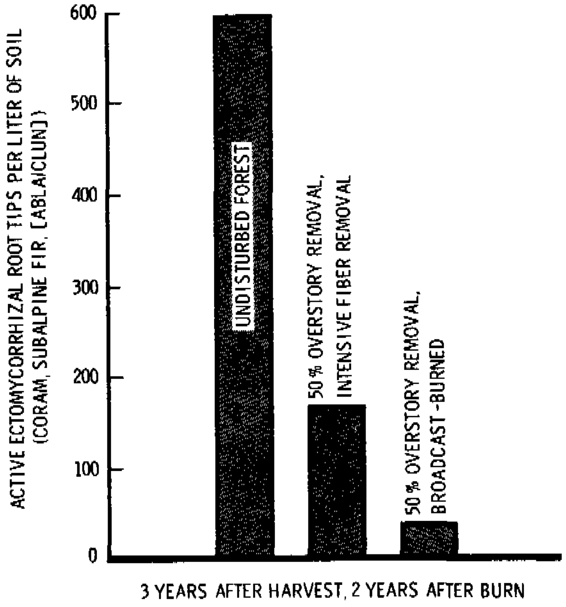


Figure 17.-- Average numbers of ectomycorrhizal root tips (per liter), from matched samples of: undisturbed forest; a 50 percent overstory removal with intensive fiber removal; and a 50 percent overstory removal accompanied by broadcast burning. Samples taken in August 3 years after harvest, 2 years after burning. Coram subalpine fir site.

Distinguishing between the effects of changes in tree density and the effects of changes in soil suitability required a comparison of numbers of ectomycorrhizal tips on a per tree basis. Figure 18 presents such a comparison. Thus, reducing the basal area did not reduce the number of ectomycorrhizae per tree volume on an intensively utilized site. However, broadcast burning did cause such a reduction in a stand sampled two years after the burn.

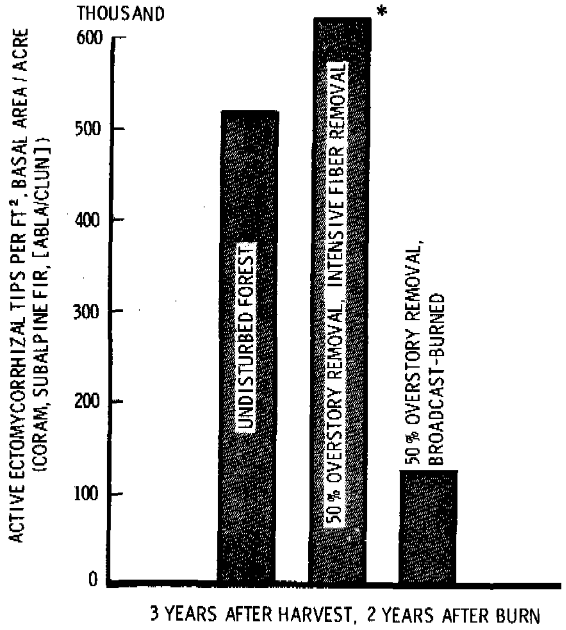


*Figure 18.-- Based on average numbers of ectomycorrhizal root tips (per acre), calculated from same samples as in figure 17, ectomycorrhizae are divided by the basal area of the live tree stems (per acre) remaining on the site. *Increase not significant at p = 0.05.*

CLEAR-CUT

As was the case in a partial cut situation, clear-cutting reduced ectomycorrhizal tips in direct proportion to the loss of trees. When all the trees were removed, active ectomycorrhizae were eliminated. However, low numbers of active ectomycorrhizal tips persisted on residual roots until July following a fall harvest (fig. 19). Similarly, the number of active ectomycorrhizal tips dropped when we sampled from an undisturbed stand into an adjacent clear-cut-broadcast burn two years after treatment (fig. 20). In fact, the presence of the clear-cut burn appeared to reduce ectomycorrhizal tips in the bordering uncut stand. This finding agrees with the previously noted suppression effect of broadcast burns in partial cuts.

How long this reduction of ectomycorrhizal tips on burned sites may be is not known. However, we suspect that the burn-related reduction is caused by the increase in soil reaction following fire (Jurgensen and others 1980). This shift in soil reaction was as much as a full pH unit and on one experimental site values were higher than the control even after four years.

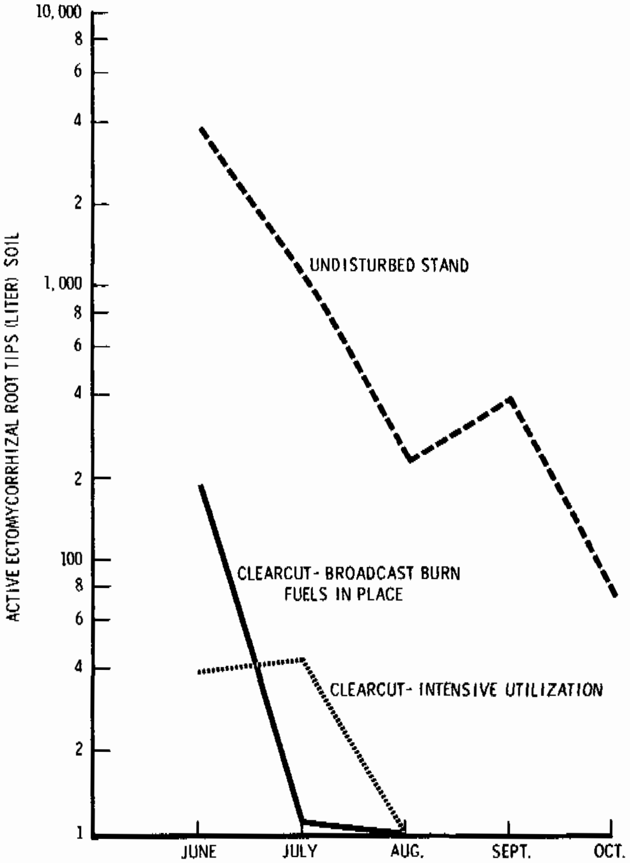
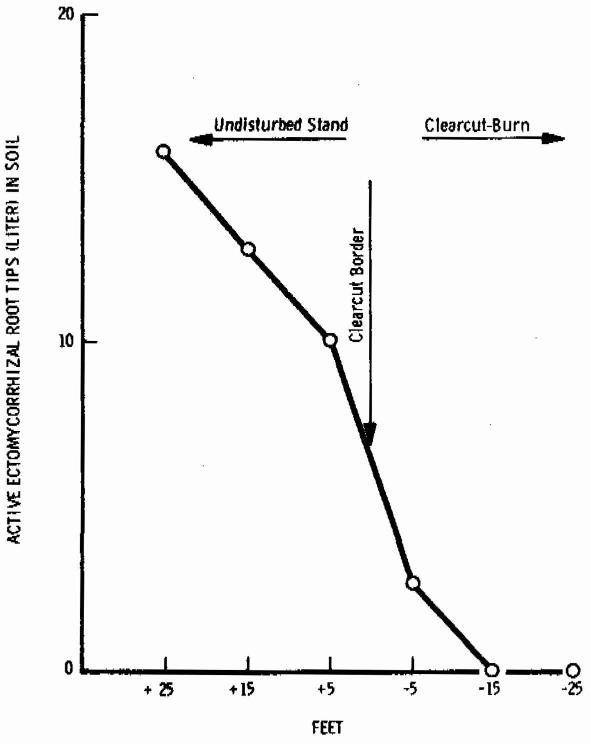


Figure 19.-- Average numbers of active ectomycorrhizal root tips (per liter) from matched samples of: undisturbed forest; a clear-cut with intensive fiber removal; and a clear-cut with fuel left in place for a broadcast burn. Samples taken the growing season after an October harvest. Coram subalpine fir site.

Figure 20.-- Average numbers of active ectomycorrhizal root tips (per liter) from soil samples taken along straight lines going from an undisturbed stand into a clear-cut-broadcast burn, 2 years after burning, 3 years after harvest. Coram subalpine fir site.



CONCLUSIONS

The quantity and distribution of ectomycorrhizal activity in forest soils are governed by a variety of environmental and stand variables. Most important among these are stand productivity, stand density, accumulation of various types of soil organic matter (as determined by fire and harvesting history), season and gross climatic characteristics of the site as reflected in soil temperature and moisture. We probably can predict the effects of these variables and their interactions in controlling ectomycorrhizae.

The immediate impacts of broadcast burning on ectomycorrhizae proved to be negative; however, the fertilizing effect of a burn may compensate for this initial loss. Intensive fiber removal had no immediate detrimental effect on ectomycorrhizae, but on sites with low organic reserves it probably would have negative effects over long periods of time.

The direct effect of tree harvesting on ectomycorrhizae is a function of host density. This symbiotic association is usually obligatory for both conifer and fungus. Residual root systems from cut trees can support only a much reduced level of ectomycorrhizae for a short time.

Adequate colonization of root systems by ectomycorrhizal fungi is prerequisite to the growth of conifers in relatively infertile forest soils. Preventing harvest-related excess losses in organic materials which support ectomycorrhizal associations will prevent man-caused site deterioration. On the other hand, natural catastrophies can also remove or disturb organic soil components over large areas. We feel natural catastrophies have reduced capacity to support ectomycorrhizae on many sites now managed for timber production. Harvest, residues and fuel management procedures for these sites can be designed to improve organic matter quantity, type, and distribution, thus potentially increasing timber growth beyond the capability of natural systems.

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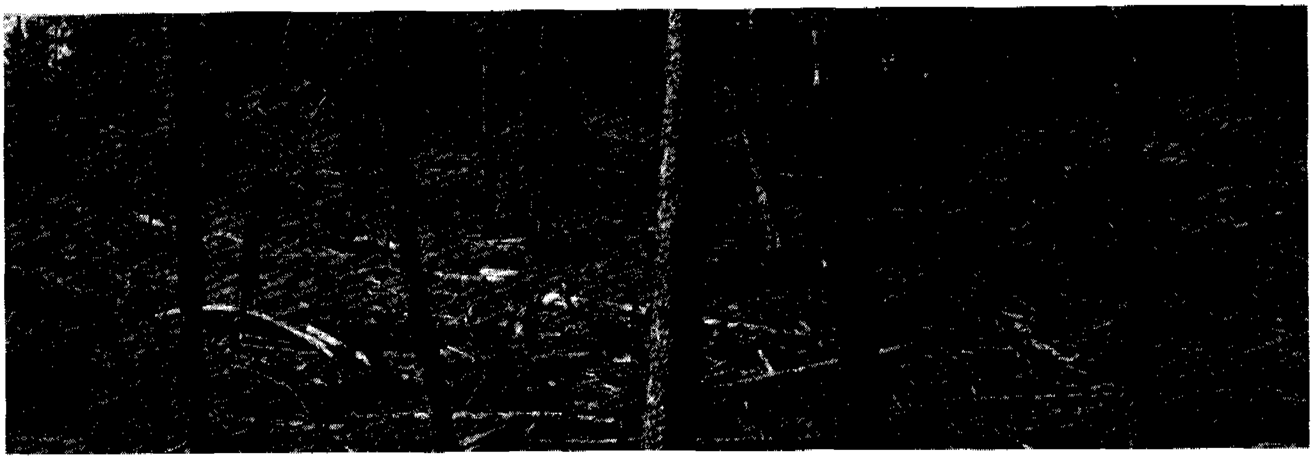

BIOLOGICAL IMPLICATIONS

Initial changes in the physical and biological characteristics of the forest ecosystem combine and interact to bring about a secondary series of responses. These responses -- termed "2nd order responses" by Program researchers -- include changes in site productivity, in vegetative growth and diversity, and in susceptibility to loss from insects, disease, or fire. Whether a particular response is desirable or undesirable depends upon the management objectives for the site. In general, those secondary responses viewed as desirable include early regeneration and development of a new stand of trees; development of understory vegetation favored by wildlife; and reduced levels of forest pest activity. Generally undesirable responses may include reduction in site productivity; inability to obtain tree regeneration; excessive vegetative competition for natural or planted regeneration; and development of severe insect, disease, or fire hazards.

In this section, researchers discuss observed or measured biological responses of a secondary nature -- those resulting from the combined effects of basic changes in the character of the ecosystem. These responses provide an early indication of what the aggregate effects of harvesting-induced environmental changes are likely to be. They provide a basis for defining cause-and-effect relationships, and for predicting longer-term implications for resource management.

BIOLOGICAL IMPLICATIONS OF INCREASING HARVEST INTENSITY ON THE MAINTENANCE AND PRODUCTIVITY OF FOREST SOILS

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ABSTRACT

The microbiological populations of a forest soil are largely responsible for its relative quality and productivity, within limitations of climate and geology. Organisms that contribute to decay processes, nitrogen conversions (particularly fixation) and ectomycorrhizal activity provide soils with important biological characteristics. All of these organisms are dependent on organic matter (biomass) input as an energy source or, after it has decayed, as an organic substrate with specific chemical and physical characteristics. Thus, there is an interdependence between above-ground (organic matter input) and below-ground (nutrient and moisture availability) processes, and this interdependence can strongly influence site productivity. Wood can be a particularly critical and functional soil organic component; its relative importance varies with site. Its relative input to a given site and the quantity of organic reserves on that site help determine how much wood fiber can be removed without risk to future soil quality. There is an opportunity for residues management to enhance sites with inherent limitations to organic matter production and for fire management to protect sites where there are high fire risks to available organic reserves.

KEYWORDS: residues, fire, microbial activity, environmental impact, forest management

FOREST SOIL BIOLOGY

The act of increasing harvesting intensity has both obvious and subtle potentials for causing biological impacts on the quality of forest soils. Perhaps the most obvious impacts of harvesting concern the loss of nutrients contained in the wood removed and the potential for increased microbial nitrification that can increase nitrates in groundwater. Stark (1980) has indicated that if modest increases of fiber removal in the northern Rocky Mountains are limited to stemwood low in nutrient content, nutrient reserves would be adequate. Similarly, as reported elsewhere in this symposium (Stark 1980; Jurgensen and others 1980), nitrate losses caused by clearcutting, even in combination with intensive fiber removal, do not appear to be a serious problem. On the other hand, other factors related to nutrient cycling processes should restrain the use of intensive harvesting on some northern Rocky Mountain forest sites.

Microbial processes are influenced by both nutrient inputs and transfers of nutrients within ecosystems. Importance of soil nutrients cannot be determined on the basis of content alone. Rather, plant nutrient availability must be viewed as a dynamic, microbe-related process that occurs over long periods of time--equal to the longevity of the particular soil components that support the activity. For example, microorganisms supported by decaying or decayed soil wood fix atmospheric nitrogen (N) into forms available for plant use (Jurgensen and others 1980), and other microbial activities supported by such woody materials (ectomycorrhizae) facilitate the export of this N to conifer vegetation (Larsen and others 1980). Therefore, N inputs to the ecosystem must be calculated throughout the 100-500 year lifespan of the decaying wood. Nitrogen content of soil wood at any given time depends primarily on the levels of microbial activity; therefore, N content at any one time is not indicative of the major role wood can play in providing plant available nitrogen.

The relationship of microorganisms to soil productivity is pivotal to the application of management activities which alter the nature and quantity of surface soil composition. For that reason, the types of microorganisms most likely to be associated with the growth of forest trees in northern Rocky Mountain soils (table 1) were closely examined in a number of undisturbed and variously disturbed experimental sites throughout the Rocky Mountain region (Harvey and others 1980; Jurgensen and others 1980; Larsen and others 1980). The general implications of these studies to forest management are emphasized in this report.

Table 1.--Factors affecting soils or tree growth that are based on specific microorganisms.

Microbial action	Effect
Nitrogen fixation (symbiotic and non-symbiotic)	Nitrogen input
Nitrification	Nitrogen loss
Ectomycorrhizal symbiosis	Nutrient availability Water availability Pathogen resistance
Decay (non-pathogenic)	Nutrient flux Production of organic base Nitrogen input
Decay (pathogenic)	Nutrient flux Production of organic base Nitrogen input Genetic turnover of host Vegetation changes

MICROORGANISMS AND SOIL QUALITY

As demonstrated in this symposium (Larsen and others 1980; Jurgensen and others 1980; Harvey and others 1980; Fellin 1980), microbial activities are integral to both positive and negative inputs on soil productivity. Decay organisms convert aboveground biomass into biologically active soil materials and, in the process, recycle bound nutrients and support fixation of atmospheric N. Various components of the soil continue, throughout their lifespan, to support both N-fixing and ectomycorrhizal activities. The ectomycorrhizal association is necessary to the survival of conifers in infertile, natural soils (Trappe and Fogel 1977), as is an adequate supply of N. Conversely, activities of certain soil-borne microbial pathogens, particularly root decay organisms, may limit productivity to non-susceptible vegetation (Fellin 1980).

ORGANIC MATTER AND SOIL QUALITY

All soil microbe activities are supported by the organic fraction of a soil. In terms of wood decay, non-symbiotic N-fixation and ectomycorrhizae, this relationship is usually positive, i.e., the more organic materials the greater the soil productivity. In a developing forest soil, productivity increases with accumulation of organic matter, at least within certain limits (Harvey and others 1980). Therefore, if these organic accumulations are not lost during harvesting and site preparation, the soil will retain its ability to support tree growth. If organic matter is destroyed, the productivity associated with it also is destroyed until restoration occurs. In instances where organic matter in the form of pathogen infested residues is responsible for the spread of disease, organic matter removal and the resulting loss of N or of ectomycorrhizal activity may be the best choice for production of susceptible conifers. In other words, in an active root disease center, the losses from root decay are likely to exceed any potential gain from leaving the infested residues on the site if a susceptible species is the major component of the stand. Where possible, conversion to disease tolerant species would be the preferred method of dealing with pathogen-infested residues if organic matter is in short supply.

POTENTIAL HARVEST-RELATED IMPACTS ON SOIL QUALITY

Since ectomycorrhizal activity and non-symbiotic N-fixation rates vary directly with forest site productivity (temperature-moisture), and are somewhat predictable within soil components, the importance of these components to conifer growth can be estimated. If we assume microbial activities provide direct support to the growth of a stand, as appears to be the case, then one can estimate the cost or benefit, in terms of percent of growth change, from manipulating quantities or types of soil organic matter on a given site. Our present data base provides an appropriate example.

Figure 1 outlines trends in ectomycorrhizal activity within the wood and humus of three forest stands with adequate organic matter. Although the data are not equivalent to a regression, they are indicative of well founded statistical changes that can be expected. If, for instance, we were considering application of intensive fiber utilization practices to these three sites, it is evident that the greatest potential for negative impact would exist on the Douglas-fir/ninebark habitat type. The figure indicates that up to about 38 percent of the seasonal growth on the Douglas-fir/ninebark site may be based on ectomycorrhizal activities supported by soil wood. Therefore, if we removed the source of soil wood, there would be a potential for reducing growth from the time the existing wood was dispersed in the soil until new wood could be produced, decayed and reincorporated into the soil. Turnaround time for such processes approximates 150 to 200 years (fig. 2). If it takes 100 years to disperse the existing soil wood, then there would be a period of 50 to 100 years during which the growth potential of that site would be reduced. Additionally, there would be a period of time during which a lesser reduction in growth, proportionate to the gradual loss or restoration of soil wood, would occur.

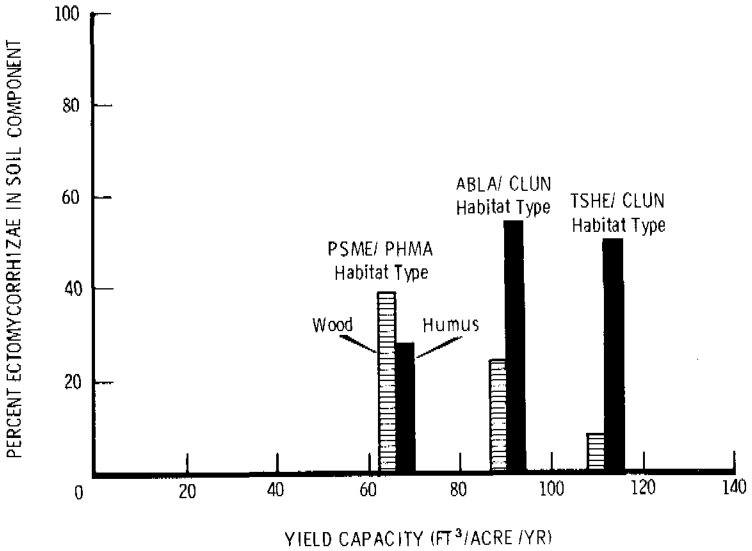

Figure 1.--Relative percentage of active ectomycorrhizae in humus and decayed wood on three sites in the Coram Experimental Forest; yield capacity data are from Pfister and others (1977).

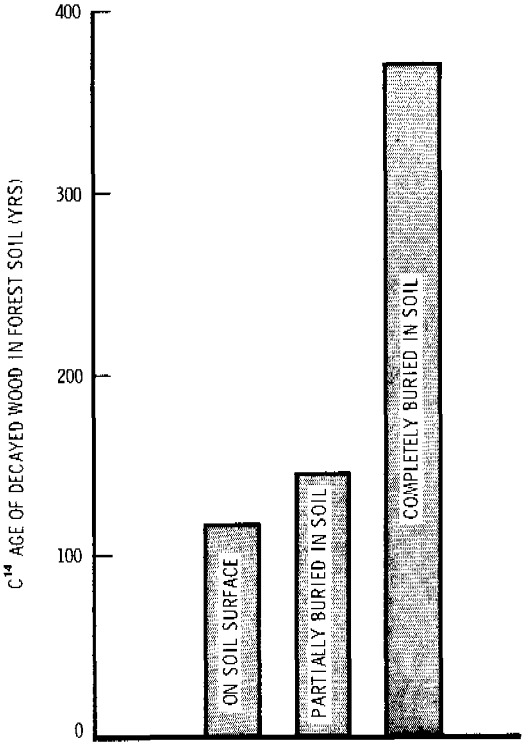

Figure 2.--Mean C^{14} age of decayed wood samples.

Since the best quantity of organic matter for ectomycorrhizal development can be determined (fig. 3), the advantage of increasing soil wood or other soil organic fractions through management of residues can also be estimated. Using the same data as an example, on a site with half the organic reserves of the Douglas-fir/ninebark experimental site depicted in figure 2, doubling soil wood content through residues management might eventually increase the seasonal growth potential of that site by as much as 19 percent. In terms of cubic feet of stemwood on that habitat type, this would equal 13 cubic ft/acre/year (0.90 m^3/ha/yr) (Pfister and others 1977). In terms of the future value of the increased wood production, this would amount to a substantial sum; it also would represent the prevention of a significant loss by avoiding management practices or wildfires that might have destroyed the soil organic matter base. Quantifying this concept implies precision that is probably not appropriate; however, it serves to demonstrate the potential to quantify soil biological and physical characteristics in terms of their ability to support tree growth.

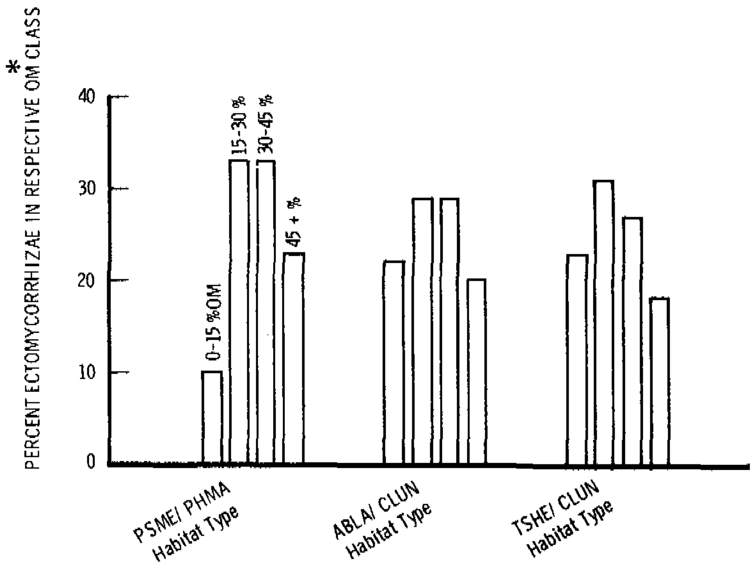

*Figure 3.--The relative distribution of active ectomycorrhizae in soil samples with a specific organic matter content (including litter, charcoal, humus, and decayed wood); samples taken from three sites on the Coram Experimental Forest with a gradient of intermediate temperature and moisture regimes representative of the northern Rocky Mountains. *OM refers to organic matter.*

SITE DIAGNOSIS AND MANAGEMENT

The relative ability of wood, humus and shallow mineral layers of northern Rocky Mountain soils to support selected microbial activities appears to be based on a capacity to buffer changes in temperature, moisture and possibly pH (Larsen and others 1980; Jurgensen and others 1980; Harvey and others 1980 a and b). This appears to hold throughout a series of habitat types featuring a wide range of intermediate temperature and moisture conditions. However, we would expect that extreme sites (i.e., very cold, wet, dry, or a combination thereof) induce different behavior. If the threshold values of temperature, moisture or other conditions for the various microorganisms are exceeded, the microorganisms may either become dormant or die (fig. 4). For example, the Teton experimental site (location and description provided elsewhere in Harvey and others [1980a] this proceedings) apparently is too cold or too dry most of the time to support decay organisms. As a result, periodic fuel accumulations and wildfire function as the principal carbon recycling agent on this site, and all types of organic matter, especially soil wood, tend to be in short supply. Although our data indicate that intense ectomycorrhizal activity is supported by accumulations of humus or decayed wood, these accumulations rarely occur on the Teton site.

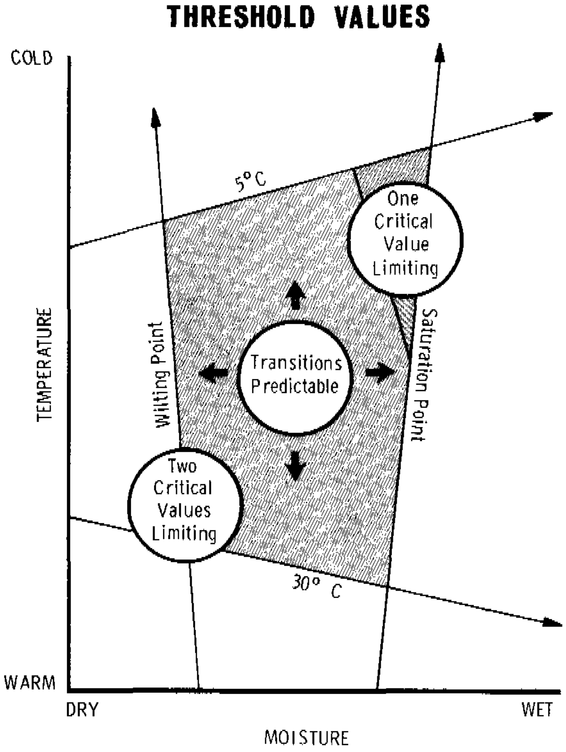

Figure 4.--Some proposed theoretical factors limiting the activities of soil microorganisms and the predictability of changes in their activities over a temperature-moisture gradient.

The Teton site provides an excellent example of how forest management practices could: 1) limit fuel accumulations to levels that would minimize the occurrence of extremely hot fires; 2) lop and scatter residues to get them in contact with the ground for increasing decay and decreasing fire hazard; and 3) protect the integrity of the organic accumulations that have occurred by limiting the disturbance of upper soil layers. In these ways we might eventually be able to achieve a higher level of site productivity than would occur through natural processes.

We can also visualize situations on a cold, wet site, for example (as depicted in the upper right-hand circle of figure 4), where the ability of soil wood or other organic matter to retain moisture could become a problem. In such cases the organic materials would remain saturated with water, have a very low gas exchange to support microbial activity and remain highly acid. Although conjectural, it would appear prudent to encourage removal of wood from the soil on such a site. On a very hot-dry site, however, there may rarely be enough moisture available over a sufficient length of time to support decay or ectomycorrhizal activities at the levels needed to provide useful inputs to the ecosystem. In such a situation, accumulations of soil wood and other organic materials provide fewer benefits but pose no problem except where they represent high fuel accumulations. In this case, removal of some of these materials or modest soil disturbance are not likely to cause adverse impacts, even on a harsh site.

In general, useful disturbances to forest ecosystems (e.g., fire, site preparation, removal of fuels, etc.), cause beneficial effects only when they occur in moderation. Harsh sites exhibit the lowest degree of tolerance to excess disturbance. In fact, the potential impacts of disturbances appear to conform to the theoretical performance curve for perturbed ecosystems recently developed by Odum and others (1979) (fig. 5). Site preparation provides an example of this relationship. Day and Duffy (1965) provided data regarding the efforts of logging on natural regeneration by seedbed type in the Crowsnest Forest, Alberta, Canada, just north of our Coram Experimental Forest site. Their data (fig. 6) illustrate that the regeneration of some species can occur on a wide variety of seedbed types. If site preparation on these logging sites had been extreme (leaving, for example, mostly mineral soil--a frequent objective of regeneration management), the regeneration that occurred in the organic seedbeds would have been lost. In this case the organic materials were generally the most effective seedbeds for species other than pines. A little mineral soil was good, but plowed ground would have been bad for regenerating these sites to fir and spruce.

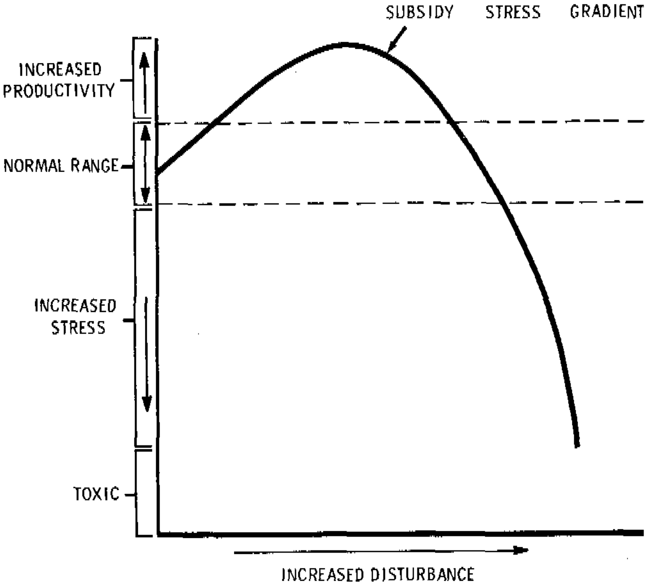

Figure 5.--The theoretical performance curve of a usable input (disturbance) into an ecosystem; adapted from Odum and others (1979).

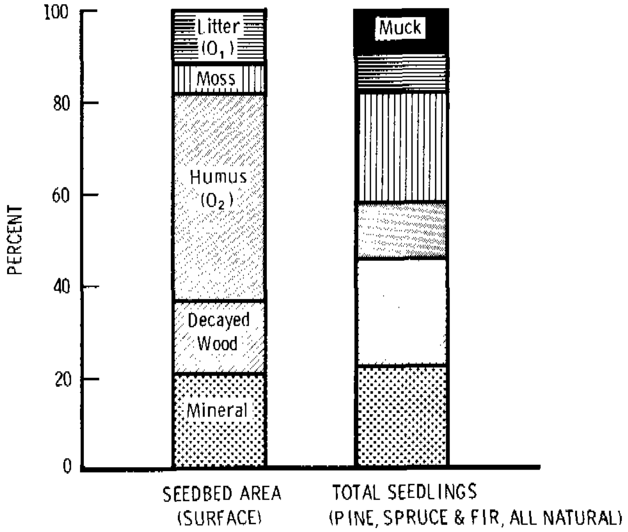

Figure 6.--The percentage of natural regeneration occurring on various seedbed types on a northern Rocky Mountain ecosystem; data derived from Day and Duffy (1965).

CONCLUSIONS

A forest manager should know that many important aspects of soil quality depend directly on microbial activity, and that this activity is supported to varying degrees (dependent on temperature and moisture gradient) by soil organic components. Therefore, managing the soil for organic matter diversity, i.e., preserving or creating a variety of microsites, would usually be the method of choice. In no case should soil disturbance, organic matter accumulations, or depletions be extreme over large areas.

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Understory Vegetation Response to Harvesting and Residue Management in a Larch/Fir Forest

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ABSTRACT

This paper reports the response of understory shrubs and herbs to combinations of three silvicultural harvest-cutting systems--clearcut, shelterwood, group selection--and four residues treatments--intermediate utilization of harvest residues followed by broadcast burning, conventional-utilization-and-broadcast-burn, intense removal of all woody residues, and understory-protected treatments. Volume, cover, and biomass of shrubs and herbs were evaluated before, and at 2 years and 4 years after harvesting.

All treatments substantially reduced the volume and biomass of live shrubs to as little as 3 percent of the preharvest volume on burned treatments. However, all vegetation responded rapidly under all treatments, in some cases approaching preharvest levels in as few as 4 years. Herbs responded earlier and more to treatments than did the shrubs. Total biomass of live understory vegetation (not including trees) averaged over 5 000 kg/ha (4,500 pounds/acre) in the mature forest, reached about half that 2 years after harvesting, and about three-fourths of that 4 years after harvesting.

KEYWORDS: *Larix occidentialis*, *Pseudotsuga menziesii*, larch/Douglas-fir, understory vegetation, residues utilization, prescribed burning, shrubs, herbs, silvicultural system

INTRODUCTION

Vegetation integrates the effects of biological and physical intrusions into an ecosystem and provides the best indicator of response to various treatments that man and/or nature impose on the system. Vegetation also provides both direct and indirect benefits to man in a variety of resources ranging from timber products, to forage and cover for wildlife, water regulation, protection of the soil mantle, and esthetics. This is particularly apparent in the extensive larch/Douglas-fir (*Larix occidentalis/ Pseudotsuga menziesii*) forests of the Northern Rockies where no single resource predominates (Schmidt and others 1976).

Natural succession in Northern Rocky Mountain forests slowly but inexorably drives vegetation toward a greater complement of shade-tolerant species. This is particularly striking in larch/fir forests because of the wide range in species and shade-tolerance levels. Vegetation classification schemes capitalize on these tolerance differences, and classifications based on climax stages of the vegetation have been developed (Daubenmire and Daubenmire 1968; Pfister and others 1977). Under the climax concept, nature has had sufficient time to integrate time and space variation in vegetation development.

Natural intrusions of fire, insects, disease, wind, and other factors disrupt succession and can either set vegetation back to year one, have little effect, or greatly accelerate succession toward more shade-tolerant forest vegetation. However, man's activities in the forest, particularly harvest cuttings, now create most physical, biological, and esthetic change. Even-aged silvicultural systems--clearcutting, seed tree, and shelterwood--coupled with site preparations that expose mineral soil and reduce vegetative competition, have proved most successful in regenerating larch/ Douglas-fir forests (Schmidt and Shearer 1973). However, changing management objectives and wood-utilization standards have made it necessary to reevaluate some of these silvicultural systems in terms of environmental effects. As utilization of woody residues intensifies, the number of microsites provided by material formerly left in the woods decreases, the amount of fuel for prescribed burning decreases, and the amount and form of nutrients may be changed. Some of these changes may positively influence one resource and negatively influence others. There is no single combination of harvest cutting, utilization level, and subsequent cultural practice that will meet all forest management objectives. Combinations of these practices are dictated by economics, public needs, protection of the basic soil resource, biological and physical practicability, forest type, landform, and a host of other factors.

One resource needing increased emphasis in forest management is understory vegetation. It serves both actively and passively to increase wildlife and esthetics values, and to protect basic soil resources. However, understory vegetation can also serve as competition for tree seedlings, often delaying tree regeneration for decades (Schmidt and Shearer 1973). This paper presents preliminary results demonstrating the effects of three different silvicultural practices combined with four different residue utilization treatments on understory vegetation in a larch/Douglas-fir forest in Montana. Four years of understory vegetation-response data are presented.

STUDY TREATMENTS AND AREA

The overall design of this study coupled three silvicultural harvest-cutting systems--clearcut, shelterwood, and group selection--with four residues treatments for a total of 12 treatment combinations. In addition, control plots were established in the uncut adjacent mature forest. All treatments and controls were replicated once.

The three silvicultural harvest-cutting systems consisted of:

1. Two shelterwoods of 14.2 and 8.9 ha (35 and 22 acres), where about half of all standing timber was cut.
2. Two sets of eight group-selection cuttings (small clearcuts), averaging 0.3 ha (0.8 acre) and ranging from 0.1 to 0.6 ha (0.3 to 1.4 acres), where all standing timber was cut within each of the groups, and intervening timber between the groups was left uncut.
3. Two clearcuts of 5.7 and 6.9 ha (14 and 17 acres) where all standing timber was cut.

The four residues utilization treatments consisted of:

Treatment	Trees Cut	Harvest Utilization Standard	Subsequent Treatments
1. Intermediately utilized and broadcast burned.	All trees except designated overstory shelterwood trees.	Remove all material (live and dead, standing and down) to 7.6-cm (3-inch) small end diameter, 2.4-m (8-foot) in length, and 1/3 sound.	Broadcast Burned
2. Conventionally utilized and broadcast burned.	All trees except designated overstory shelterwood trees.	Remove all sawtimber material (live and recently dead) to 1974 Forest Service standards: 17.8-cm (7-inch) d.b.h. and 15.2-cm (6-inch) top diameter, 2.4-m (8-foot) in length, and 1/3 sound.	Broadcast burned
3. All residues removed (Intensive fiber utilization).	All trees except designated overstory shelterwood trees.	Remove all material (live and dead, standing and down) to 2.5-cm (1-inch) d.b.h.	None
4. Understory trees protected (Understory trees under 17.8-cm (7-inches) d.b.h. were left uncut, but were subject to damage and loss during the cable logging process).	All trees 17.8-cm (7-inches) d.b.h. and over, except designated overstory shelterwood trees.	Remove all material (live and dead, standing and down) to 7.6-cm (3-inches) small-end diameter, 2.4-m (8-feet) in length, and 1/3 sound.	None

Because of cool, wet weather in 1975, burning conditions were unfavorable. As a result, none of the designated areas burned very hot, and areas designated for burning on the lower replicate of the shelterwood were left unburned. A complete description of the burning was reported by Artley and others (1978). Some tree regeneration implications of different intensities of burning have been reported (Shearer 1975; Shearer 1980).

The study was conducted on the 3 019-ha (7,460-acre) Coram Experimental Forest, on the Flathead National Forest in northwestern Montana (fig. 1). The study sites are located below the main ridge facing east into Abbott Basin (lat. 48° 25' N., long. 113° 59' W.). The six blocks shown in figure 1 were cable logged in 1974 and, where designated, broadcast burned in the fall of 1975. Each harvest-cutting block was further divided into four subblocks where the four residues utilization treatments were superimposed: (1) intermediate utilization followed by burning, (2) conventional utilization and burning, (3) all residues removed, and (4) understory protected.

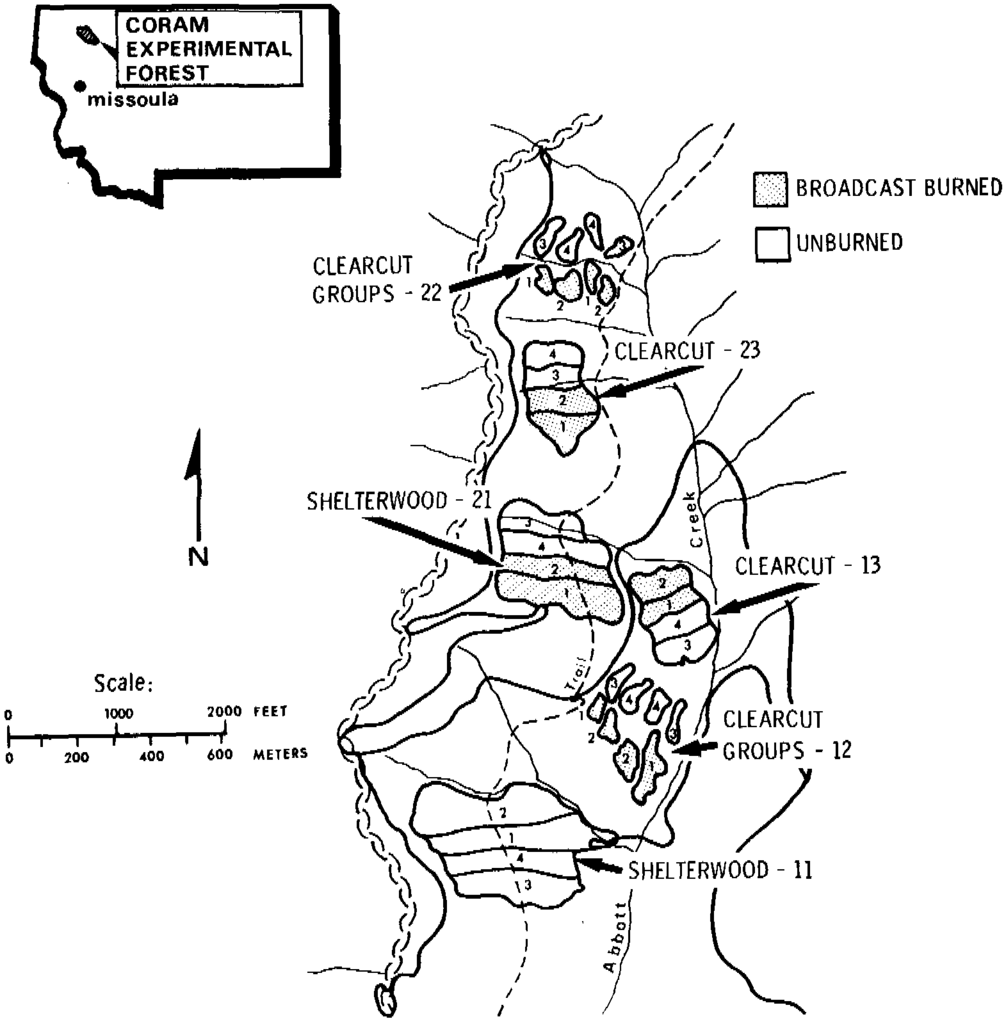

Figure 1.--Location of cutting blocks in Abbott Basin, Coram Experimental Forest. Timber was harvested in 1974 and subsequent treatments were completed by fall 1975.

The timber type on the study area is larch/Douglas-fir (Cover Type 212, Society of American Foresters 1954). This type is composed primarily of western larch and Douglas-fir. Associated species include subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) and Engelmann spruce (*Picea engelmannii* Parry). The study area falls primarily in the *Abies lasiocarpa/Clintonia uniflora* habitat type, with the following phases represented: *Aralia nudicaulis*, *Menziesia ferruginea*, *Clintonia uniflora*, and *Xerophyllum tenax* (Pfister and others 1977; Bernard L. Kovalchik 1974, unpublished data).

Topography ranges in steepness from 30 to 80 percent (17° to 39°), while elevation ranges from 1 189 to 1 585 m (3,900 to 5,200 feet) m.s.l. Soils are derived from impure limestone and underlying material of loamy-skeletal soil families (Klages and others 1976).

Methods

Before logging, ten permanent points were systematically located at 30.5-m (100-foot) intervals within each subblock in the clearcut and shelterwood cuttings and the control areas. Five points were located within each of the eight group-selection cuts (small clearcuts) at variable intervals, depending on the size of the opening. At each of the 280 permanently established points, understory vegetation was measured before logging (1974), and at 2 and 4 years later (fig. 2).

Figure 2.--Researchers measure the volume of all shrub vegetation to determine 4-year response of various species to different combinations of silviculture and residues management treatments on Coram Experimental Forest.

We determined volume and cover using a nested quadrat system that stratified vegetation into height classes (fig. 3). The classes of vegetation measured within each quadrat were as follows:

Quadrat Size (m)	(feet)	Kind and Size of Vegetation Measured
5 X 5	(16.4 X 16.4)	woody shrubs 2.5 m (8.2 feet) and greater in height
3 X 3	(9.8 X 9.8)	woody shrubs 1.5 to 2.4 m (4.9 to 7.9 feet) tall
1.5 X 1.5	(4.9 X 4.9)	woody shrubs 0.5 to 1.4 m (1.6 to 4.6 feet) tall
0.5 X 0.5	(1.6 X 1.6)	low woody shrub and tree vegetation less than 0.5 m (1.6 feet) tall, and all herbaceous vegetation regardless of height

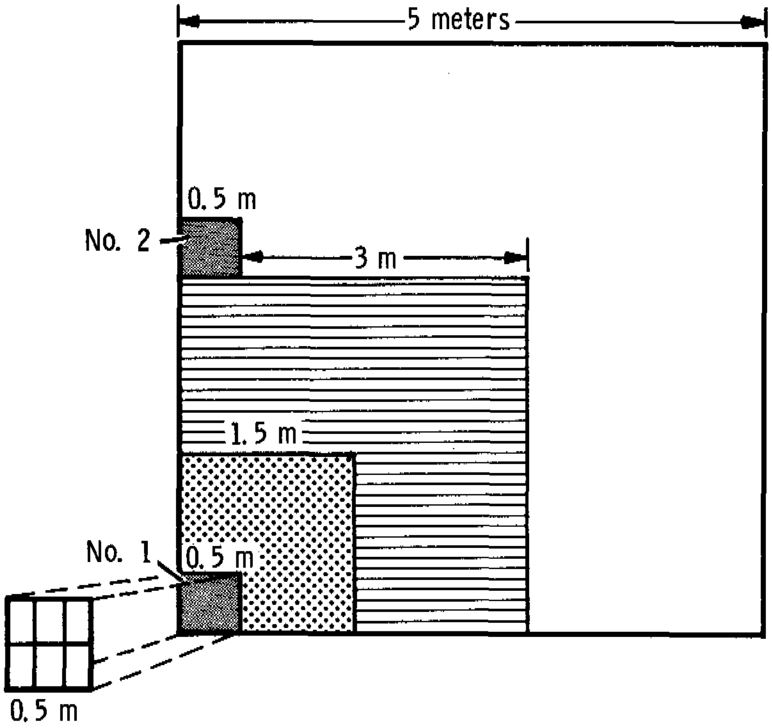

Figure 3.--Nested quadrat method used for measuring vegetation of different size classes.

Shrub volume was determined by measuring two horizontal dimensions and the height to the top of each shrub crown in the sample. Volume was calculated from these three dimensions, considering the shrub an ellipse. Because different shrub species occupy varying height strata, some shrubs were partially or entirely under the crowns of taller shrubs. Where this layering occurred (common in larch/fir forests), shrub volume summaries can appear unrealistically high. Thus, by definition in this study, cubic shrub volume is aerial crown area X total height of the shrub.

Cover was defined as any forest floor component that covers the mineral soil, including primarily small shrubs less than 0.5 m (1.6 feet) tall, all herbaceous vegetation, and down woody material.

Biomass equivalents were determined for shrubs by collecting representative samples of major species in areas adjacent to the permanent sample plots and then breaking the shrubs into three components--leaves, stems less than 4-mm (0.16-inch) diameter, and stems more than 4 mm (0.16 inch). Regressions were developed to relate these biomass values before and after treatments to volumes measured on the permanent plots (fig. 4).

Figure 4.--Researchers collect representative samples of shrub vegetation to determine the relationship of shrub biomass to volume.

The stems were divided at 4 mm (0.16 inch) to provide some estimate of potential browse on the area; observations of big-game feeding on the study area had indicated nearly all browsing was on stems less than 4 mm (0.16 inch). Elk (*Cervus canadensis*) and deer (*Odocoileus* sp.) were the primary ungulates found in the study area.

To determine biomass of small shrubs and trees less than 0.5 m (1.6 feet) tall, and all herbaceous vegetation, vegetation on two 0.5 X 0.5-m (1.6 X 1.6-foot) quadrats adjacent to each permanent set of quadrats was clipped, dried, and weighed.

RESULTS AND DISCUSSION

The results presented here highlight major effects or trends found in these preliminary data. Evaluations of the vegetative response to silvicultural and residues management treatments will be emphasized, focusing on (1) shrub response, (2) cover, and (3) biomass. Further analyses of these data in subsequent publications will aim at (1) refining this information, (2) identifying significant vegetation trends and their interactions between silvicultural and residues utilization treatments, and (3) evaluating individual species responses. Ultimately, long-term vegetation responses will be determined from periodic remeasurements.

Vegetation responses usually relate closely to plant species status prior to treatment. Because of this, we measured vegetation in the undisturbed forest immediately before treatments were imposed, and found that shrub volume averaged 31 100 m^3/ha (16,468 $yards^3$/acre) in the mature forest prior to harvest--equivalent in biomass to 4 687 kg/ha (4,180 pounds/acre). Shrub biomass was comprised of 4 063 kg/ha (3,624 pounds/acre) of large stems, 348 kg/ha (310 pounds/acre) of small stems, and 276 kg/ha (246 pounds/acre) of leaves. Lesser vegetation, which included herbs and small shrubs less than 0.5 m (1.6 feet) tall, accounted for 57 percent of the surface cover, with litter and woody material accounting for most of the remaining cover. The equivalent biomass of this 57-percent "living" cover averaged 1 184 kg/ha (1,056 pounds/acre). Thus, total live biomass of understory vegetation (not including understory trees) in the mature forest was 5 871 kg/ha (5,237 pounds/acre). This indicates a relatively lush understory flora, about a third more than found on nearby larch/fir forests where spruce and subalpine fir were more in evidence (Stickney [In press]), and substantially above the 280 kg/ha (250 pounds/acre) biomass measured on a cold, high-elevation lodgepole pine site in Wyoming (Schmidt and Lotan 1980).

As shown in Appendix I, 11 tree species, 21 major shrub species, and 58 herbaceous species were found on the study area.

Response of Major Shrubs

SILVICULTURE TREATMENT EFFECTS

All harvest-cutting systems--shelterwood, group selection, and clearcut--reduced average shrub volume to less than 25 percent of preharvest levels and as low as 10 percent on the group-selection cuttings (fig. 5). These are average values that include all residues treatments within each silviculture treatment. Because plots were measured 2 years after harvesting, they likely show somewhat more volume than was present immediately after logging. We have no data with which to verify that assumption, but Stickney's (In press) data indicates this is generally true.

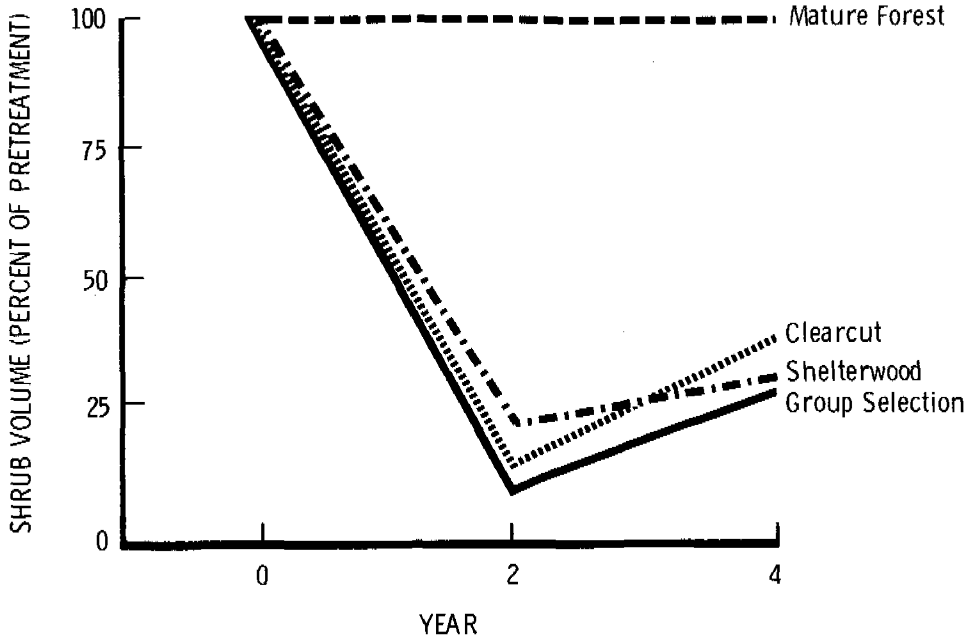

Figure 5.--Effect of three silvicultural harvest-cutting systems on understory shrub volume 2 and 4 years after harvesting a larch/fir forest.

As shown in figure 5, the volumes measured at year two are ranked as one would expect for the three harvest-cutting systems. The group-selection cutting areas, at 10 percent of their preharvest level, had been subjected to highly concentrated falling and cable-skidding activities because of their small sizes (averaging < 0.3 ha [0.8 acre]). The same was true to a lesser extent on the clearcuts where activity was not necessarily as confined, and where no internal trees, such as those in the shelterwood, were left to protect the understory vegetation during logging. Conversely, shrubs averaged 23 percent of their preharvest level on the shelterwoods. Shelterwoods retained about one-half their original tree volume. As a result, there was not only less falling and skidding, but reserve trees provided some protection from the logging activities.

Shrub volume recovered rapidly on all three harvest-cutting systems (fig. 5). However, differences in recovery slopes follow expectations--the greater the release from the overstory trees, the greater the percentage shrub recovery. Clearcuts were recovering the fastest, followed by the group selections and shelterwoods. As shown in figure 5, shrub volume in clearcuts had returned from 14 percent of preharvest volume at 2 years to 37 percent in 4 years. Shrubs on the group-selection cuttings went from 18 percent of preharvest volume at year two to 28 percent at year four. Although shrubs on the shelterwoods had a higher base value at 2 years--23 percent of preharvest volume--than those on the other cuttings, their recovery rate was slower. The mature forest showed no detectable change in shrub volume during the 4-year study period.

RESIDUES TREATMENT EFFECTS

As described earlier, silviculture treatments, accomplished by harvesting, reduced volume of understory vegetation on the various sites. However, when data from the three silvicultural treatments were combined, we found that residue treatments also substantially affected understory vegetation. The residues treatment that sought to protect understory trees during harvesting also resulted in substantially less loss of the associated understory vegetation. As shown in figure 6, harvesting with this treatment (understory protected) reduced shrub volume 2 years after harvesting to 35 percent of its preharvest level. At the other end of the scale, the two treatments that burned remaining residues reduced shrub volume 2 years after harvesting to less than 3 percent of their preharvest volume. Little of the shrub volume left after harvesting remained after burning. Intensively removing all residues resulted in an intermediate loss in shrub volume.

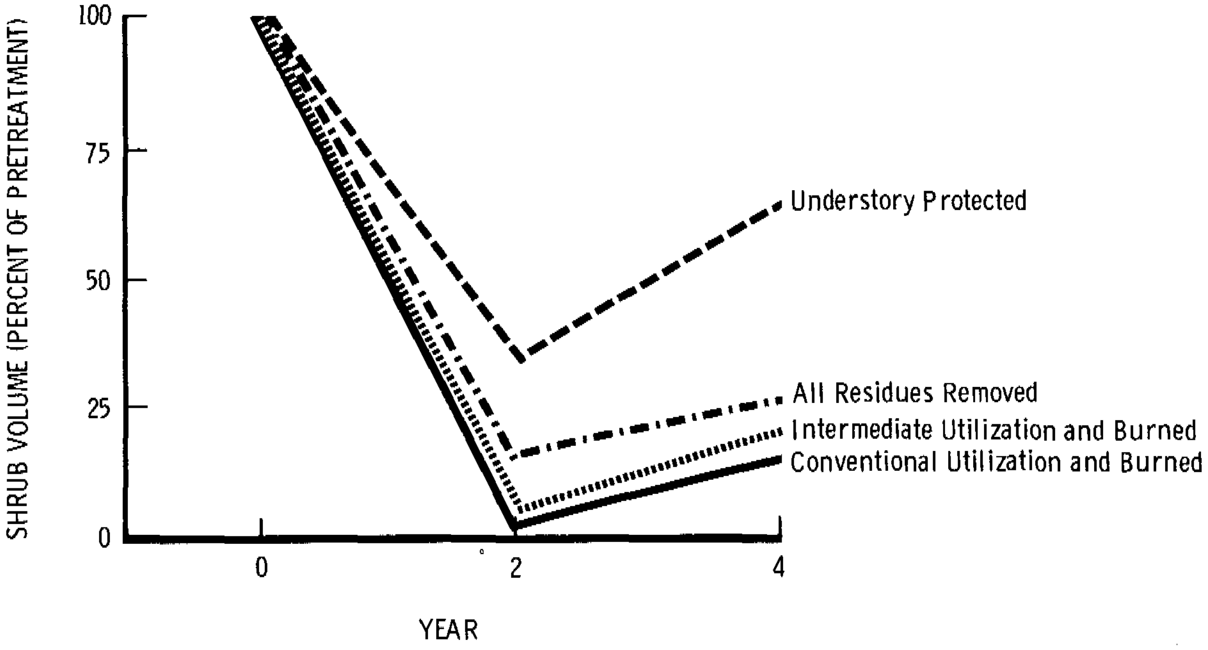

Figure 6.--Effect of four residues management treatments on understory shrub volume 2 and 4 years after harvesting in a larch/fir forest.

The recovery rate of shrub volume from year two to four was also most favorable on the understory-protected treatment; volumes increased from 35 percent of preharvest volume at 2 years to 62 percent at 4 years (fig. 6). Shrub volume recovery rates were roughly comparable on the other three treatments, ranging from 12 to 16 percent between year two and four.

Twenty-three shrub species were found on the study area but six of these species accounted for well over 90 percent of the total preharvest shrub volume. These six were mountain maple (*Acer glabrum*), ninebark (*Physocarpus malvaceus*), thimbleberry (*Rubus parviflorus*), rose (*Rosa gymnocarpa*), alder (*Alnus sinuata*), and serviceberry (*Amelanchier alnifolia*). Their relative importance in terms of volume was a function of treatment and number of years since harvest. The examples shown in figure 7 illustrate the relative stability of some species and the responsiveness of others following treatment. Ninebark, for example, retained the same relative amount of volume in both treatments shown, whereas serviceberry changed little on the understory-protected treatment and changed a lot on the intermediate-utilization-and-burned treatment; mountain maple's relative amount of volume changed substantially on both treatments (fig. 7).

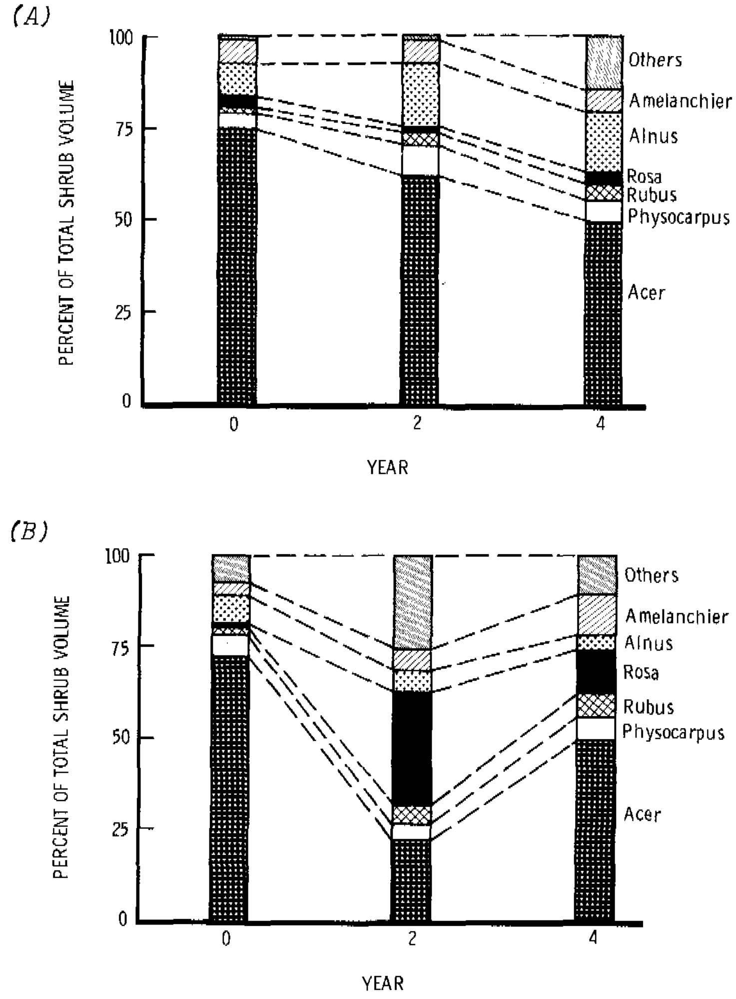

Figure 7.--Relative response, as measured by volume, of the major shrub species to two residues management treatments: (A) Understory-protected treatment, (B) Intermediate-utilization-and-burned treatment.

Overall shrub recovery rates do not necessarily reflect individual species responses to different treatments. Four typical shrub species were chosen to illustrate relative changes in shrub volumes, but these relative values should not be confused with absolute changes. For example, relative shrub volume of mountain maple could decline even though its absolute values increased. It simply is not growing as fast in relative terms as the shrub population as a whole.

As shown in figure 8, mountain maple, a large shrub, accounted for about three-fourths of the total preharvest shrub volume on all of the different study sites. All treatments produced a decline in relative importance of maple, but the treatment that protected the understory showed the least loss in relative volume of maple at 2 years. The other three treatments reduced maple to less than a third of the total shrub volume 2 years after harvesting.

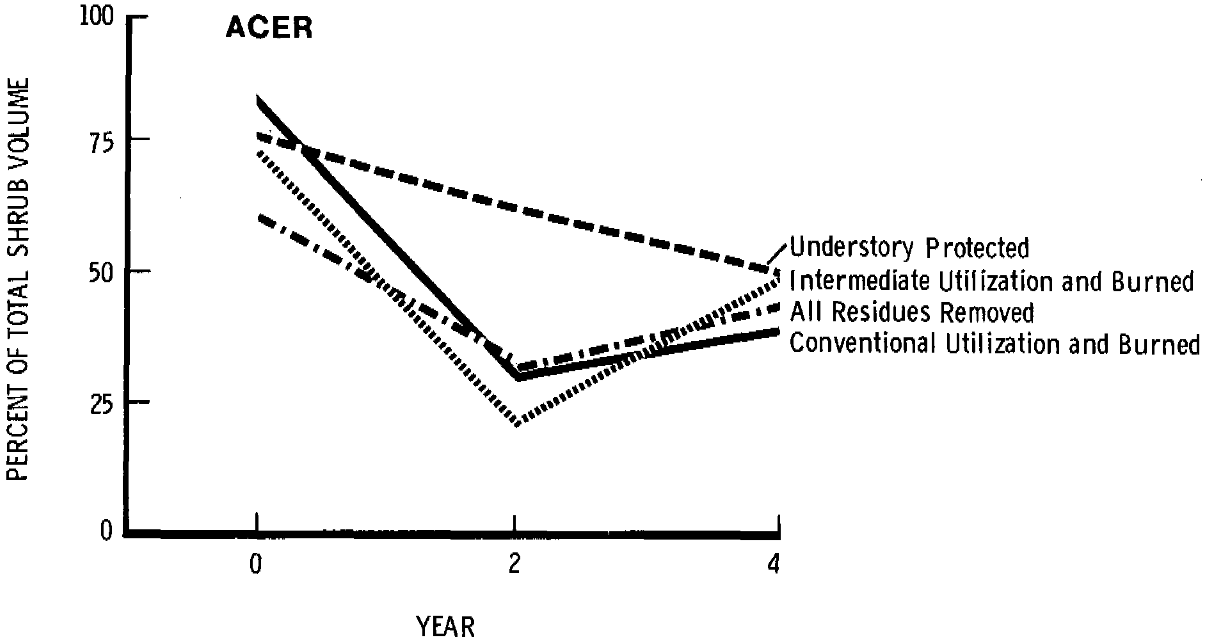

Figure 8.--Relative volume response of mountain maple to four residues management treatments, 2 and 4 years after harvesting.

More important for maple is the trend between year two and four. As shown in figure 8, maple volume was on an upward swing on all three intensively treated areas (burned or intensively utilized), but it was gradually declining on the understory-protected treatment. This is likely due to vigorous resprouting from root crowns in the intensive treatments. Many shrubs in the understory-protected treatment remained relatively intact and root sprouting was less pronounced.

Ninebark, a medium-size shrub, behaved much differently than maple (fig. 9). It accounted for only about 5 percent of the preharvest shrub volume. However, it rapidly increased its relative position regardless of treatment, accounting for as much as 13 percent 2 years after harvesting on the conventionally-utilized-and-burned treatment. However, its moment of glory appears short-lived because its relative importance declined between year two and four after harvesting, with the most pronounced decline in the all-residues-removed treatment.

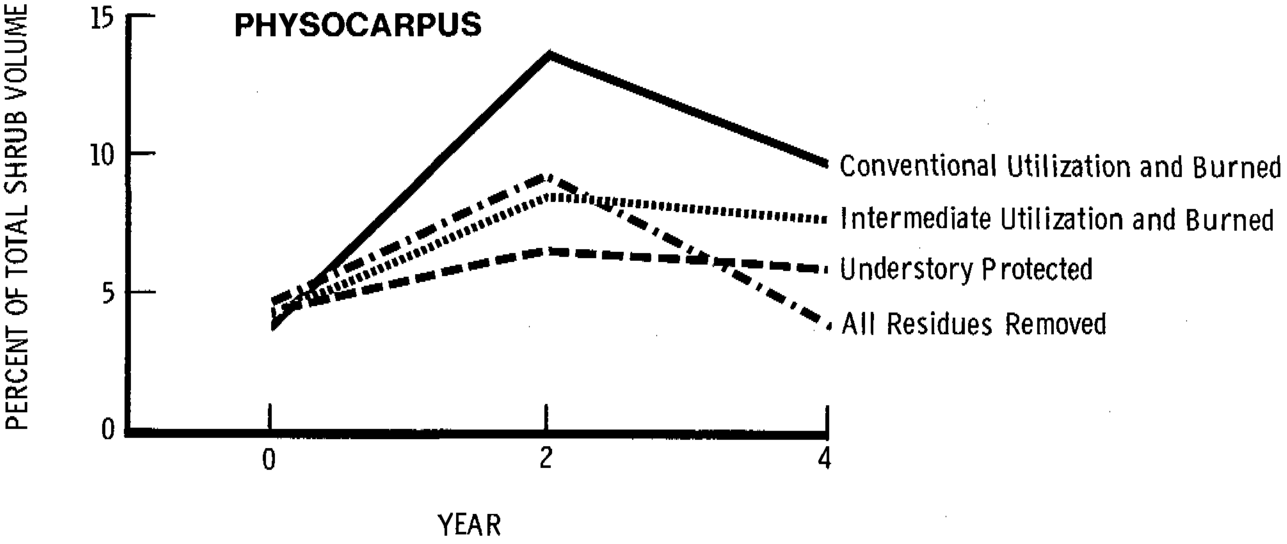

Figure 9.--Relative volume response of ninebark to four residues management treatments 2 and 4 years after harvesting.

Rose behaved similar to ninebark (fig. 10). Rose is a small shrub and it accounted for 3 percent or less of the total preharvest shrub volume. Like ninebark, its relative importance increased substantially 2 years after harvesting on the two burned treatments, accounting for a third of all shrub volume on the intermediate-utilization-and-burned treatment. However, its relative importance was short-lived; it dropped to between 5 and 10 percent of the total volume on all treatments 4 years after harvesting.

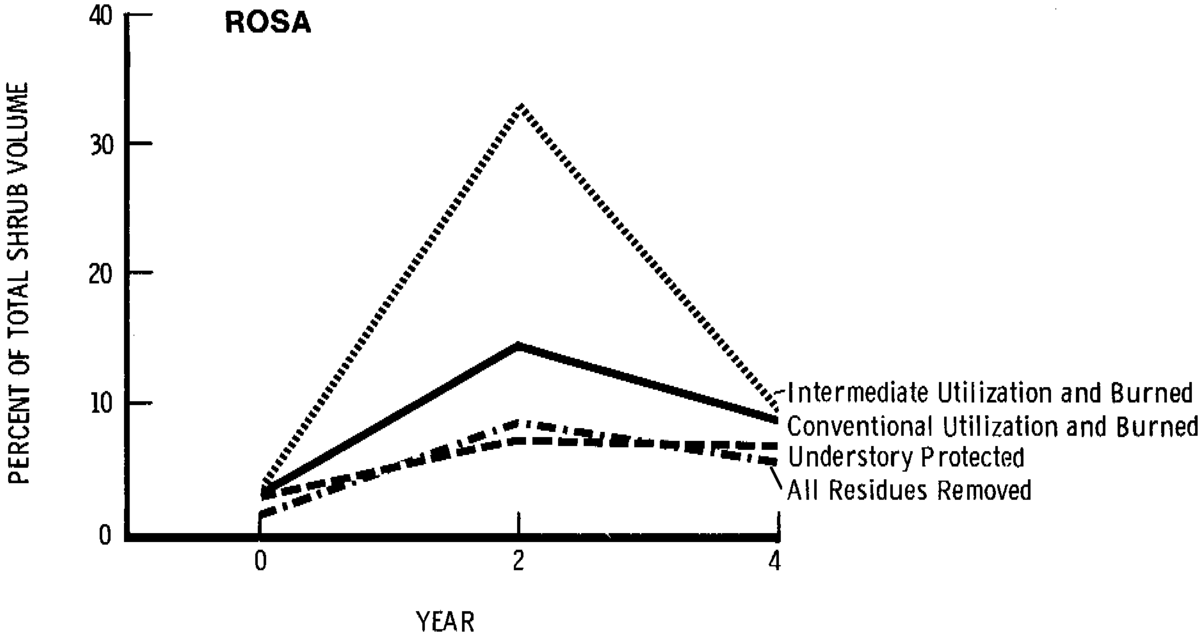

Figure 10.--Relative volume response of rose to four residues management treatments 2 and 4 years after harvesting.

Thimbleberry is a pioneer species that accounted for only about 2 percent of the preharvest shrub volume. As expected, it increased in relative importance on all treated areas, benefiting most on the most intensively treated areas (fig. 11). For example, its relative importance increased from 2 percent to over 15 percent on both the all-residues-removed and conventionally-utilized-and-burned treatment areas. However, its relative importance changed very little with the understory-protected treatment, which disturbed the areas much less than the others and thus did not create the environment most desirable for a pioneer species like thimbleberry.

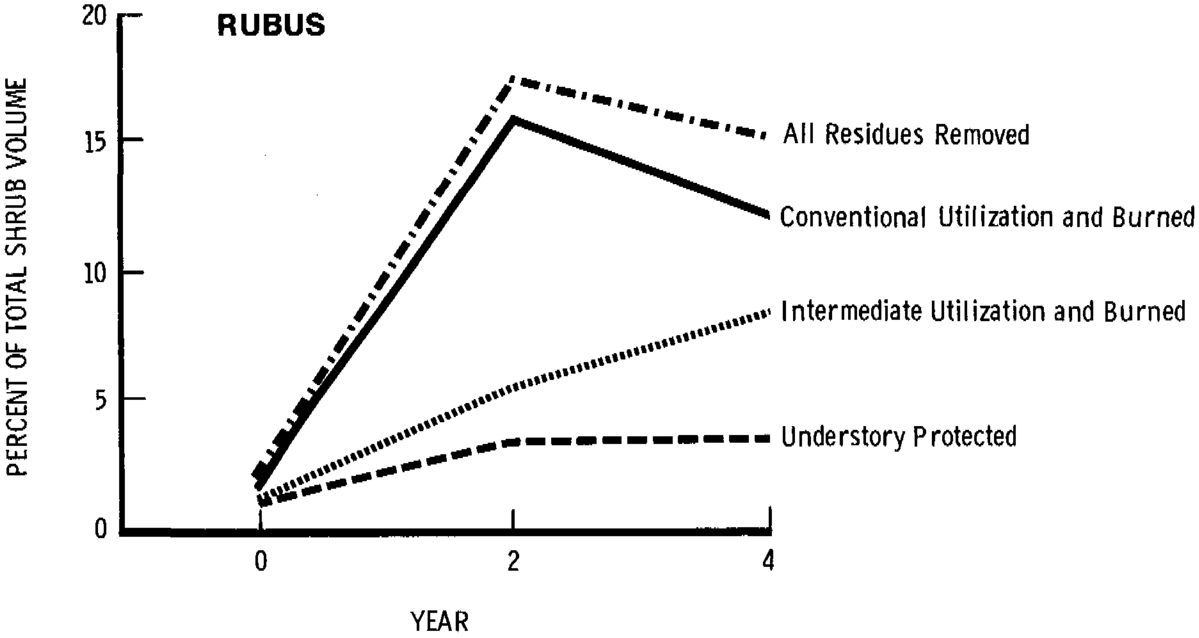

Figure 11.--Relative volume response of thimbleberry to four residues management treatments 2 and 4 years after harvesting.

Cover

Cover is an important descriptor of forest surface conditions. In this study, percent cover is a vertical projection of what occurs at the forest floor. It includes all herbaceous vegetation, small shrubs less than 0.5 m (1.6 feet) tall, and other cover such as litter, wood, rocks, etc. Our study was concerned primarily with the "living" cover--herbs and small shrubs.

Compared to the large shrubs described earlier, herbaceous vegetation comprised a less conspicuous but still important segment of the total vegetation complex. In the mature stand prior to harvest, herbaceous vegetation accounted for 37 percent of the cover on the forest floor. Small shrubs (less than 0.5 m [1.6 feet] tall) accounted for 20 percent of the cover, and the remaining 43 percent was occupied by other surface cover, primarily forest litter and woody material.

Harvesting, under three silvicultural systems with four residues management methods, created a wide range of conditions and altered the cover composition of the small vegetation accordingly. Combining values from all treatments, herbaceous cover increased from 37 percent before harvesting to 45 percent 4 years after harvesting in response to release from overtopping trees and shrubs.

Meanwhile, small shrub cover changed very little overall, accounting for 20 percent before harvesting and 22 percent 4 years after harvesting. The "other" cover reflected increases found in the herbs and shrubs--it decreased from 43 percent preharvest to 33 percent 4 years later.

SILVICULTURE TREATMENT EFFECTS

Looking at the silvicultural systems overall, and combining residues management treatments, we found that absolute values of herbaceous cover 4 years after harvesting had increased an average of 13 percent on group-selection cuttings, increased 6 percent on clearcuts, but decreased 3 percent on shelterwoods. In relation to preharvest values, this was equivalent to a 38-percent increase on group selections, a 15-percent increase on clearcuts, and a 7-percent decrease on shelterwoods (fig. 12). Because cover sampling was limited to 100 percent with our study method, any increases or decreases in herbaceous cover were reflected in the cover of small shrubs and other cover items like litter and woody material. Small shrub cover increased most on clearcuts, increased moderately on shelterwoods, and decreased on group selections in relation to preharvest values. The "other" cover decreased on all cutting methods in direct response to increases in herbs and small shrubs.

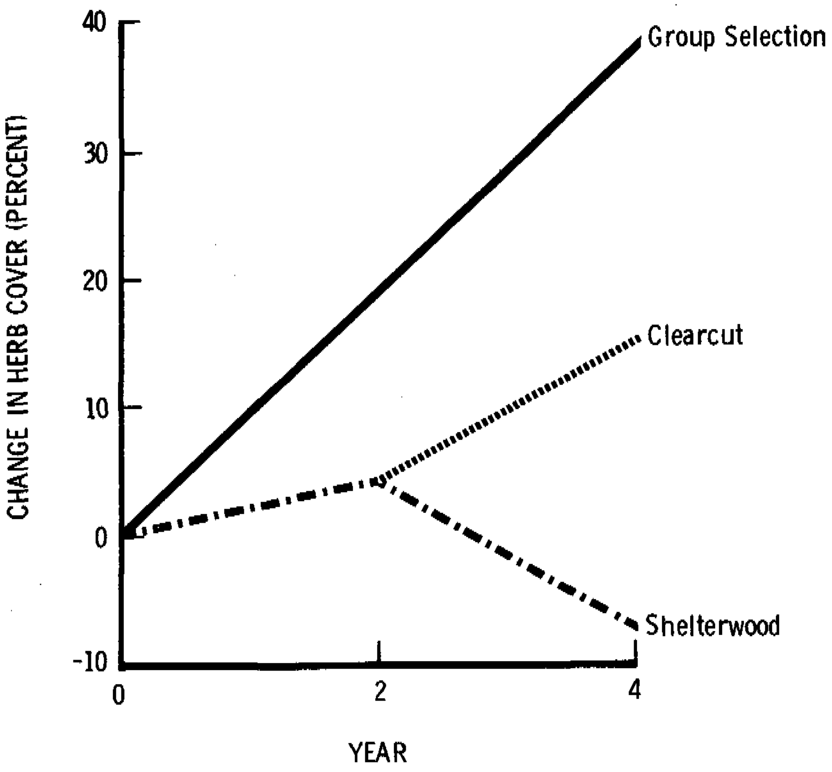

Figure 12.--Postharvest change in herb cover in relation to preharvest cover $\left(\frac{\textit{postharvest}}{\textit{preharvest}}\right)$ *by silviculture treatment.*

RESIDUES TREATMENT EFFECTS

Residues treatments also affected cover values differentially. This is illustrated by summarizing cover values of specific residue treatments across all silviculture treatments tested. Herbaceous cover increased on all residues treatments, but removing all residues increased herbaceous cover the most--from a preharvest 37 percent to 48 percent 4 years later. Undoubtedly, some of this increase was related to the fact that the intense residue-removal treatment removed some of the woody material that occupied the surface. A similar response was noted with the intermediate-utilization-and-burned treatment, a moderate response occurred with the conventional-utilization-and-burned treatment, and practically no overall change occurred with the understory-protected treatment. The 2- and 4-year change in herbaceous cover, relative to the preharvest values, probably provides the best response index. As shown in figure 13, herbaceous cover was still increasing at year four on all treatments. However, both the increases by year four and the upward trends differ substantially by treatment; the residues-removed and intermediate-utilization-and-burn treatments exceed the other two treatments in both categories.

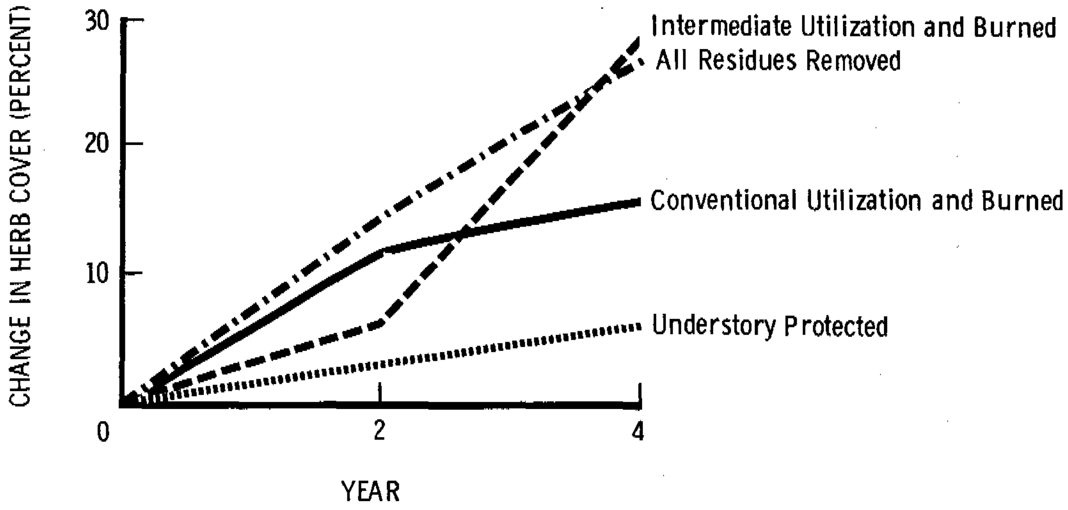

Figure 13.--Postharvest change in herb cover in relation to preharvest cover $\left(\frac{\textit{postharvest}}{\textit{preharvest}}\right)$ *by residues treatment.*

Biomass

Regression analyses relating shrub volume to total biomass and to biomass of the shrub components demonstrated strong linear relationships with r^2 values exceeding .90 for nearly all major shrub species. This corresponds closely with Brown's (1976) findings for many of these same shrubs. Although Brown's biomass predictions were based on shrub basal stem diameters, and this study based the biomass predictions on shrub volume, both methods accounted for about the same amount of variance. In this study, equations were developed for shrubs growing under mature forest conditions as well as for those growing on the treated areas. Leaf, stem, and total biomass were also determined for herbs and small shrubs.

Total biomass followed the same pattern as that of shrub volume and cover values; biomass was reduced by the logging and followup activities, but started recovering rapidly. As shown in the following tabulation,

Biomass	Mature Forest	Average of All Treatments: At 2 years	Average of All Treatments: At 4 years
	kg/ha (pounds/acre)		
Large shrubs	4 687 (4,180)	1 235 (1,102)	2 049 (1,828)
Herbs and small shrubs	1 184 (1,056)	2 052 (1,830)	2 360 (2,105)
Total live shrubs and herbs	5 871 (5,236)	3 287 (2,932)	4 409 (3,933)

the rapid recovery resulted primarily from the quick response of herbs and small shrubs, which in 2 years nearly doubled their preharvest biomass. Total biomass of herbs and shrubs on the treatment areas reached 56 percent of preharvest values at 2 years and 75 percent at 4 years.

As shown in the following tabulation, a high proportion of biomass found in the major shrubs of the uncut mature forest was stored in the large stems (> 4 mm [0.16 inch] diameter).

Biomass Components of all Major Shrubs in the Mature Forest

Large stems	Small stems	Leaves	Total
	kg/ha (pounds/acre)		
4 063 (3,624)	348 (310)	276 (246)	4 687 (4,180)

Leaf and stem components of the understory vegetation varied greatly by species, and as one would expect, a high proportion of the biomass of large shrubs was in stems. As shown in figure 14, mature forests stored substantial biomass in annual leaves of some species, but little in others. For example, thimbleberry leaves accounted for over half of its total biomass, while its small stems (less than 4 mm [0.16 inch]), accounted for less than 10 percent, and large stems (more than 4 mm [0.16 inch]) for about 40 percent. Huckleberry's (*Vaccinium myrtilus* and *Vaccinium membranaceum*) total biomass was split roughly in thirds between leaves, small stems, and large stems. On the other end of the scale, alder, mountain maple, and serviceberry carried small proportions of leaves (5 percent and under), and small stems (5 to 10 percent), but stored large proportions of biomass in stems greater than 4 mm (0.16 inch) in diameter.

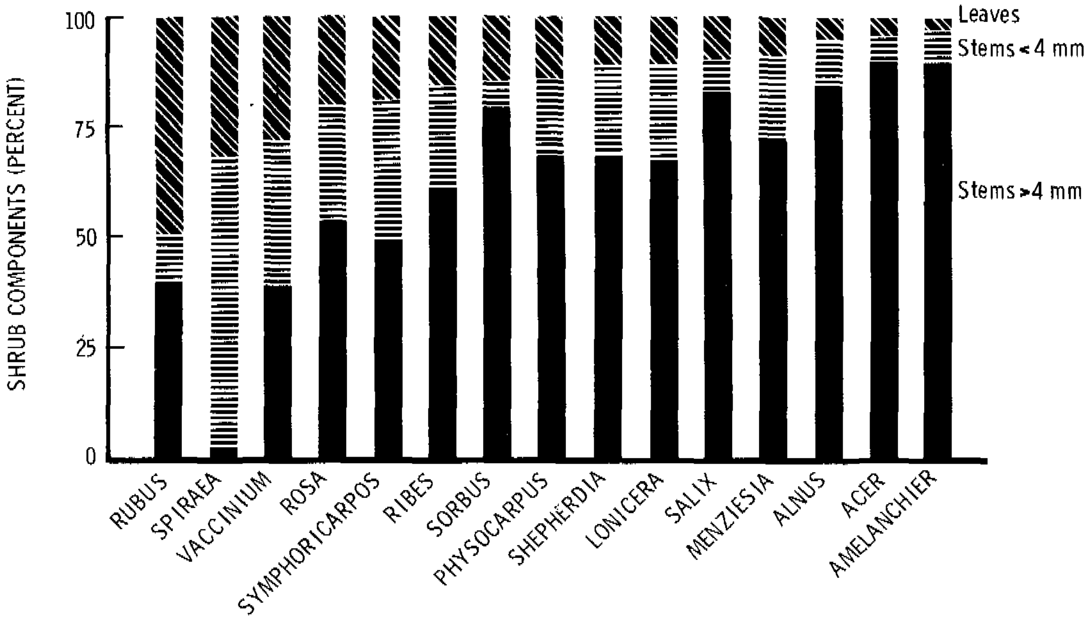

Figure 14.--Components--leaves, stems less than 4 mm (0.16 inch) in diameter, and stems larger than 4 mm (0.16 inch) in diameter--of major shrubs in a mature larch/fir forest.

Biomass of the lesser vegetation--herbs and small shrubs--was divided into two categories: (1) woody stems, and (2) leaves (leaves included nonwoody stems). As shown in the following tabulation, leaves accounted for about two-thirds and woody stems one-third of the lesser vegetation biomass in the uncut mature forest.

Lesser Vegetation

Leaves	Woody stems	Total
	kg/ha (pounds/acre)	
756 (674)	428 (382)	1 184 (1,056)

SILVICULTURE TREATMENT EFFECTS

Harvest-cutting and the followup treatments substantially reduced the amount of major shrub biomass, following the same pattern as that of shrub volume (fig. 15). However, biomass recuperated more than its equivalent volume, with each unit of shrub volume weighing more after the shrubs had time to respond to their new environment of increased light, water, and possibly nutrients. For example, if the biomass of maple in the mature forest averaged 1 000 kg/ha (892 pounds/acre), the same volume of maple 4 years after clearcutting and broadcast burning averaged 1 704 kg/ha (1,520 pounds/acre), and 4 years after shelterwood cutting and broadcast burning averaged 1 351 kg/ha (1,205 pounds/acre).

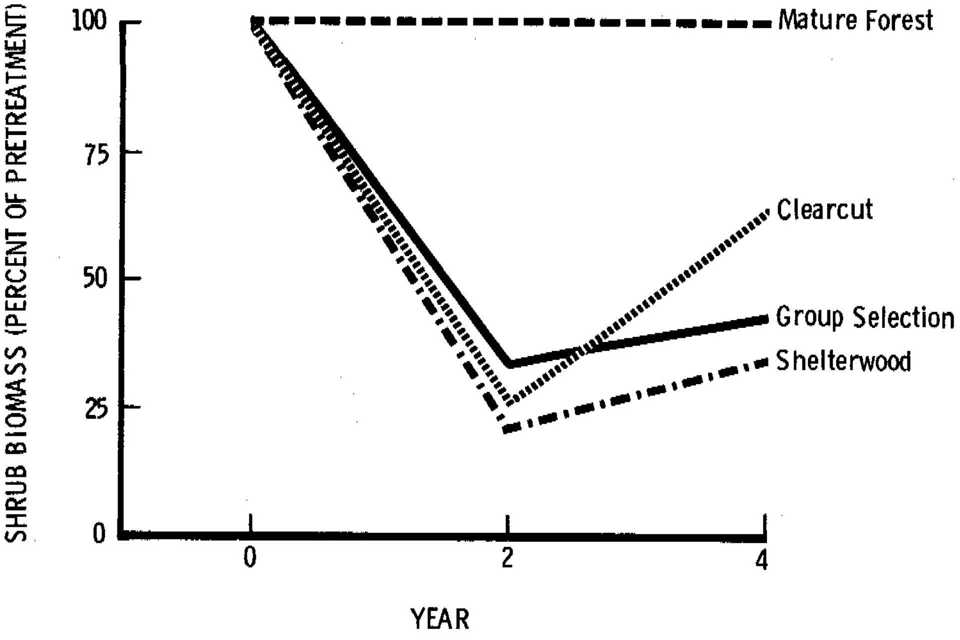

Figure 15.--Shrub biomass changes resulting from silviculture treatments, in relation to preharvest values in a larch/Douglas-fir forest.

Similar trends were noted for most other species. Some, such as *Menziesia ferruginea*, more than doubled their biomass per unit of volume on the clearcut and broadcast-burned treatment in relation to that of the mature forest. Some species such as *Ribes* sp. tripled in biomass, and some such as *Rosa* quadrupled.

In general, clearcutting and group-selection cutting increased the ratio between biomass and volume the most, followed by the shelterwood cutting. The ratio remained the same during the same period in the mature forest.

Harvest cutting produced a decided shift in the leaf and stem composition of major shrubs (fig. 16). Those shrubs such as maple, whose leaves accounted for very little of the total biomass in the mature forest, showed a decided increase in the percentages of leaves and small stems 4 years after harvesting. The same held true for those shrubs such as ninebark, whose leaves comprised a moderate percentage of biomass. However, the release of thimbleberry resulted in a decrease in its percentage of leaves, an increase in percentage of small stems, and almost no change in percentage of large stems.

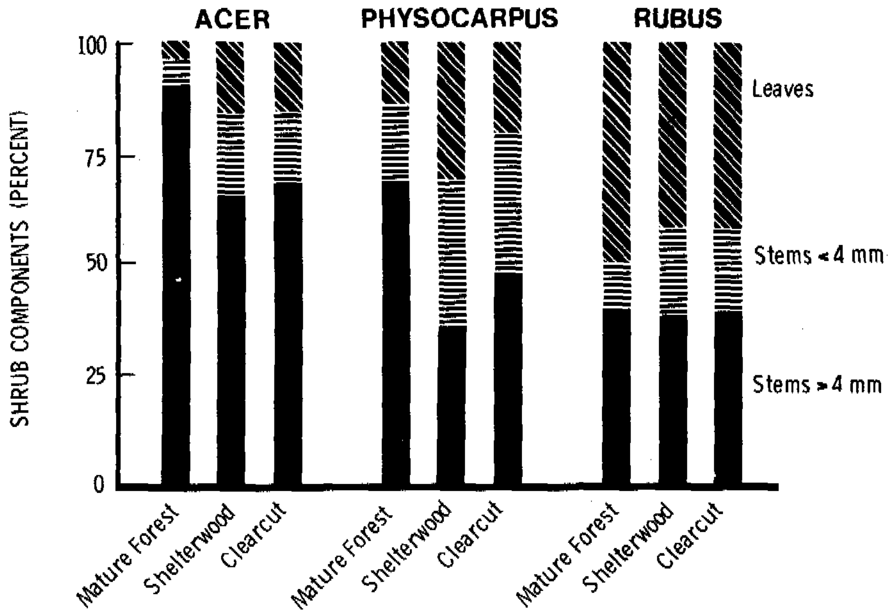

Figure 16.--Components--leaves, stems less than 4 mm (0.16 inch) in diameter, and stems larger than 4 mm (0.16 inch) in diameter--of three typical shrubs 4 years after harvest cutting in a larch/fir forest.

The biomass of lesser vegetation--herbs and small shrubs--responded more to silviculture treatments than did biomass of the major shrubs in the same treatments. As expected, cuttings that provided the most release from the overstory trees produced the most response in the lesser vegetation (fig. 17). After 4 years, and averaging all residues treatments, lesser vegetation in clearcuts had increased 125 percent over preharvest values, in group selections it increased about 100 percent, and in shelterwoods about 70 percent.

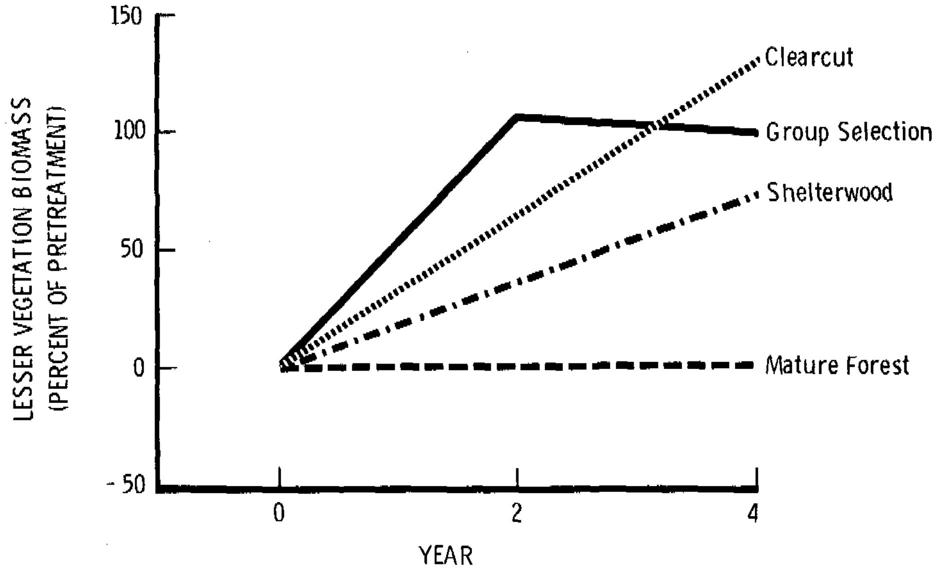

Figure 17.--Biomass change of lesser vegetation (herbs and small shrubs) in response to silviculture treatments.

RESIDUES TREATMENT EFFECTS

Major shrubs responded to the residues treatments in about the same manner as they did to silviculture treatments. The understory-protected treatment produced decidedly more shrub biomass than the other three residues treatments, with biomass of the major shrubs on the understory-protected treatment already approaching its preharvest level after only 4 years (fig. 18). Meanwhile, the other three residues treatments reached about one-fourth of their preharvest level.

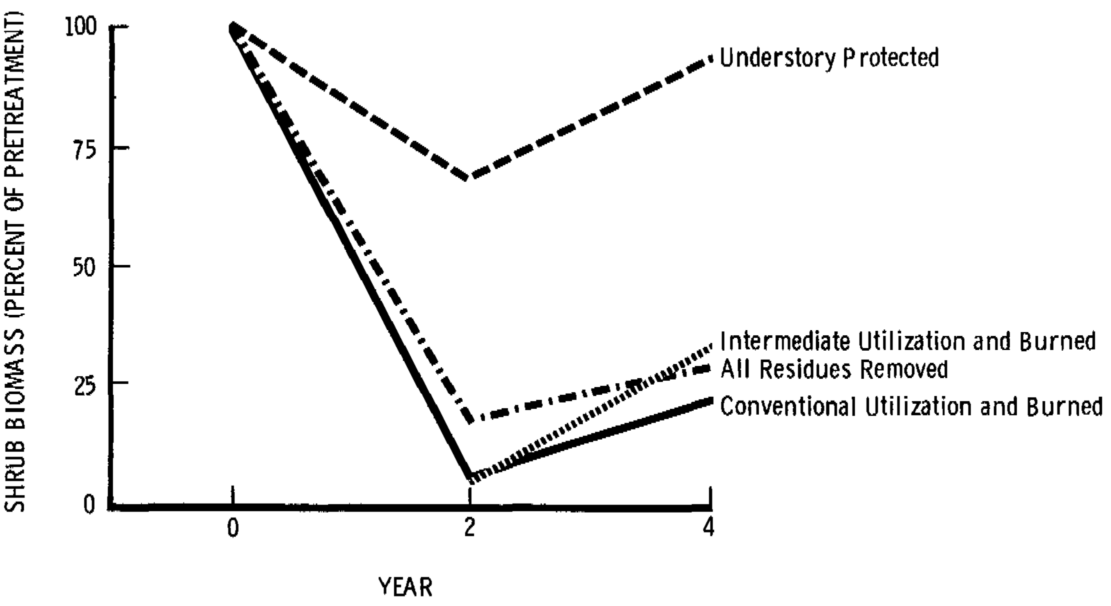

Figure 18.--Shrub biomass changes in relation to preharvest values by residues treatment.

All residues management treatments altered the proportions of shrub leaves, small stems, and large stems from that found in the mature forest. An example of three shrubs that normally have widely different proportions of leaves, small stems, and large stems illustrates these residue treatment effects (fig. 19). Residue treatments that included burning affected leaf and stem proportions the most. Differences were most pronounced in the larger shrubs. As expected, treatments generally effected a shift toward higher proportions of leaves and small stems at the expense of large stems. For example, leaves accounted for only 4 percent, and small stems 5 percent, of the total biomass of maple in the mature forest. Broadcast burning changed this to 22 and 21 percent, respectively, 4 years after harvesting. Similar trends were apparent in ninebark, a medium-size shrub, and to a lesser extent in thimbleberry, a smaller shrub.

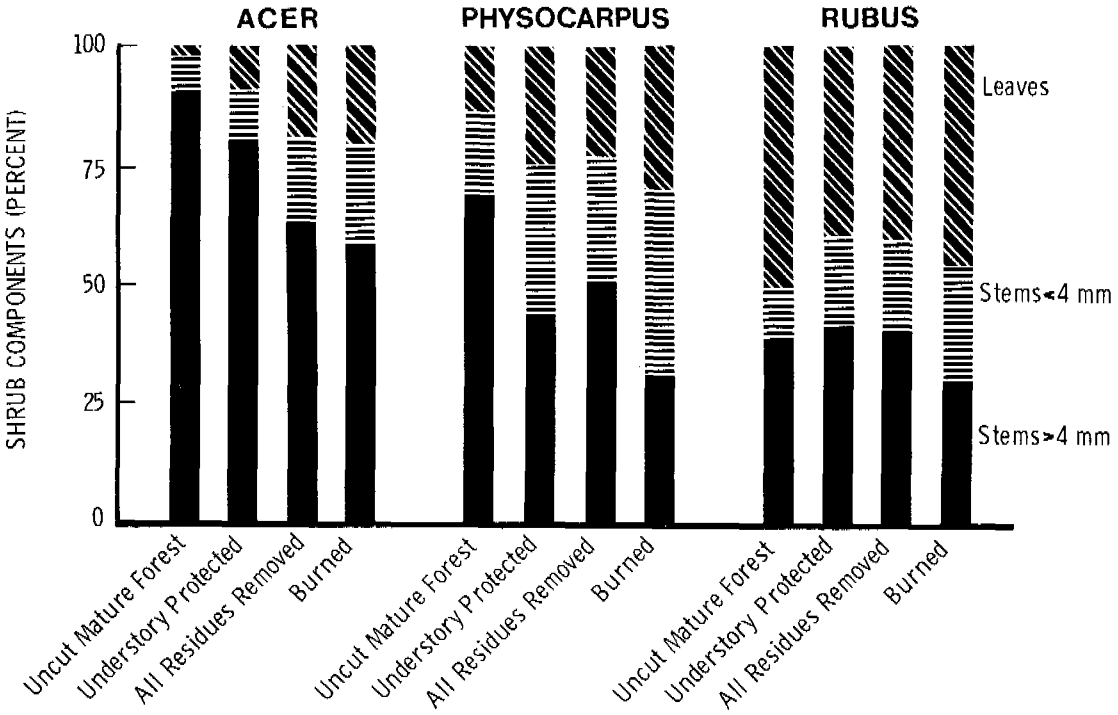

Figure 19.--Components--leaves, small stems less than 4 mm (0.16 inch) diameter, and large stems more than 4 mm (0.16 inch) diameter--of three typical shrubs 4 years after harvest cutting in a larch/fir forest.

The understory-protected treatment resulted in a relatively minor shift in the shrub components of maple, but produced a moderate shift in the other two species at the 4-year measurement. Removing all the residues resulted in a moderate shift for all three species.

Lesser vegetation--herbs and small shrubs--responded dramatically to the all-residues-removed treatment, where after 4 years, its biomass had reached 250 percent of its preharvest level (fig. 20). This increase tripled the corresponding increases on the other three residues treatments which increased 75 to 90 percent over their preharvest levels. The removal of all the pre and postlogging residues, coupled with little site disturbance, apparently created very favorable conditions for the lesser vegetation in the all-residues-removed treatment. The understory-protected treatment, which was very favorable for biomass production in the major shrubs, showed the least biomass production in the lesser vegetation.

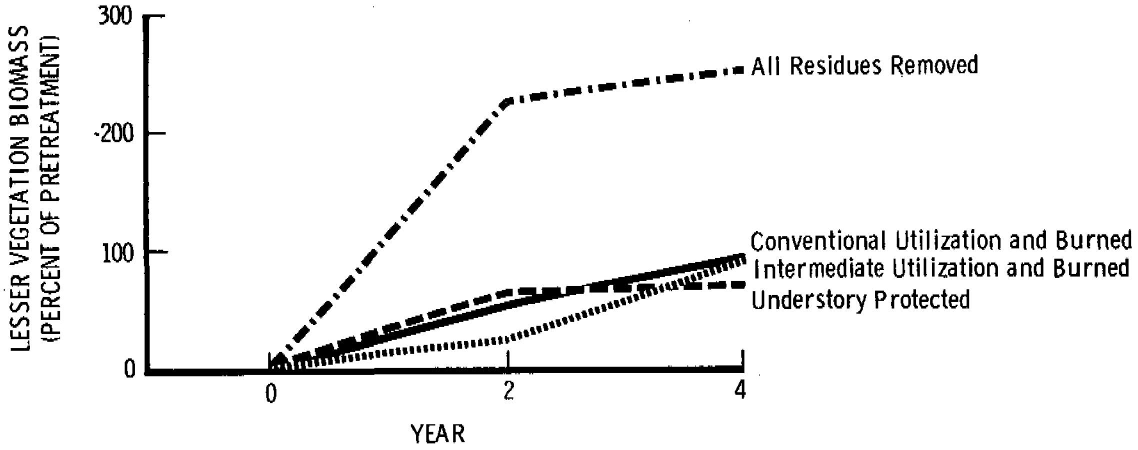

Figure 20.--Change in biomass of the lesser vegetation (herbs and small shrubs) in in relation to preharvest biomass by residues treatment.

SUMMARY

The results presented in this paper briefly summarize the major effects of silviculture and residues treatments on understory vegetation in a larch/Douglas-fir forest. Subsequent reports will analyze complex species trends and interactions to illustrate some of the more basic aspects of the study. Although the data reported here cover only the first 4 years after harvesting, some immediate treatment effects and trends are apparent.

1. All of the harvest cuttings drastically reduced total shrub volume and biomass, but 4 years after harvesting all treatments had regained one-fourth or more of their shrub volume and one-third to two-thirds of their preharvest biomass. Clearcuts recouped their logging-caused shrub losses most effectively. Shelterwood cuttings reduced shrub volume somewhat less than did the clearcuts and group selections, but the recovery of shrubs was slower on the shelterwood sites.

2. Residues treatments affected shrubs more than silviculture treatments for the first 4 years. The understory-protected treatment stood out as being dramatically different than the other three residues treatments. It resulted in a much smaller loss of major shrubs during logging, and its 4-year recovery of both shrub volume and biomass far exceeded that of the other three treatments. This effect was particularly apparent in the shelterwood cuttings where the residual stand of trees afforded some protection of the understory during logging.

3. Burning, coupled with either intermediate- or conventional-wood-residues-utilization standards, consistently reduced major shrub vegetation more than either the understory-protected or all-residues-removed treatments. However, even on the burned areas, shrubs recovered substantially within 4 years after harvesting.

4. The relative importance of different shrub species in terms of volume and biomass varied substantially--some positively, some negatively, some showing little change--in response to the different combinations of silviculture-residue treatments.

5. Lesser vegetation, comprised of herbs and small shrubs, responded rapidly and differentially to the various combinations of treatments. Before harvesting, herbs and small shrubs provided cover on 57 percent of the soil surface in the mature forest, and litter and woody material accounted for most of the remainder. Four years after treatment, cover on all treatments averaged 67 percent. Most of this increase was in herbaceous material. Removing all the residues on the group selections increased herbaceous cover the most. At the other end of the scale, herbaceous cover decreased slightly on the shelterwoods where the understory trees and shrubs had been protected during harvesting.

6. Of the total live understory biomass (not including trees) in the uncut mature forest, major shrubs accounted for 80 percent, and herbs and small shrubs the remainder of the understory vegetation. Four years after treatments, an average of all treatment combination responses shows that herbs and small shrubs now account for over half the total biomass. Collectively, shrubs and herbs returned to 56 percent of their preharvest biomass at 2 years and 75 percent at 4 years, but a far larger proportion was now in the lesser shrubs and herbaceous material.

7. Leaf and stem components of the shrubs in the mature forest varied greatly by species. Some large shrubs had as little as 5 percent of their total biomass in leaves--smaller shrubs had as high as 50 percent. On the average, about one-fourth of the total shrub biomass in the mature forest understory was in stems less than 4 mm (0.16 inch) in diameter.

8. Leaf and stem composition of shrubs changed in response to both silviculture and residues treatments, but residues treatments had the greatest effect on the components. As expected, the more drastic the silviculture-residue treatment combinations, such as clearcutting and broadcast burning, the greater the relative increase in leaf biomass.

9. Shrub biomass per unit of volume generally doubled or tripled following treatments, but this change varied by species and treatment combinations. As a general rule, the silvicultural treatment of clearcutting, and the residues treatment of broadcast burning, changed the ratio of shrub biomass to volum more than did the other treatments. The corresponding shelterwood and understory-protected treatments changed this ratio the least.

What these different understory vegetation responses mean in relation to water use, wildlife forage and shelter, nutrient cycling, competition or protection for the young tree seedlings, entomological and microbiological activities, and other factors will be the subject of further analyses.

ACKNOWLEDGEMENTS

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APPENDIX I

Trees and shrubs found on the Coram E. F. study area included:

Trees

Abies lasiocarpa
Betula papyrifera
Larix occidentalis
Picea engelmannii
Pinus albicaulis
Pinus contorta
Pinus monticola
Populus tremuloides
Pseudotsuga menziesii
Thuja plicata
Tsuga heterophylla

Shrubs

Acer glabrum
Alnus sinuata
Amelanchier alnifolia
Lonicera utahensis
Berberis repens
Menziesia ferruginea
Pachistima myrsinites
Physocarpus malvaceus
Ribes lacustre
Ribes viscossissimum
Rosa acicularis
Rosa gymnocarpa
Rubus parviflorus
Salix scouleriana
Shepherdia canadensis
Sorbus scopulina
Spiraea betulifolia
Symphoricarpos albus
Taxus brevifolia
Vaccinium membranaceum
Vaccinium myrtillus

In addition to the above trees and shrubs, 58 herbaceous species were found on the study area.

REGENERATION ESTABLISHMENT IN RESPONSE TO HARVESTING AND RESIDUE MANAGEMENT IN A WESTERN LARCH--DOUGLAS-FIR FOREST

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ABSTRACT

Natural regeneration lagged on all sites on a recent logging study, regardless of previous residue utilization standards or understory and seedbed treatments. Two factors have reduced regeneration potential: (1) little mineral soil was exposed either during timber harvest or as a result of prescribed burning, and (2) in 1974 (year of logging) western spruce budworm destroyed nearly all cones except western larch.

Seed dispersal usually occurred via thermal slope winds with uphill motion, beginning in September. However, in 1976 most seed was dispersed by erratic winds associated with a dry cold front in October. Less than 10 percent of the sound seed dispersal in the fall survived until germination. Germination and seedling survival of western larch, Douglas-fir, lodgepole pine, Engelmann spruce, and subalpine fir was substantially higher on burned seedbeds than on unburned seedbeds. Subalpine fir was the only species that germinated relatively well on unburned duff. Surface temperatures were not critical on any treatment (except on charred surfaces the first year following prescribed burning), because competing vegetation quickly shaded all cutover areas.

Douglas-fir and Engelmann seedlings planted during 1976-1978 have become established on all treatments. The effects of residue utilization on understory and seedbed treatments may be more important in the later growth of conifers than in the establishment stage.

KEYWORDS: residues, tree regeneration, seed production, seed dispersal, western larch, Douglas-fir, Engelmann spruce, subalpine fir.

INTRODUCTION

Many western larch (Larix occidentalis Nutt.) forests began as a result of catastrophic fires that followed years in which litter and other flammable debris had accumulated within maturing stands. Western larch, the most shade-intolerant species in the Northern Rockies, requires a major disturbance for successful regeneration (Schmidt and others 1976). Indeed, fire-exposed soils enhance the regeneration of most conifers in the western larch-dominated forests.

Experience has shown that western larch can be regenerated using any method of management that favors even-aged stands if: (1) soil is exposed through prescribed burning or scarification, (2) seed is present, and (3) favorable microsite conditions occur during the year of germination (Schmidt and others 1976). Regeneration of shade-intolerant species such as western larch is less certain when land managers face the need to modify cutting practices, utilization standards, or seedbed preparation methods to protect or enhance other multiple-use values by reducing disturbance of the site.

OBJECTIVES

The problem faced in this study was to identify: (1) silvicultural systems that enhance natural regeneration of western larch and its associated species, and (2) sites where conifer stocking could be increased through planting Engelmann spruce (Picea engelmannii Parry), and Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco). No western larch planting stock was available.

The objectives of the regeneration portion of the R&D Program were to evaluate the ways in which silvicultural prescription, harvesting methods, and forest products residue reduction treatments affected the regeneration of western larch and associated species.

STUDY AREA AND TREATMENT

The study was conducted on the 7,460 acre (3019 ha) Coram Experimental Forest, on the Flathead National Forest in northwestern Montana (fig. 1). The study sites were located below the main ridge facing east into Abbott Basin (lat. 48° 25' N., long. 113° 59" W.). Six blocks, (fig. 2) were logged in 1974, including two clearcuts (14 and 17 acres or 5.7 and 6.9 ha), two shelterwoods (35 and 22 acres or 14.2 and 8.9 ha), and two sets of eight small clearcuts representing group selection cuts (averaging 0.8 acre, or 0.3 ha). Each block was further divided into four subblocks, each of which received a different standard of timber and residue utilization (fig. 1). Of the four subblocks, No. 1 and 2 were broadcast burned and No. 3 and 4 were left unburned. A description of the utilization standards and tree cutting requirements follows:

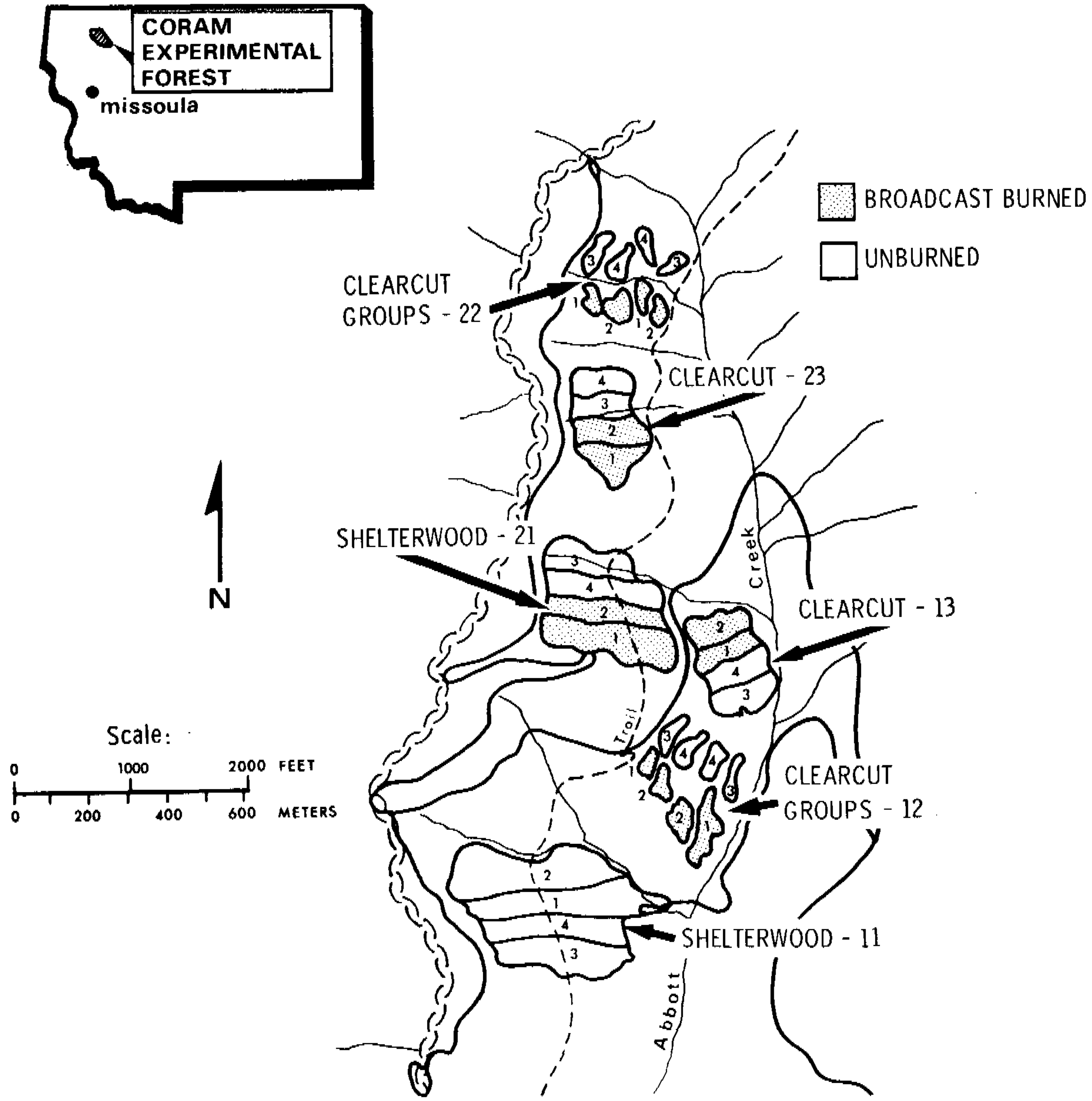

Figure 1.--Location of cutting blocks in Abbott Basin, Coram Experimental Forest; timber harvested in 1974 and broadcast burned in September 1975.

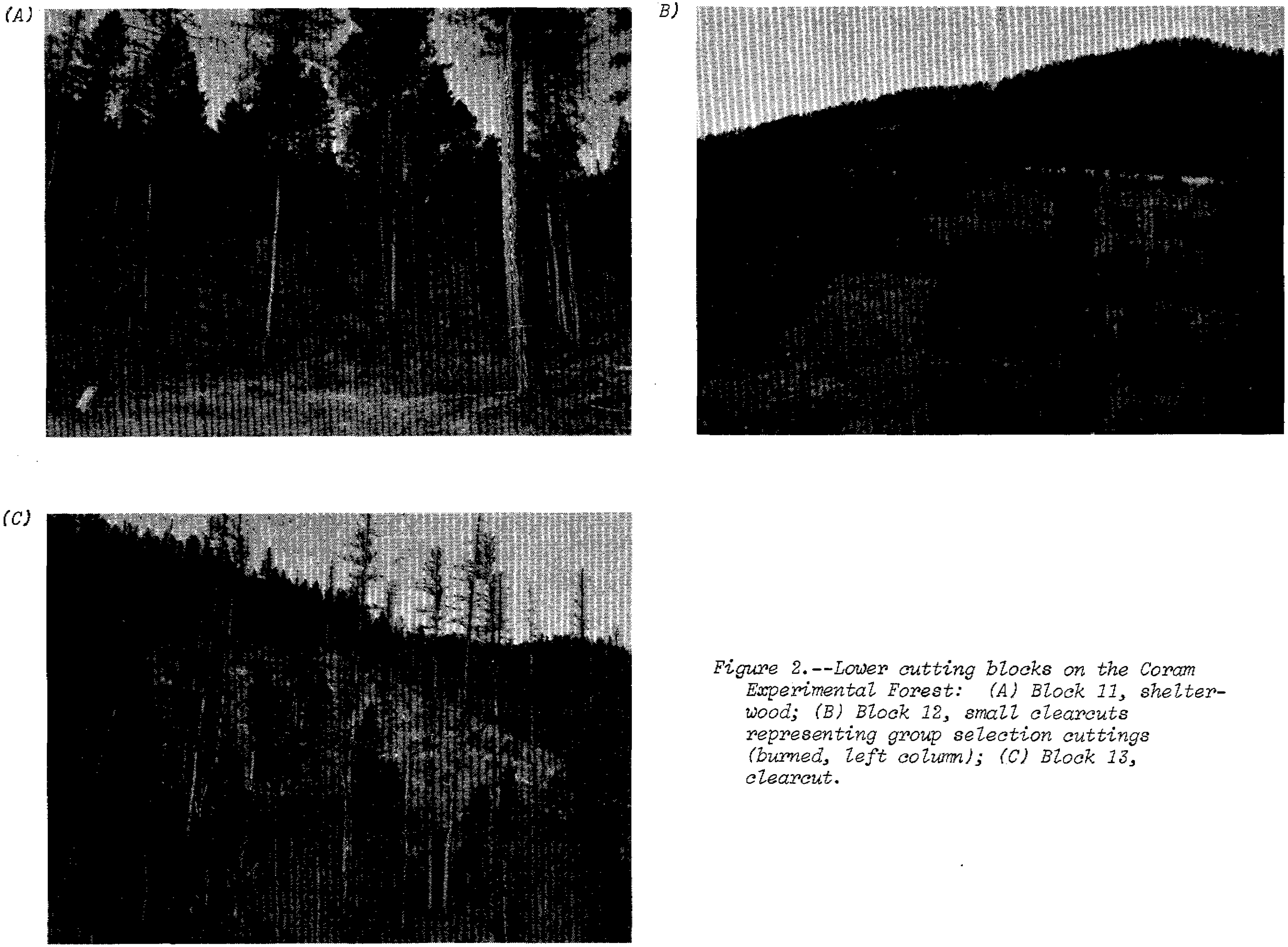

Figure 2.--Lower cutting blocks on the Coram Experimental Forest: (A) Block 11, shelterwood; (B) Block 12, small clearcuts representing group selection cuttings (burned, left column); (C) Block 13, clearcut.

Subblocks	Trees cut	Utilization standard
1	All trees except designated overstory shelterwood trees	All material (live and dead, standing and down) to 3 inch (7.6 cm) diameter, 8 foot (2.4 m) length, and 1/3 sound, removed
2	All trees except designated overstory shelterwood trees	Sawtimber material (live and recently dead) to 1974 Forest Service standards--7 inch (17.8 cm) d.b.h., 8 foot (2.4 m) length, and 1/3 sound, removed
3	All trees except designated overstory shelterwood trees	All material (live and dead, standing and down) to 1 inch 2.5 cm) diameter (intensive fiber utilization)
4	Trees to 7 inches (17.8 cm) d.b.h. except designated overstory shelterwood trees	All material (live and dead, standing and down) to 3 inch (7.6 cm) diameter, 8 foot (2.4 m) length, and 1/3 sound, removed

The timber type on the study area is larch--Douglas-fir, Cover Type 212, (Society of American Foresters 1954). Associated species include subalpine fir (Abies lasiocarpa (Hook.) Nutt.) and Englemann spruce. The study area falls primarily in the Abies lasiocarpa/Clintonia uniflora habitat type, with the following phases represented: Aralia nudicaulis, Menziesia ferruginea, Clintonia uniflora, and Xerophyllum tenax (Pfister and others 1977; Bernard L. Kovalchik 1974, unpublished data[1]).

The topography ranges in steepness from 30 to 80 percent (17^{o} to 39^{o}), while the elevation ranges from 3,900 to 5,200 feet (1189 to 1585 m) m.s.l. The soils on the slopes are derived from impure limestone and underlying material of loamy-skeletal soil families (Klages and others 1976).

METHODS

Before logging, 10 permanent points were systematically chosen at 100-foot (30.5 m) intervals within each of the subblocks in the clearcut and shelterwood cuttings. Five points were chosen within each of the eight small clearcuts, at variable intervals depending on size of the opening. All plots were referenced to these points.

Seedbed

A companion study (Artley 1976; Artley and others 1978) describes the methods used to determine duff reduction and mineral soil exposure on prescribed burned subblocks in the clearcuts and shelterwood cuttings. Artley (1976) randomly established fifty 4x4 ft (1.2x1.2 m) plots in each subblock (five referenced to

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[1] On file at Forestry Sciences Laboratory, Missoula, MT.

each permanent point) of the clearcut and shelterwood blocks (none was established in the group selection cuts). The following preburn measurements were taken at each plot: (1) duff depth, (2) mineral soil exposure, (3) weight of downed woody material, (4) woody shrub weight, (5) depth of down woody material, (6) slope, and (7) aspect. About one hour prior to ignition samples of duff, downed woody material and herbaceous vegetation were taken at each of the permanent points to determine their preburn water contents. After each fire, the following measurements were taken: (1) duff depth, (2) mineral soil exposure (in percent of area), and (3) weight and depth of downed woody material (Artley and others 1978). Duff reduction was estimated on the group selection cuttings (small clearcuts) near the permanent points by other researchers, but mineral soil exposure was not measured.

In addition, within the top 4 inches (10.16 cm) of soil on all burned subblocks, the following were identified near each permanent point: (1) the amount of soil water before and after each broadcast fire, (2) soil heating during each broadcast fire, and (3) the number of living non-coniferous roots before and after each broadcast fire (Artley and others 1978).

Cone Production

The potential cone crop in the uncut timber was classified from 1973-1978 as good, fair or poor, using a sequential sampling method (Roe 1966). The best potential cone-producing tree of each species within a 25-foot radius (7.6 m) plot was examined in May or June of each year.

Time of Seedfall

Four seed collectors, each about 32 square feet (3 m^2) in surface area, were placed in uncut timber to help determine the time of seedfall in 1974 and 1976. During periods of peak dissemination, these traps were emptied several times each day to relate the effect of environmental factors to timing of seedfall.

Seed Distribution

Seed dispersal was measured within the cutover areas and the uncut stands using 6-square-foot (0.5 m^2) seed traps. There were 40 of these seed traps placed within each of the two clearcuts (one associated with each permanent plot), 20 placed within each of the two shelterwoods (in association with half the permanent plots), two placed within each group selection cut (small clearcuts), and 40 within the uncut timber. The seed traps were installed within the uncut (control) timber in 1973 and within the cutover units after cutting and site treatments were completed. The seed traps were emptied during the spring following seedfall. The total number and the number of filled seeds were counted from each seed trap.

Seed Loss After Dispersal

From the time tree seed reaches the ground in the fall until it germinates the following spring, many factors (chiefly rodents, birds, invertebrates and diseases) reduce the number of seed potentially capable of germination. The number of viable seeds was estimated from seed traps. Seed loss during winter was estimated from 6-square-foot (0.5 m^2) samples of duff and soil taken from surfaces about 10 feet (3 m) from selected seed traps. These samples were taken in May 1975 at 16 points within each cutting method and within the control (uncut) areas.

The difference between the number of filled seed found in the seed traps and those found at the surface represents an estimate of seed loss.

Seedling Establishment

Seedling establishment is influenced not only by the number of seeds that germinate but by a broad range of biological and physical factors affecting survival, particularly during the first year following germination.

Establishment of natural regeneration was studied on permanent circular milacre plots (43.56 ft^2, or 4.05 m^2, in surface area) within each subblock; the locations of these plots were chosen to reflect the conditions of the treatment areas in which they were installed. The center of each plot was located 23 feet (7 m) from each permanent point at the lower right corner (looking uphill) of the 53.82 ft^2 (5 m^2) vegetation quadrants. Measurements were made in the summers of 1978 and 1979. In 1979, the sample size was doubled by establishing temporary points 50 feet (15.24 m) downhill from each permanent point. Seed-seedling ratios were estimated using the seed trap closest to each natural regeneration plot.

Seeded Plots

In order to identify the probable causes of seedling mortality, plots were established on each of the seedbed and residue subblocks within all cutting blocks (fig. 3). Two and four plots were seeded on each of the burned and unburned subblock, respectively. These plots were sown with 200 seeds of each of the following species: western larch, Douglas-fir, Engelmann spruce, subalpine fir, and lodgepole pine (Pinus contorta Dougl. ex Loua.). All plots were sown from mid- to late-October for 5 consecutive years (1974 - 1978), except those that were unburned in 1974 on subunits 1 and 2 of the shelterwood cutting (block 11), shown in fig. 3.

These plots were located and marked as soon as possible after the treatments were completed--in the fall of 1974 on unburned seedbeds and in the fall of 1975 on burned seedbeds.

The seeds used in this study were collected near the Coram Experimental Forest in the fall of 1974, in an area of the same habitat type, elevational zone and aspect as the study area. Extraction and cleaning was done at the Coeur d'Alene nursery; chemical repellent coating was not used, so that field germination would be as similar to that of naturally dispersed seed as possible.

Figure 3.--Marking germination and checking survival in the spring of 1977 on plots sown in October 1976 with 200 seeds of each of the following species: western larch, Douglas-fir, Engelmann spruce, subalpine fir, and lodgepole pine.

None of these plots was disturbed; natural conditions were maintained as nearly as possible. Data from these plots were used to help interpret and extend the results obtained from the natural regeneration plots.

Germination

Weekly or bi-monthly counts were taken beginning in early May to determine peak and total germination. Germinated seedlings (those with cotyledons in an upright position) were marked, and the times of their germination noted.

Planting

In May of 1976 through 1979, 25 2-0 bare root Douglas-fir and Engelmann spruce grown at the U.S. Forest Service, Coeur d'Alene nursery were auger planted on subblocks 1, 2, and 3 of each cutting block at a 6-foot (1.8 m) average spacing (fig. 4). Survival and growth characteristics are being evaluated. Growth of planted seedlings will be compared with growth of natural regeneration of the same species.

Figure 4.--Planting Douglas-fir and Engelmann spruce in holes made by 4 inch (10 cm) diameter augers, on burned seedbed within the burned portion of the lower clearcut (block 13) in early May, 1977. Note that the competing vegetation has not begun to leaf out.

RESULTS

Seedbed Treatments

Each cutting unit had four different site conditions following timber harvest and other site treatments.

Timber harvest occurred in 1974. Removal of logs that were not fully suspended above the ground by the skyline yarding system exposed some mineral soil (probably less than 5 percent). Most of this scarification occurred within distinct "skyline trails," principally up and down the slope, where passing logs repeatedly tore out the vegetation, moved the litter and duff and exposed mineral soil. This minor scarification occurred rather uniformly throughout all cutting blocks.

The prescribed burns took place between September 8-13, 1975. These fires did not accomplish the prescription objectives for duff reduction and mineral soil exposure because of the high water content of the duff layer. The water content of the upper duff was above prescription limits in all blocks and except for the lower group selection cuts (block 12), the average lower duff water content exceeded 100 percent in all blocks (Artley and others 1978).

More than twice as much duff was burned on the clearcut and group selection blocks than on the shelterwood cutting because they had relatively drier slash. Treatments 1 and 2 (see Study Area and Treatment) were averaged on the clearcuts and group selections because the differences in duff reduction and exposed mineral soil were not significant. These treatment differences were significant on the burned shelterwood cutting. The percentage of mineral soil exposed ranged from 7 percent on shelterwood subblock 21-1 to 20 percent on clearcut block 23 (Artley and others 1978). Duff was reduced an average of 25 percent (less than 0.8 inch (2.3 cm)) on all blocks.

A more complete discussion of prescribed burns is given by Artley and others (1978).

Seed Production and Dispersal

In June, from 1973 through 1978, cone production was estimated on specific sample trees located within the control blocks. Each year these estimates (fig. 5) showed that western larch had greater potential cone production than Douglas-fir, Englemann spruce, or subalpine fir. The high proportion of trees with poor cone crops in 1974 on the study area was attributed mainly to the influence of western spruce budworm (Choristoneura occidentalis Freeman), which caused heavy defoliation for several seasons on the Coram Experimental Forest before its decline started in 1974. Cone crops of all species were generally good in 1974 where defoliation by western spruce budworm was low or absent. There are two main ways in which the western spruce budworm influences cone production. First, the larvae feed on the buds, flowers, and developing cones, perhaps less on western larch than on Douglas-fir, Engelmann spruce, or subalpine fir. Second, top kill in subalpine fir, eliminated much of its potential for cone production for several years. Hence, larch, Douglas-fir and spruce were able to respond more quickly than subalpine fir in cone production when populations of western spruce budworm decreased. It is not known what effect repeated heavy defoliation has on cone production.

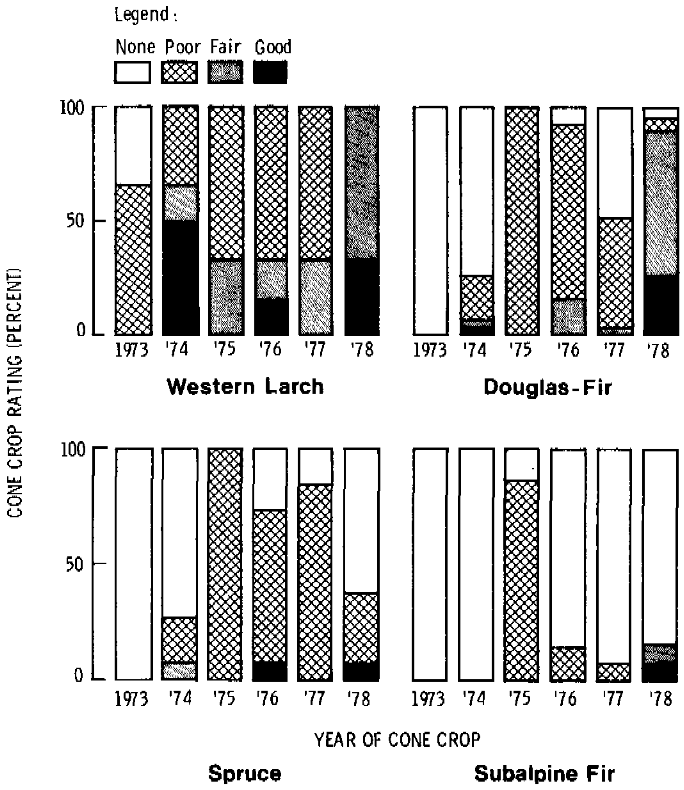

Figure 5.--Cone crop rating (percent of trees in each production class) by tree species and year, Coram Experimental Forest.

Seed dispersal was measured from 1973 through 1977 in the two uncut stands (controls). On these sites, only a few filled western larch seeds were dispersed per acre in 1973, 1975 and 1977. In 1974, over three-fourths of the total seedfall was western larch (table 1). This was, in part, an indication of the greater impact of the budworm on cones of Douglas-fir, Engelmann spruce and subalpine fir. In areas with low populations of budworm after 1974, the number of seed dispersed in 1976 nearly doubled for larch, but increased over 20 times for Douglas-fir. Subalpine fir cone production will not recover on trees whose tops were killed by the western spruce budworm until new tops are formed.

Table 1.--Filled conifer seed (thousands) dispersed per acre (hectare) within the uncut timber (controls), 1973 - 1977.[1]

	Western Larch	Douglas-Fir	Engelmann Spruce	Western Hemlock	Other[2]	Total
			LOWER BLOCKS			
1974	13.4 (5.4)	0.8 (0.3)	2.0 (0.8)	4.0 (1.6)	0.8 (0.3)	21.0 (8.5)
1976	18.6 (7.5)	41.3 (16.7)	1.6 (0.6)	21.9 (8.9)	0.8 (0.3)	84.2 (34.0)
Total	32.8 (13.3)	42.1 (17.0)	3.6 (1.4)	25.9 (10.5)	1.6 (0.6)	106.0 (42.9)
			UPPER BLOCKS			
1974	23.1 (9.4)	2.8 (1.1)	0.0 (0.0)	0.4 (0.2)	0.4 (0.2)	26.7 (10.8)
1976	53.0 (21.4)	35.2 (14.2)	2.0 (0.8)	0.8 (0.3)	0.0 (0.0)	91.0 (36.8)
Total	76.1 (30.8)	38.0 (15.3)	2.0 (0.8)	1.2 (0.5)	0.4 (0.2)	117.7 (47.6)

[1] Only a few western larch seeds were dispersed in 1973, 1975, and 1977.

[2] Lodgepole pine, western white pine, ponderosa pine, and western red cedar.

Seedfall in the cutover areas was measured starting in 1974 on the shelterwood cuts and the clearcuts, in 1975 on the upper group selection cuttings and in 1976 on the lower group selection cuttings (table 2). Greatest seed dispersal occurred within the lower clearcut (block 13). Seedfall was lowest in the upper clearcut and group selections (blocks 23 and 22).

Table 2.--Filled conifer seed (thousands) dispersed per acre (hectare) within the various cutting units, 1974-1977.[1]

	Western larch	Douglas-fir	Engelmann spruce	Western hemlock	Other	Total
			LOWER SHELTERWOOD CUT			
1974	22.7 (9.2)	0.0 (0.0)	0.0 (0.0)	6.9 (2.8)	0.0 (0.0)	29.6 (12.0)
1975	5.7 (2.3)	0.0 (0.0)	0.4 (0.2)	0.0 (0.0)	2.8 (1.1)	8.9 (3.6)
1976	37.2 (15.0)	29.9 (12.1)	0.0 (0.0)	2.8 (1.1)	1.2 (0.5)	71.1 (28.7)
			UPPER SHELTERWOOD CUT			
1974	82.6 (33.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	82.6 (33.4)
1975	0.4 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (0.2)
1976	46.1 (18.7)	29.9 (12.1)	0.8 (0.3)	0.0 (0.0)	0.4 (0.2)	77.2 (31.3)
			LOWER GROUP SELECTION CUTS			
1974	----	----	----	----	----	----
1975	----	----	----	----	----	----
1976	6.1 (2.5)	17.8 (7.2)	10.9 (4.4)	62.7 (25.4)	18.6 (7.5)	116.1 (47.0)
			UPPER GROUP SELECTION CUTS			
1974	----	----	----	----	----	----
1975	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1976	9.3 (3.8)	11.3 (4.6)	0.4 (0.2)	0.4 (0.2)	0.0 (0.0)	21.4 (8.7)
			LOWER CLEARCUT			
1974	63.9 (25.9)	1.2 (0.5)	6.5 (2.6)	1.6 (0.6)	0.0 (0.0)	73.2 (29.6)
1975	10.5 (4.2)	0.0 (0.0)	3.2 (1.3)	6.9 (2.8)	0.0 (0.0)	20.6 (8.3)
1976	45.3 (18.3)	9.3 (3.8)	0.4 (0.2)	142.4 (57.6)	0.8 (0.3)	198.2 (80.2)
			UPPER CLEARCUT			
1974	2.8 (1.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.8 (1.1)
1975	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1976	15.4 (6.2)	11.7 (4.7)	1.6 (0.6)	2.0 (0.8)	0.0 (0.0)	30.7 (12.4)

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[1] No sound seed was found in 1977.

In the lower clearcut (block 13), dispersal of sound seed from 1974 through 1977 decreased rapidly for a distance of 300 feet (91 m) upslope from the lower timber edge, then decreased slowly to 500 feet (153 m) from the bottom (about 100 feet, 30 m, below the upper timber edge) (fig. 6). Much less seed fell within the upper clearcut (block 23), but it followed a similar, though less distinct, pattern (fig. 6). This pattern indicated most seed was dispersed by thermal winds with upslope motion--the same as has been recorded on other clearcuts at Coram (Shearer 1959). However, in 1976, seed was dispersed by erratic winds associated with a dry, cold front in October that interacted with the upslope winds. An average of 146,000 and 17,000 sound seed per acre (361,000 and 42,000 per hectare) fell within the lower and upper clearcuts from the 1974, 1975, and 1976 seed crops. This ranged from an average of 396,000 and 26,000 sound seeds per acre (979,000 and 64,000 per hectare) along the bottom row of seed traps, to 51,000 and 14,000 sound seeds per acre (126,000 and 35,000 per hectare) along the top row of seed traps within the two clearcuts. An estimate of variation in total sound-seed dispersed over the lower clearcut (block 13) through three seed years can be seen by the iso-seed lines in a map of the clearcut (fig. 7).

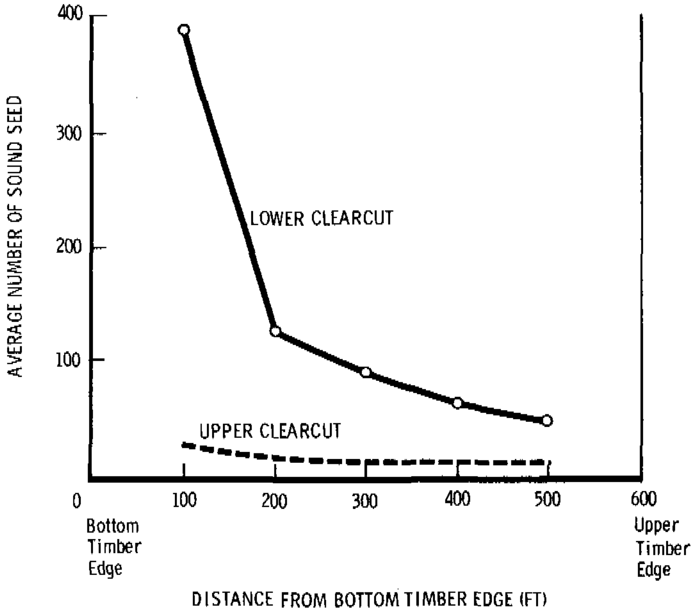

Figure 6.--Average number of sound seeds (thousands) dispersed into two clearcut blocks from 1974-1977, from bottom to top, Coram Experimental Forest.

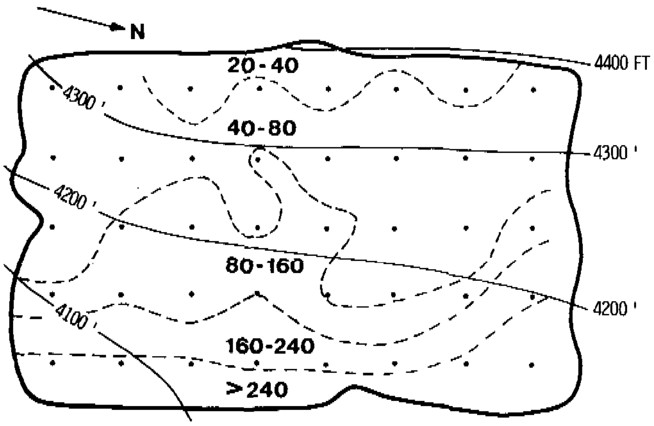

Figure 7.--Dispersal of sound seed into the lower clearcut (Block 13), 1974-1977, Coram Experimental Forest. Dashed lines indicate iso-seed lines separating numbers (thousands) of sound seeds. Dots represent permanent sample points where seed traps were located.

Dispersal of sound seed on the upper shelterwood area (block 21) was extremely variable from 1974 - 1977, averaging 160,000 seeds per acre (395,000 per hectare), but ranging from 8,000 to 550,000 seeds per acre (20,000 to 1,359,000 per hectare) at the 20 sampling points. Heaviest seedfall (averaging 204,000 sound seeds per acre, or 504,000 per hectare) occurred on the south half of the area. An average of 117,000 sound seeds per acre (289,000 per hectare) fell on the north half of the area. Because the heavier seedfall in 1974 was on the area that was prescribed burned in September 1975, many of the seedlings that germinated in the spring of 1975 were killed by the fire.

During the period September 23 - October 17, 1974, seed dispersal followed a characteristic pattern on the study units. Greatest seedfall occurred during the windy portions of the day (fig. 8).

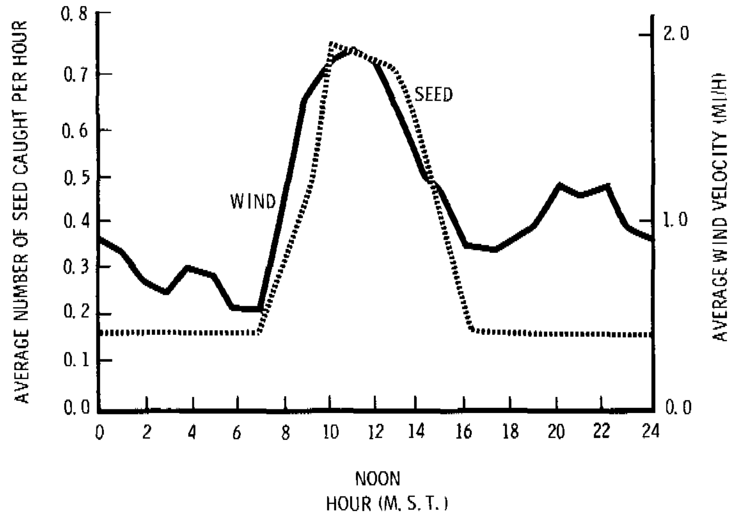

Figure 8.--Average number of seed caught per hour in four seed collectors and average wind velocity (m.p.h.) by hour of day, Coram Experimental Forest. Collections of seed were made during 20 days of the period September 23 through October 17, 1974; wind measurements were taken each day of the period.

Temperature, humidity and probably other factors influenced the amount of seed dispersed. Figure 8 shows averages only; periods of high seedfall usually were associated with upslope (easterly) winds of greater than average velocity, lower than average humidity and warmer than average temperature. Because seed counts were not made during the hours of 1600 through 0700, an average of overnight seedfall is shown in figure 8. Seedfall probably increased during the hours of 2000 through 2200, instead of remaining constant as shown in figure 8.

Seed Loss

The amount of seed eaten or otherwise removed from the seedbed between the time of seedfall in 1974 and germination in May 1975 was estimated by counting the seed in seed traps and in adjacent duff samples at the time of germination in the spring. The data show that only about 9 percent of the sound seed (mostly western larch) dispersed in 1974 was available for germination in May 1975; the amounts ranged from 3 percent on clearcuts to 16 percent in uncut timber.

Natural Regeneration

In September 1979, 5 years after logging, natural regeneration was considered inadequate on all areas regardless of cutting method or site conditions (utilization level and understory or seedbed treatment). Both the number of 3- and 5-year-old seedlings per acre and their stocking were greater on the shelterwood cuts (table 3) than on the group selection cuts (table 4) or the clearcuts (table 5). First-year seedlings were counted but not included in these data because they will be greatly reduced in number through competition for available light and moisture.

Table 3.--Number of 3- and 5-year-old seedlings per acre and percent of milacre plots stocked by them on shelterwood cuttings, by site condition, September 1979

Utilization level	Site condition		Seedlings per acre (ha)			Stocking		
	Understory	Seedbed treatment	WL	DF	All species	WL	DF	All species
				Number			Percent	
			Lower Shelterwood (Block 11)					
Intensive	Cut	Not burn[1]	650 (263)	250 (101)	900 (364)	25	20	30
Conventional	Cut	Not burn[1]	900 (364)	0 (0)	900 (364)	35	0	35
Close fiber	Cut	None	650 (263)	200 (81)	850 (344)	25	10	30
Intensive	Uncut	None	450 (182)	250 (101)	700 (283)	30	25	40
			Upper Shelterwood (Block 21)					
Intensive	Cut	Burn	700 (283)	100 (40)	800 (324)	20	10	20
Conventional	Cut	Burn	1100 (445)	150 (61)	1250 (506)	40	15	40
Close fiber	Cut	None	200 (81)	150 (61)	400 (162)	10	15	25
Close fiber	Uncut	None	150 (61)	50 (20)	200 (81)	10	5	10

[1] Subblocks were never burned.

Table 4.--Number of 3- and 5-year-old seedlings per acre (hectare) and percent of milacre plots stocked on group selection cuttings, by site condition, September 1979.

Utilization level	Site condition		Seedlings per acre (ha)			Stocking		
	Understory	Seedbed treatment	WL	DF	All species	WL	DF	All species
				Number			Percent	
		Lower Group Selection (Block 12)						
Intensive	Cut	Burn	0 (0)	50 (20)	50 (20)	0	5	5
Conventional	Cut	Burn	0 (0)	50 (20)	50 (20)	0	5	5
Close fiber	Cut	None	0 (0)	0 (0)	50 (20)	0	0	5
Intensive	Uncut	None	50 (20)	0 (0)	50 (20)	5	0	5
		Upper Group Selection (Block 22)						
Intensive	Cut	Burn	50 (20)	50 (20)	100 (40)	5	5	10
Conventional	Cut	Burn	50 (20)	0 (0)	50 (20)	5	5	5
Close fiber	Cut	None	50 (20)	0 (0)	50 (20)	5	0	5
Intensive	Uncut	None	0 (0)	0 (0)	0 (0)	0	0	0

Table 5.--Number of 3- and 5-year-old seedlings per acre (hectare) and percent of milacre plots stocked on clearcuttings, by site condition, September 1979.

Utilization level	Site condition		Seedlings per acre (ha)			Stocking		
	Understory	Seedbed treatment	WL	DF	All species	WL	DF	All species
				Number			Percent	
		Lower Clearcut (Block 13)						
Intensive	Cut	Burn	200 (81)	0 (0)	300 (121)	20	0	20
Conventional	Cut	Burn	250 (101)	0 (0)	250 (101)	15	0	15
Close fiber	Cut	None	0 (0)	0 (0)	0 (0)	0	0	0
Intensive	Uncut	None	0 (0)	50 (20)	50 (20)	0	5	5
		Upper Clearcut (Block 23)						
Intensive	Cut	Burn	450 (182)	100 (40)	550 (223)	10	10	20
Conventional	Cut	Burn	50 (20)	50 (20)	100 (40)	5	5	10
Close fiber	Cut	None	50 (20)	50 (20)	100 (40)	5	5	10
Intensive	Uncut	None	0 (0)	0 (0)	50 (20)	0	0	5

SHELTERWOOD CUTTINGS

The number of 3- and 5-year-old seedlings was greater on the shelterwood cuts (table 3) because of the greater protection on that site. The lower shelterwood site had nearly the same number of seedlings and level of stocking throughout the study because the planned fire treatments had not been applied. The upper shelterwood site had more seedlings and greater stocking on the burned seedbed than on the unburned area.

GROUP SELECTION CUTTINGS

The group selection cuttings regenerated poorly during the five years following timber harvest (table 4). The possibility of any sudden increase in stocking seems remote because of the heavy vegetative competition on all seedbed conditions. About the same amount of western larch and Douglas-fir seed fell on both the lower and upper group selection cuts from 1974 through 1977. The lower groups also had heavy western hemlock and western redcedar seedfall in 1976. Practically no hemlock or redcedar regeneration from the 1976 seed crop was found in September 1979.

CLEARCUTTINGS

The number and stocking of 3- and 5-year-old seedlings in 1979 was greater on the clearcuts (table 5) than on the group selection cuts (table 4), but less than on the shelterwood cuts (table 3). Most seedlings were found on the burned seedbeds. The number of seedlings found on the upper clearcut decreased with distance from the lower timber edge, corresponding with the seed dispersal pattern. This relationship did not hold on the lower clearcut, however, probably because of greater competition for moisture by dense vegetation on the lower portion of the clearcut.

Seed Germination and Seedling Survival

From 1975 through 1978, germination of sown seed on unburned seedbeds was poor for all species except subalpine fir. In contrast, germination improved greatly for all species on the seedbeds that were burned in 1975 (table 6). Survival of seedlings was usually much higher on burned seedbeds than on the undisturbed forest floor. For example, in October 1976, subalpine fir that had germinated the previous May and June averaged 23 percent survival on burned seedbeds, compared to 5 percent on the undisturbed forest floor. Because of consistently low germination for other species, similar comparisons were not made for those species.

Table 6.--Germination of conifers by site condition (1975-1978).

Site Condition			Species				
Utilization Level	Understory	Seedbed Treatment	Western Larch	Douglas-fir	Engelmann spruce	Subalpine fir	Lodgepole pine
			Percent				
Intensive	Cut	Burn	1.5	1.1	0.3	14.6	1.7
Conventional	Cut	Burn	0.7	0.2	0.6	11.7	1.0
Close fiber	Cut	None	0.1	0.1	0.1	3.9	0.1
Intensive	Uncut	None	0.1	0.1	0.1	2.9	0.1

Although no attempt was made to identify rodent species or population levels, much of the seed--particularly Douglas-fir--was eaten by rodents. High soil surface temperatures had little influence on natural regeneration because of the rapid recovery of vegetation on the most exposed sites. Frost, by heaving the soil and damping off fungi, caused some losses in the late spring. Insufficient soil water was the cause of most seedling mortality during this study. Competing vegetation drew heavily from the available water reserves in the surface soil, and roots of many new seedings had difficulty penetrating unburned duff and soil rapidly enough to obtain sufficient amounts of water.

Seed:Seedling Ratios

The number of filled seed (dispersed on the study areas), required to establish one 3- to 5-year-old seedling on natural regeneration plots varied widely but generally reflected the difficulty of seedling establishment throughout the area (table 7). Except for the upper clearcuts, the shelterwood cuttings had the lowest ratio under most conditions. Average seed:seedling ratios were highest on the moister habitat types where vegetative competition usually was extreme, as shown in the following tabulation:

TSHE/CLUN-ARNU	1339:1
ABLA/CLUN-CLUN	215:1
ABLA/CLUN-ARNU	409:1
ABLA/CLUN-XETE	152:1
ABLA/CLUN-MEFE	179:1

All habitat types had some plots or entire subblocks without natural regeneration, where seed:seedling ratios could not be calculated. On each habitat type the average seed:seedling ratio combined all seeds caught in seed traps with all seedlings counted on the nearest natural regeneration plots within that habitat type.

New seedlings were found on many plots, but were not included in this tabulation because the probability for continued mortality during the next two years is high.

Table 7.--Seed:seedling ratios as influenced by cutting method and site condition.

		Site condition				
Cutting block	Block average	Utilization understory seedbed	Intensive cut burned	Conventional cut burned	Close fiber cut unburned	Intensive uncut unburned
Lower Shelterwood	123:1		128:1[1]	99:1[1]	135:1	130:1
Upper Shelterwood	233:1		152:1	229:1	194:1	680:1
Lower Group Selection	2732:1		1174:1	404:1	8094:1	1254:1
Upper Group Selection	429:1		486:1	324:1	364:1	[2]
Lower Clearcut	780:1		289:1	484:1	[2]	2476:1
Upper Clearcut	75:1		28:1	108:1	227:1	258:1

[1] Not burned.

[2] No seedlings on plots; seed:seedling ratios could not be determined.

Planting

Plantations of 2-0 bare root Douglas-fir and Engelmann spruce were established in the spring of 1976, 1977, 1978 and 1979 on all subunits where understory trees had been cut. Survival in the fall of 1978 was high on all subunits:

	Survival, fall 1978	
Year of Planting	Douglas-fir	Englemann spruce
	Percent	Percent
1976	94	90
1977	97	88
1978	96	95

No differences between subblocks were evident in survival rates.

Survival, growth and form will be monitored for several years to compare these characteristics with those of naturally regenerated trees.

MANAGEMENT IMPLICATIONS

Seedfall of western larch in 1974 and 1976 and of Douglas-fir in 1976 was sufficient to expect excellent natural regeneration throughout most of the cutover blocks. However, seedlings were slow to establish under nearly all conditions created by the several combinations of cutting methods, utilization levels, understory treatments and seedbed preparation. The combined effects of scarification during yarding (which occurred on probably no more than five percent of the study area) and of prescribed broadcast burning were inadequate for the establishment of sufficient natural regeneration. Most of these seedlings are found on mineral soil exposed during skyline yarding. Results of this study once again point out the necessity of creating well-distributed patches of exposed mineral soil on cutover areas within these habitat types.

During the early 1970's, the western spruce budworm heavily defoliated vulnerable species and probably decimated the cone crops within the study area. In June 1974 (lower budworm population) cone counts showed the crops were fair to good in western larch and poor to fair in Douglas-fir and Engelmann spruce, but none in subalpine fir. However, only the western larch cones matured to disperse much seed. In nearby stands, without noticeable defoliation in the early 1970's, all vulnerable species produced abundant cones in 1974. Probably, the budworm population on the study area in 1974 was sufficiently high and/or the residual effects of previous years heavy defoliation carried over to greatly decrease the cone production there in contrast to the nearby areas without noticeable defoliation. Subsequent seedling counts showed that in 1975 only larch regenerated on the study area.

When the land manager must restock an area through natural regeneration but cannot assure adequate site preparation, the shelterwood system provides conditions most favorable to seedling establishment. It not only produces more seed for the area but also ameliorates the extremes in temperature at the surface and reduces evapotranspiration. Once sufficient regeneration is established, the shelterwood should be removed to optimize growth opportunities for seedlings and to maintain dominance of shade intolerant species.

This study demonstrates that any site preparation performed usually increases germination rates and establishment of seedlings. Wherever mineral soil was exposed, seedlings are now evident. Prescribed burning enhanced germination and initial survival of seedlings.

The planted Douglas-fir and Engelmann spruce seedlings have survived well on all treatments. If other species had been planted, such as western larch or lodgepole pine, initial survival probably would have been high. The forest manager may consider planting more shade-tolerant species on poorly prepared sites because bare root and containerized seedlings are not as subject to the multitude of adverse site factors as are newly regenerated seedlings.

The effects of differing residue utilization standards, or of different understory treatments, on growth of natural or planted tree seedlings is not evident yet. These treatments may be more important in the later growth of conifers than in the establishment stage.

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Establishment and Initial Development of Lodgepole Pine in Response to Residue Management

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ABSTRACT

Four lodgepole pine clearcuts in Wyoming were quartered and wood residues treated as follows: (1) dozer piled and burned (scarified), (2) broadcast burned, (3) completely removed, and (4) chipped and spread over the site. Equal portions of each quarter were auger-planted, hand-seeded, or left to regenerate with seed dispersed from nearby trees.

Five growing seasons after outplanting, nearly 90 percent of the seedlings survived on the dozer-scarified and the broadcast-burned treatments, and only 50 to 60 percent survived on the chips-spread and complete residue-removal treatments. Height growth followed the same pattern--trees on the scarified and broadcast-burned treatments grew nearly twice as fast as those on the other two treatments.

Stocking rates and initial height growth for hand-seeded spots were about twice as great on the scarified and broadcast-burned treatments as on the chips-spread and complete residue-removal treatments.

Natural regeneration was plentiful on the scarified and residues-removed treatments, and lacking on the chips-spread treatment. Lack of a good seed crop after broadcast burning resulted in little natural regeneration on that treatment.

KEYWORDS: *Pinus contorta*, lodgepole pine, natural regeneration, artificial regeneration, residues disposal, prescribed burning, seedling development

INTRODUCTION

Lodgepole pine (Pinus contorta) may well be our most promising species for increased fiber production and short rotations on many areas. It occurs on millions of acres in the Rockies, much of it grows on relatively gentle terrain, and its dual serotinous and nonserotinous cone characteristics provide a mixture of regeneration opportunities available for but few species (Lotan 1975a, 1975b). Clearcutting is the most viable silvicultural method of regenerating lodgepole pine (Tackle 1954; Lotan 1975b) but large amounts of residue left after logging leave the areas unsightly, create fire hazards, are obstacles for forest management activities, and are a waste of a wood resource. Lodgepole residues consist primarily of branches, cull logs, and treetops above the merchantable limit. There lies the problem--what do you do with all the residue and how does the disposition affect the total resource?

In 1971, the U.S. Forest Service Intermountain Forest & Range Experiment Station, Intermountain Region, and U.S. Plywood Champion Paper Company (now Champion International)[1] started a cooperative study aimed at assessing the effects of different utilization and residue disposal methods on esthetics (Benson 1974), fiber yields (Gardner and Hann 1972), nutrient cycling and subsurface water chemistry (Hart and DeByle 1975), soil stability (Packer and Williams 1980), and seedling establishment and development (Lotan and Perry 1977). This paper is a followup to the latter; it reports the regeneration establishment and development the first 5 years after residues treatment.

METHODS

Area

This study was conducted in overmature lodgepole pine stands on the Bridger-Teton National Forest in northwest Wyoming. This area is a gently rolling plateau at an elevation of about 2 850 m (about 9,300 feet). It falls within Reed's (1969) Picea engelmannii/Vaccinium scoparium habitat type. The climate is severe, with the mean July minimum about -2°C (28°F). Precipitation is evenly distributed throughout the year, averaging about 75 cm (30 inches) annually (Baker 1944). The area has been heavily glaciated, and the soils are shallow, brown podzols (Reed 1969).

Treatments

Four timbered blocks were selected for clearcutting in overmature lodgepole pine. Two blocks were logged to conventional utilization standards and two were logged to near-complete utilization (trees were skidded intact, and down and broken material was brought to the landing and chipped). Slash was tractor piled and burned on two separate quarters of each conventionally logged unit; it was broadcast burned on the other two quarters. Two separate quarters of each near-complete utilization unit was left as it was following logging (there was about 11 000 kg per ha (5 tons per acre) of wood fragments left on the soil surface); the other two quarters were covered with 10 to 13 cm (4 to 5 inches) of wood chips roughly equivalent in weight

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[1] The use of trade, firm, or corporation names does not constitute an official endorsement of or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

to the amount of residue originally removed from the area. To simplify the treatment terminology, treatments will be identified throughout the remainder of this paper as follows:

Treatment Name	Treatment Description
Scarified	Slash from conventionally utilized blocks was tractor piled and burned
Burned	Slash from conventionally utilized blocks was broadcast burned
Residues removed	Residues from the near complete utilization blocks were removed from the blocks
Chips spread	Residues from the near complete utilization blocks were removed, chipped, and the chips spread back on the blocks

Slash piling, burning, and chip spreading were done in 1972. Broadcast burning was done in the spring of 1973--immediately before planting and seeding.

Each quarter block was divided into thirds for the following three treatments: (1) auger-planting of about 700 lodgepole pine seedlings into 45 cm (18 inches) square scalps, (2) spot seeding of 12 to 15 lodgepole pine seeds on each of about 2,500 spots per ha (1,000 per acre) after the spots--45 cm (18 inches) square--were scalped free of competing vegetation (Lotan and Dahlgreen 1971), and (3) left for natural regeneration (this study area had primarily nonserotinous cones).

In the seeded and planted areas, samples of 7 to 10 percent of the above populations were randomly selected for survival and height development measurements. Trees were measured in the fall of 1973, summer and fall of 1974, fall of 1975, and fall of 1977.

To evaluate natural regeneration, 16 to 20 plots, 4.05 m^2 (milacre), were randomly located in each unit. Seedlings were counted to measure seedling distribution (percent milacre stocking) and seedling density.

In addition to the tree measurements, the amount of material in various cover classes of forbs, grasses and sedges, shrubs, and dead material was estimated in 1975. In 1977, biomass of the lesser vegetation was measured for each of the live vegetation categories.

Thus, the two primary treatment variables affecting the results in this paper were residues treatment and regeneration method. Because this study was originally designed for other purposes, the experimental design does not permit statistical inference from these data. However, we feel that our experience with other studies permits a valid judgement of the significance of these results.

The study area was fenced to keep livestock out, and pocket gophers were effectively controlled with poisoning. However, large ungulates such as moose (Alces alces [Nelson]), elk (Cervus canadensis [Bailey]), and deer (Odocoileus sp.) frequented the area.

RESULTS

Planted

Planted seedlings survived very well on areas that had been scarified or burned, exceeding 95 percent at 3 years and 87 percent at 5 years (fig. 1). Meanwhile, their counterparts fared poorly in the residues-removed and chips-spread treatments. Although planted seedlings in the residues-removed treatment were surviving at the rate of over 90 percent at 3 years, they had declined rapidly to 59 percent survival two years later. Planted seedlings in the chips-spread treatment declined in a similar fashion, dropping from 84 percent survival at 3 years to 49 percent at age 5.

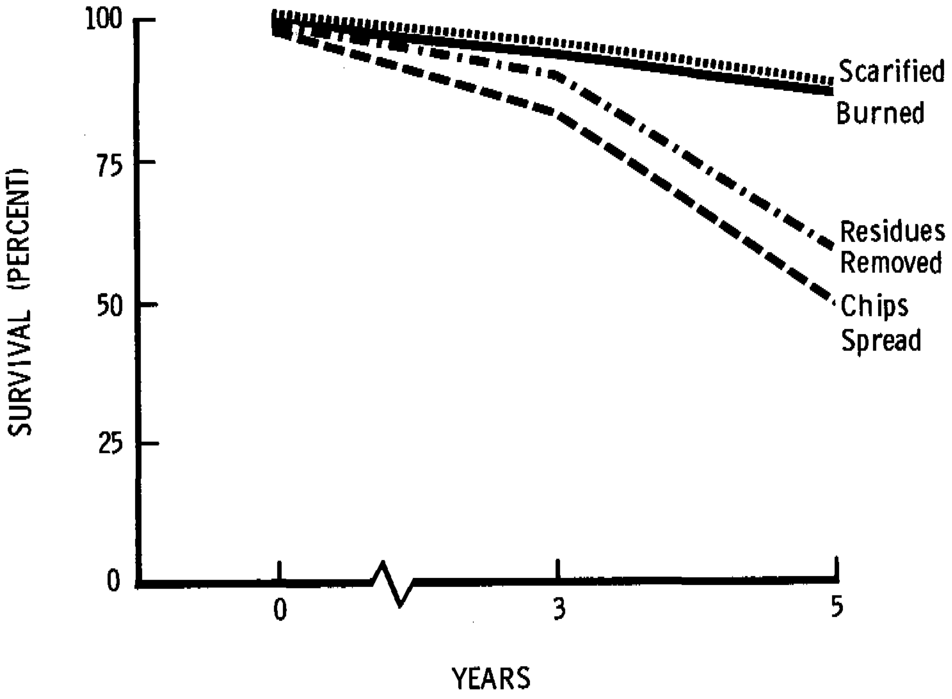

Figure 1.-- Survival of auger-planted 2-year-old lodgepole pine seedlings under different residues management methods.

As the following tabulation shows, these declines in survival from age 3 to 5 were at least partially forecast by the percent of seedlings poor in vigor at 3 years:

	Percentage of trees poor in vigor at age 3	Percentage mortality between ages 3 and 5
Scarified	11	8
Burned	10	8
Residues removed	46	22
Chips spread	40	35

Most of the trees rated poor in vigor at age 3 had died by age 5. Although this vigor rating was subjective, based on overall seedling appearance, it proved fairly accurate in forecasting survival rates for the next 2 years.

In addition to surviving at different rates, planted seedlings grew most on scarified and burned areas and least on residues-removed and chips-spread areas (fig. 2). As shown, height differences already apparent at age 3 were even more pronounced at age 5. Height ratios of trees on the different treatments remained about the same, but absolute differences between treatments were still widening.

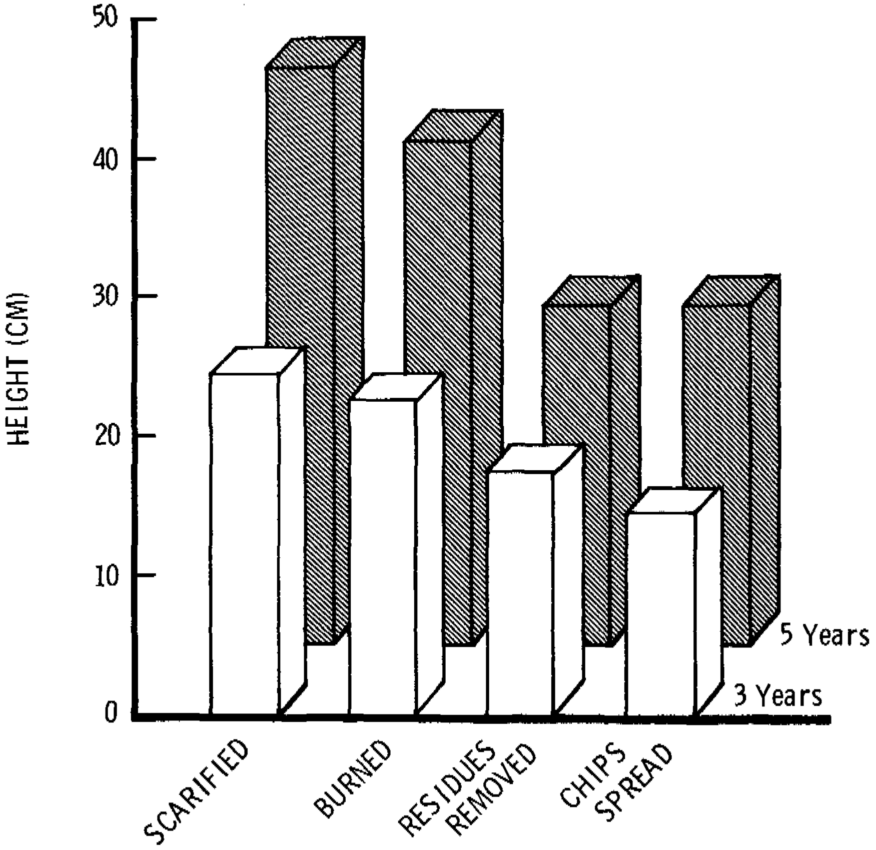

Figure 2.-- Height development of auger-planted 2-year-old lodgepole pine seedlings under different residues management methods.

Height increments of planted seedlings for the 3- to 5-year period were as follows:

Treatment	Height increment from age 3 to 5	
	(cm)	(inches)
Scarified	16.8	6.6
Burned	13.1	5.2
Residues removed	6.8	2.7
Chips spread	9.9	3.9

As one would expect, height growth of seedlings in each of the treatments varied substantially. However, the same treatment effect patterns held true for the tallest, most agressive seedlings:

Tallest Seedling Height

Treatment	Total Height		Increment age 3 to 5	
	(cm)	(inches)	(cm)	(inches)
Scarified	98	39	32	13
Burned	96	38	30	12
Residues removed	62	25	22	9
Chips spread	69	27	28	11

Spot-Seeded

Broadcast burning, and scarification accomplished by slash piling, created conditions most favorable for establishment of lodgepole pine by spot-seeding (fig. 3). Stocking rates for spot-seeding on the burned and the scarified treatment areas were about double those on the residues-removed and chips-spread treatments. None of the treatments resulted in stocking rates that exceeded 50 percent 5 years after seeding. However, these results were probably affected to some extent by an unusually early snowmelt that year, the soil surface had dried beyond the moisture level felt optimum for spot-seeding.

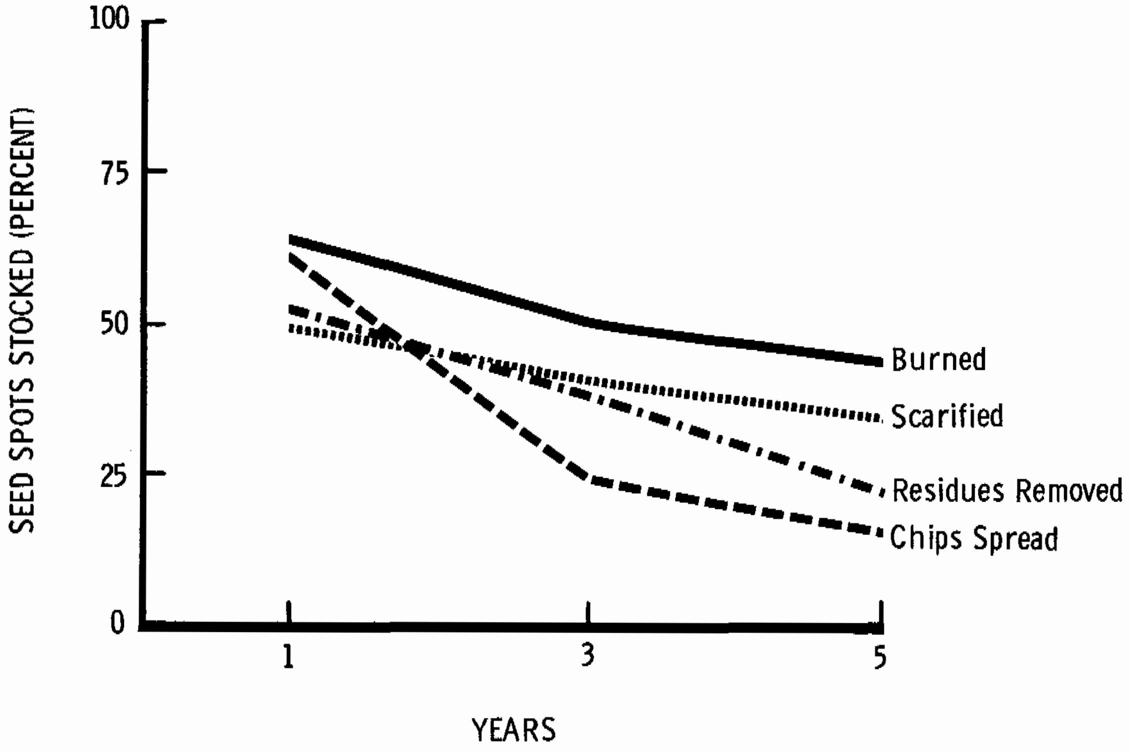

Figure 3.-- Percent of seed spots stocked with lodgepole pine seedlings under different residues management methods.

For the first 5 years, the percent of stocked plots declined in all treatments, but stocking on the burned and scarified treatments appeared to have begun leveling off. Meanwhile, those in the residues-removed treatment continued a steady decline throughout the 5-year period, and those in the chips-spread treatment dropped substantially between years 1 and 3, but declined at a slower rate in years 3 to 5 than the previous 2 years.

Residues treatments influenced the first 5 years height growth of spot-seeded seedlings in much the same manner as they did the stocking rates. The tallest seedling in each seed spot served as the monitor. Height growth was twice as great in the burned and scarifed areas as in the residues-removed and chips-spread areas (fig. 4). These differences were already pronounced at 3 years, and were even more so at 5 years.

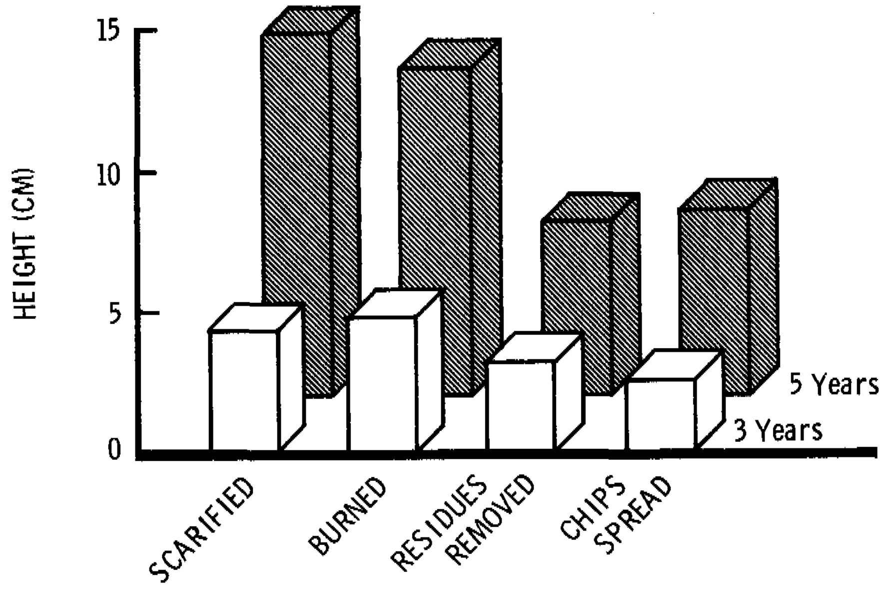

Figure 4.-- Average height of the tallest seedling per seed spot, by residue treatment and year.

Natural Regeneration

Natural regeneration was more than adequate on the scarified treatment areas, averaging about 6,500 trees per ha (2,630 per acre), with a 66-percent stocking rate (table 1). However, except for the residues-removed areas, both stocking rate and seedling density were less than adequate on the other treatment areas. A good estimate for the broadcast-burned treatment is not possible because a good seed fall occurred in 1971 immediately following logging, but before burning in the spring of 1973. It's likely that nearly all of the seedlings that germinated in 1972 were consumed in the fire. Poor seed production in subsequent years left the broadcast burn with few seedlings, even after 5 years.

TABLE 1.--Natural regeneration of lodgepole pine at 3 and 5 years under different residues management methods.

Treatment	Years after treatment	Milacre stocking	Seedling density		Height of dominant seedlings 5 years after treatment	
		(percent)	(per ha)	(per acre)	(cm)	(inches)
Scarified	3	56	5,483	2,220	—	—
	5	66	6,496	2,630	19.0	7.5
Burned	3	11	321	130	—	—
	5	20	741	300	5.1	2.0
Residues removed	3	50	4,668	1,890	—	—
	5	35	2,964	1,200	12.7	5.0
Chips spread	3	3	74	30	—	—
	5	9	568	230	4.1	1.6

Very little natural regeneration was apparent at 3 years on broadcast-burn and chips-spread treatments, and even by age 5 only a few poorly distributed seedlings were established (table 1). However, this poor showing was attributed not to treatments per se, but to the fact that the 1972 seedlings had been burned in the broadcast-burned treatment and covered with chips in the chips-spread treatment.

At age 3, natural regeneration had been fairly successful on the residues-removed treatment areas, but both stocking rate and seedling density declined during the following 2 years. At age 5, the area was stocked with nearly 3,000 trees per ha (1,200 per acre), with a 35-percent milacre stocking rate.

Average seedling heights were closely related to the number and stocking of seedlings established on the different treatment areas; those with the greatest stocking also produced the tallest average trees. Some of the differences in height were likely a function of seedling age. For example, nearly all seedlings in the broadcast-burn areas were established about 3 years after those in the areas receiving the scarified treatment.

Vegetative Competition

Vegetative cover, measured 3 years after treatment, averaged 11 percent forbs and 2 percent grasses and sedges on the scarified and broadcast-burned treatments, and 20 percent forbs and 9 percent grasses and sedges on the residues-removed treatment. There was practically no vegetative cover on areas receiving the chips-spread treatment.

Comparable cover measurements were not made at 5 years, but biomass values were determined for lesser vegetation. As shown in fig. 5, there were substantial differences in amounts of biomass under different treatments, with the residues-removed treatment areas continuing to have the most biomass, followed by scarified, burned, and chips-spread treatment areas.

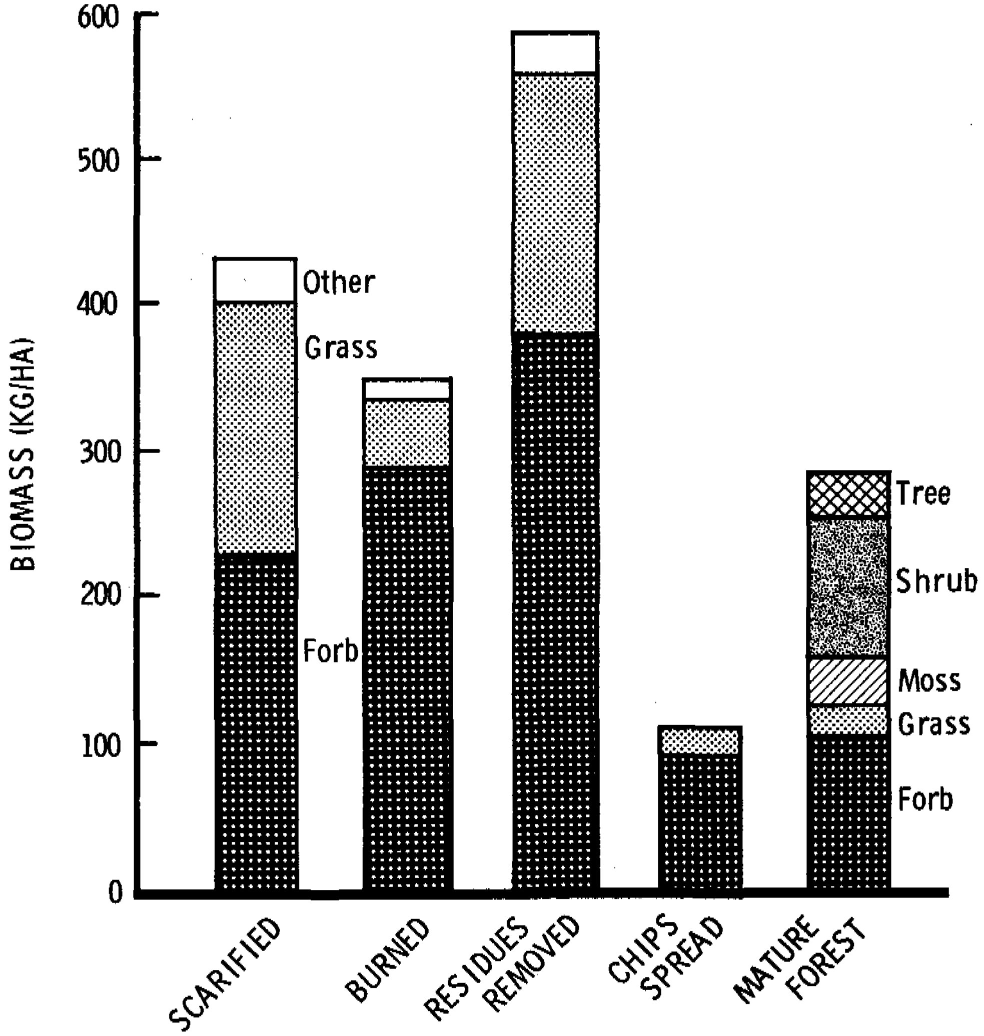

Figure 5.-- Biomass of lesser vegetation 5 years after clearcutting and different residues management methods, compared to biomass categories in a mature forest.

As shown in fig. 5, vegetation was sparse in the study area's uncut mature forests. With the exception of the chips-spread treatment, all treatments produced more vegetation than the uncut forest.

In addition, ratios between vegetative components varied substantially. Whereas forbs accounted for about a third of the biomass in the uncut forest, they predominated on the treated areas. For example, in the burned-treatment area, forbs accounted for over three-fourths of the biomass. On the other hand, shrubs accounted for a third of the biomass in the uncut forest but were practically nonexistent on treated areas. Grasses were practically nonexistent in the uncut forest and the chips-spread treatment areas, but accounted for over a third of the lesser vegetation's biomass in areas receiving the scarified and residues-removed treatments.

None of the biomass values on any of the treatment areas were high. Even the residues-removed treatment, which had the most, had only 580 kg per ha (518 pounds per acre).

DISCUSSION

When and how we dispose of wood residues following clearcutting in lodgepole pine forests has a pronounced effect on subsequent regeneration. This holds true for both survival and initial development of both artificial and natural lodgepole pine regeneration. The different effects of residues treatments are still pronounced even after 5 years, and the general trend during the first 5 years hints that these differences will continue. How long differences persist can only be speculated at this time. However, studies with western larch (*Larix occidentalis*) under somewhat similar circumstances showed seedbed treatments affecting seedling and sapling development for 10 to 15 years (Schmidt 1969; Schmidt and others 1976).

In this study, conventional methods of seedbed preparation in lodgepole pine forests resulted in the highest rates of survival and seedling development. Results from this study provide additional support for the use of scarification (dozer piling and burning of slash) and broadcast burning as far as seedling establishment and development are concerned. This appears to hold true for all three types of regeneration--planting, spot-seeding, and natural.

Neither the residues-removed nor the chips-spread treatment has much to offer as far as regeneration during the first 5 years is concerned. Planted tree survival and growth on areas receiving these treatments has been substantially less than on the two conventional treatments, and trends indicate these differences are becoming greater rather than ameliorating. The same relationship holds true for spot-seeding and to a lesser extent for natural regeneration. The natural regeneration picture for broadcast burning is clouded in our study because of the problems caused by delayed burning and subsequent loss of first-year seedlings. However, other studies have indicated that natural regeneration rates are essentially the same on scarified and broadcast-burned areas, with somewhat fewer seedlings surviving on burned seedbeds (Alexander 1966).

We cannot explain fully the differences in seedling response to the four treatments. However, there are a number of possible individual or combinations of causes. One obvious possibility relates to differences in soil temperatures. Soils under the chips-spread treatment were 5° to 20° cooler than some of those in the open. Hungerford (1980) measured minimum temperatures for a July day and showed the following variations:

Treatment	Soil Surface	5 cm above soil surface
	($^{\circ}$C)	
Uncut forest	+6	—
Burned	+2	+4
Residues removed	-6	-1
Chips spread	-8	-4

The temperature gradient reflected in these figures corresponds to the survival and development of the lodgepole pine seedlings on the different treatment areas. As described by Lotan and Perry (1977), "cool soil temperatures can inhibit plant-water uptake (Kramer 1942; Babalola and others 1968), nutrient release and absorption (Nielsen and Humphries 1966), and retard top growth of plants, perhaps by inhibiting hormone transfers from root to top (Lavender and Overton 1972)."

Hungerford (1980) also points out July net radiation differences by treatment. As expected, the chips-spread treatment has the least net radiation, most likely because of the high albedo from the light-colored chips. However, net radiation from the other treatments does not line up in the same manner as the temperature gradient. At this point, we do not understand fully net radiation implications since net radiation incorporates a wide band of wave-lengths with different levels of albedo and radiated energy.

Vegetative competition is usually an inhibitor of lodgepole pine seedling survival and development (Lotan 1975b). However, with the possible exception of the residues-removed treatment areas, vegetative competition does not appear to be the culprit in this area. The relatively low levels of vegetation measured as live biomass on this study area cast doubt on its role as a strong competitor here. The grass component would likely be the primary competitor, but the amounts of grass on the scarified treatment (which produced the best tree growth) was essentially the same as on the residues-removed treatment (which had poor growth).

A flush of phenols in 1973, the same year seedlings were planted and seeded, may have played an active role in retarding seedling establishment and subsequent growth. If so, the high content of phenols--658 parts per billion in the chips-spread areas and 320 parts per billion in the residues-removed areas--had a long-term compounding effect because the phenol levels had returned to normal by 1974 (Hart and DeByle 1975). Plant tissue commonly contains phenols (Bate-Smith 1962), with high concentrations in dead and dying woody plants (Jorgenson 1961; DeGroot 1966). Phenols are credited with both stimulating (Michniewicz and Galoch 1974) and inhibiting (Mensah 1972; Demos and others 1975) plant growth.

Interestingly, the high phenol levels on the chips-spread and residues-removed areas were associated with the organic matter levels in the top 5 cm of the soil. As described by Packer and Williams (1980), in 1975, organic matter accounted for 11 to 12 percent of the upper soil layer in the residues-removed and chips-spread treatments as compared to 4 to 6 percent in the other treatment areas. The increased organic matter in the upper soil of the residues-removed area was believed due to the incorporation of fine residues, such as pine needles and small limbs, into the upper soil by equipment traffic during the intense removal of the larger residues.

Nutrients are often felt to be a major cause of differential tree response on areas treated with some of the residue disposal methods used in this study. Broadcast burning, having increased levels of potassium, calcium, magnesium, and nitrates (DeByle 1980), may have contributed to the superior growth of regeneration that developed as a result of seeding. However, a corresponding effect in planted seedlings wasn't apparent--probably because the flush of available nutrients essentially disappeared the second season, before the newly planted seedlings developed a root system capable of capitalizing on the nutrients.

Nutrient concentrations in planted seedlings growing on the different seedbeds gave no ready explanation for growth differences. As DeByle (1980) noted, there were no striking nutrient-related differences among the different lodgepole pine seedling components under the various treatments. However, the dilution effect of larger seedlings (nutrients were evaluated on the basis of percentages) found in areas with the more favorable treatments makes it difficult to realistically evaluate nutrient availability and disposition.

Interestingly, the two treatments with the least tree response also were the treatments with the greatest percentage of organic matter in the upper 5 cm (2 inches). Much of the nitrogen in this strata may have been "tied up" in the decomposition process and as a result unavailable to the seedlings. Also, there was the possibility of tree planters getting small woody debris in the planting hole when large amounts of debris were present.

Compaction did not appear to adversely affect initial establishment and development on this study area. Packer and William's (1980) data indicate the most compaction (as measured by bulk density) occurred on the scarified areas--the areas that produced the best seedling response.

SUMMARY

Several points stand out in this study that have a bearing on residues disposal:

1. Differences in seedling survival and first 5 years of development are strongly dictated by the residues disposal method.

2. Conventional treatments of scarification (pile and burn slash) and broadcast burning are most favorable for lodgepole pine seedling establishment and initial development.

3. Spreading a thick layer of chips on site may have some benefits, such as preventing erosion, but the practice is definitely detrimental to the establishment and development of lodgepole pine under both natural and artificial regeneration methods.

4. Complete removal of residues, as done in this study, definitely retards establishment and early development of tree seedlings. However, reasons for this detrimental effect are not totally clear at this point, and it is doubtful that this particular study can shed much more light on the reasons.

5. Five years is a small segment of a tree's life on these cold subalpine sites, but lodgepole pine establishment and growth trends apparent 5 years after treatment discourage use of the chips-spread and complete residues-removal treatments.

6. Lodgepole pine is a true pioneer species, capable of capitalizing on highly disturbed conditions such as those following scarification or burning. These "raw" conditions may be the very thing that helps lodgepole pine maintain its competitive advantage over many of its associates.

7. All of the natural and artificial regeneration treatments that were tested here are acceptable and productive methods of regenerating lodgepole pine forests. With natural regeneration, the key lies in timing site preparation with anticipated seed crops. With artificial regeneration, the key lies in proper site preparation for both seeding and planting and proper handling of stock from the nursery through the planting process.

8. Even if residue treatment effects on lodgepole pine tree and stand development do not persist beyond the juvenile stage, a number of important management objectives are affected. Included are: getting trees large enough to resist rodent and livestock damage, providing a stand tall enough to provide hiding cover for game, restoring a forested appearance, and the obvious goals of increasing wood production and shortening rotations.

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EFFECT OF SILVICULTURAL PRACTICES, RESIDUE UTILIZATION, AND PRESCRIBED FIRE ON SOME FOREST FLOOR ARTHROPODS

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ABSTRACT

The combined effects of two silvicultural practices--shelterwood and clearcutting--and two residue management practices--intense fiber removal (utilization) and residue removal by prescribed fire--on forest floor arthropods (macrofauna) are discussed. Arthropods most abundant on the study area and most affected by treatments were spiders (Arachnida:Araneida), ants (Hymenoptera: Formicidae), and beetles (Coleoptera), especially the families Carabidae and Staphylinidae.

Although some populations increased between treatments or years, most treatments adversely affected most groups of macrofauna, particularly the second and third year, respectively, after burning and harvesting. Prescribed burning of residues stimulated a resurgence of some groups. The five treatments studied could be ranked in a decreasing impact on forest floor fauna in the following order: shelterwood cutting and leave residues, shelterwood and burn residues, shelterwood and mechanically remove residues (intense fiber utilization), clearcut and burn residues, clearcut and mechanically remove residues. Management implications of the effects of these harvesting and residue treatments on surface arthropods are discussed.

KEYWORDS: silviculture, forest residue, fire, arthropods, macrofauna

PREFACE

In the early 1970's, the Forest Residues Research and Development Program of the Intermountain Forest and Range Experiment Station began a 5-year study to evaluate the environmental consequences of the combined effects of silvicultural systems, harvesting, and residue disposal alternatives in western larch-Douglas-fir stands. As part of that Program several studies involving a variety of disciplines were conducted, including two entomological studies involving two groups of forest insects. The results of one study are presented in this paper (Fellin 1980b).

The objective of this study was to determine and evaluate the combined effects of harvesting methods, silvicultural prescriptions, and forest residue management, including prescribed fire on the fauna of the forest floor. This study is restricted to those soil surface or forest floor arthropods often categorized as macrofauna (Ahlgren 1974). This group consists of the larger arthropods--beetles, ants, centipedes, millipedes, spiders, etc.--usually greater than 10 mm in size (Wagner and others 1977). Fichter (1941) defines soil surface fauna as "populations composed of those species which travel, for the most part, over the surface of the ground, and though closely associated with the litter as material for abode, constitute, when active (not resting, hiding or hibernating), a distinct society."

Reported elsewhere in this proceedings (Fellin 1980c) are the partial results of the other entomological study that was concerned with the effect of harvesting and residue management practices on forest soil arthropods such as mites and collembola, intermediate-sized organisms often referred to as mesofauna (Metz and Farrier 1971).

This proceedings also offers a review of some relationships of harvesting, residue management and fire to forest insects and diseases (Fellin 1980a). The review paper summarizes the past and current research concerning the effects of forest practices on both forest floor macrofauna and forest floor mesofauna.

INTRODUCTION

Sivilcultural practices modify forests by removing all or part of both the coniferous overstory and the understory. Management of the resultant residues, including prescribed fire, modifies the forest floor and forest soil component by removing or destroying both man-generated residues as well as natural forest residues, often eliminating or seriously influencing the litter and decomposition layers of the forest floor. Silvicultural and residue management practices also dramatically affect macro- and micro-meteorological conditions and in turn nearly all flora and fauna, either by killing some plants and animals or by altering the environment, thus modifying the behavior of organisms.

The ecological consequences of all types of cuttings--especially clearcutting--are incompletely understood and are the subject of increased attention and debate. Clearcutting has been the silvicultural practice most widely employed in coniferous forests of the northern Rocky Mountains.

In managed coniferous forests in the northern Rocky Mountains, studies are under way to determine the effects of harvesting and silvicultural practices on the two most widespread and destructive insect species, the western spruce budworm and the mountain pine beetle. These two forest insect species have produced severe economic impacts and thus have been the focus of the majority of forest insect research. Relatively little is known, however, of the identity, distribution, abundance, and general ecology of forest insects that inhabit the surface and litter layers of the forest floor. These fauna are little known because of their innocuous ecological niche and because other more dramatic and population-explosive species or groups of insects have attracted more attention.

The forest floor and forest soil fauna include diverse species representing several classes of arthropods and orders of insects, each with its own unique, and not mutually exclusive role in the forest ecosystem. Forest floor arthropods include predators, species that feed on living plant tissues, and other groups involved in the comminuting and decomposition of forest floor residues. Some groups spend their entire lives in the forest floor, while others, such as some species of defoliators and bark beetles, use the forest floor only as a temporary habitat. Any manipulations of the forest can affect the food supply, shelter, competition, vulnerability to predation, reproduction, and other behavioral habits of most forest floor fauna.

STUDY DESIGN

The study area is located on the 3 019 ha (7,460 acre) Coram Experimental Forest, on the Hungry Horse District of the Flathead National Forest. It is accessible from U.S. Highway #2 at Martin City and lies about 40 km (25 miles) northeast of Kalispell, Mont. The cutting units were established along the main ridge facing east into Abbott Basin, sections 25, 35, and 36; T31N, R19W (48°25' north lat., 113°59' west long.). Timber was harvested in 1974 using one or more running skyline systems, and the residues broadcast burned in the fall of 1975.

The study area falls primarily in the *Abies/Pachistima* habitat type,[1] with a lesser amount along the bottoms within the *Thuja/Pachistima* habitat type. Soils are from impure limestone underlying material of loamy-skeletal soil families.[2] Slopes on the cutting units range in steepness from 30 to 80 percent (17° to 39°) and average about 55 percent (29°). Elevation ranges from 1 189 to 1 585 m (3,900 to 5,200 feet) m.s.l.

Six cutting units or blocks were harvested, originally designed to provide two replications of three basic silvicultural systems as follows:

(1)	Shelterwood	- Block 11	12 ha (30 acres)
		Block 21	9 ha (22 acres)
(2)	Group selection	- Block 12	0.5 ha (1.2 acres)
		Block 22	0.5 ha (1.2 acres)
(3)	Clearcut	- Block 13	6 ha (15 acres)
		Block 23	6 ha (15 acres)

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[1] Based on a habitat type survey completed in 1969 by Robert D. Pfister.

[2] Based on a soil survey completed in 1969 by R. C. McConnell.

In addition, two control Blocks, 14 and 24 were established in the adjacent uncut mature forest (figure 1).

Within each silvicultural treatment, four residue management treatments were superimposed. The residue subunits, designed to represent four basic levels of utilization, are as follows:

Subunit	Trees to be Cut	Utilization Standard	Site or Seedbed Treatment
1	All designated sawtimber; all understory trees.	Intensive log utilization. Remove all material (live and dead, standing and down) to 3" dia., 8' length, and 1/3 sound.	Broadcast burn.
2	All designated sawtimber; all understory trees.	Conventional log and tree utilization. Remove sawtimber material (live and recently dead) to current NFS sawlog merchantability standards--6" dia., 10 bd. ft., 1/3 sound.	Broadcast burn.
3	All designated sawtimber; all understory trees. (All slash removed.)	Intense fiber utilization. Remove all material (live and dead, standing and down) to 3" dia., 8' length, and 1/3 sound.	Leave as is. (All slash removed.)
4	All designated sawtimber.	Leave sub-merchantable understory. Remove all material in sawtimber trees (live and dead, standing and down) to 3" dia., 8' length, and 1/3 sound.	Leave as is.

The details of the study design discussed above are presented in a core study plan prepared by the U.S. Forest Service investigators (USDA Forest Service 1973).

The entomological study followed the overall study design as presented above and shown in figure 1, with five major exceptions:

1. Our studies were restricted to two shelterwood treatments, Blocks 11 and 21, and two clearcuts, Blocks 13 and 23; we did not consider the group selections principally because of their small size.

2. Within the shelterwood and clearcutting units, we considered only subunits 1, 2, and 3. We did not consider subunit 4 primarily because of the difficulty of leaving non-merchantable understory trees in the clearcuts with the skyline harvesting system used.

3. Harvesting and the removal of designated residues proceeded as planned during the summer of 1974, with some 10 to 15 M bd. ft. of timber cut per day, beginning about June 10. The residues scheduled to be burned in subunits 1 and 2 were

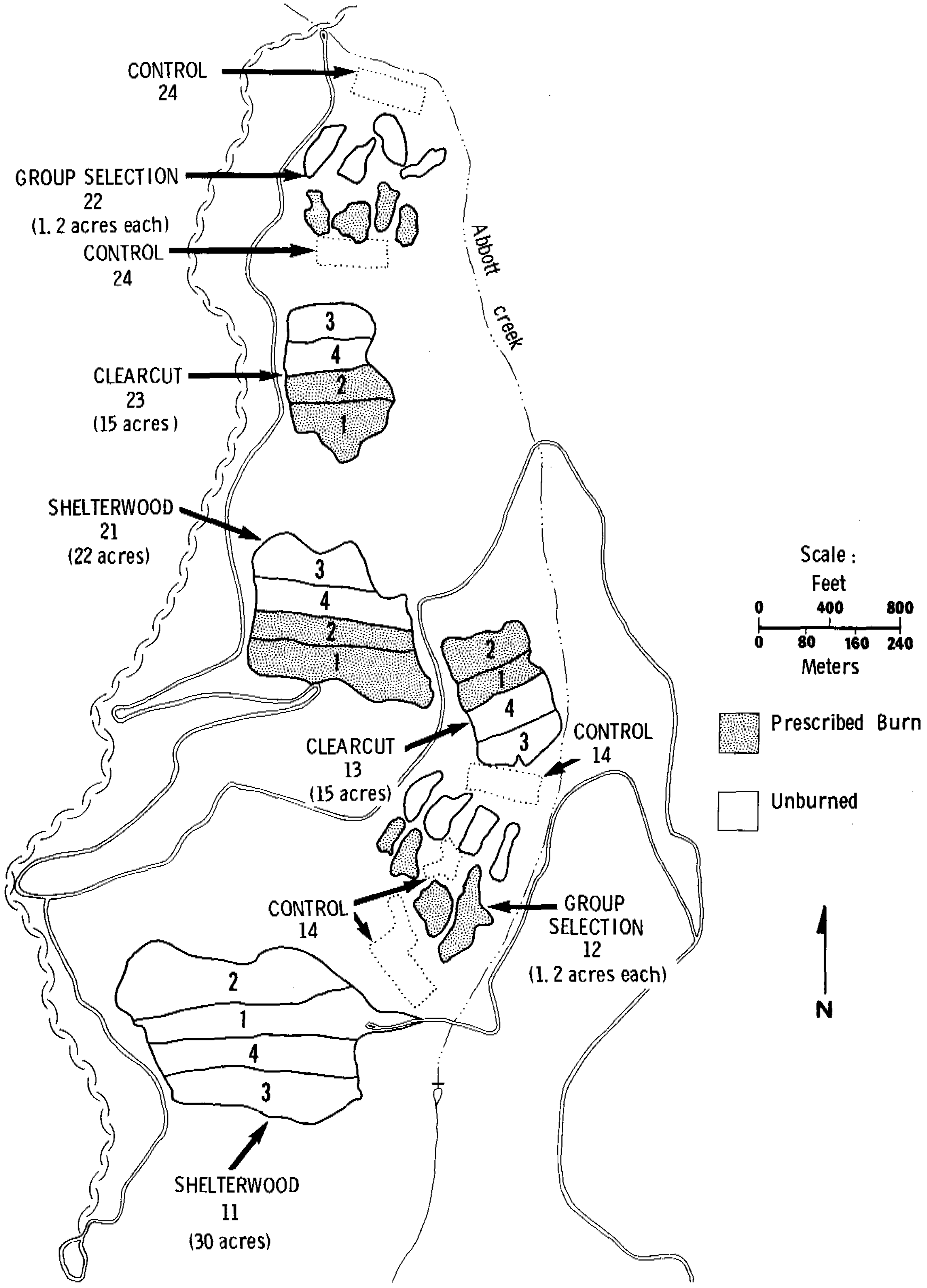

Figure 1.--Coram Experimental Forest Abbott Creek Watershed is a study area for evaluation of alternative harvesting and residue utilization practices showing: location of cutting blocks, residue management subtreatments within the cutting blocks, control areas, access roads, Abbott Creek, and main ridge.

allowed to cure for 1 year or more until the fall of 1975. In September of 1975, the residues in subtreatments 1 and 2 were burned in clearcut blocks 13 and 23 and shelterwood block 21. Poor burning conditions, however, prevented burning the residue in subtreatments 1 and 2 in shelterwood block 11, in effect, adding another treatment.

4. In all 4 cutting blocks, the differences in the amount of residues left under the two different utilization standards were insignificant. Because of this, and the similarities in broadcast burning, we considered subunits 1 and 2 as a single treatment.

5. Our entomological study did not begin until the early summer of 1975. Hence we were unable to sample forest floor macrofauna during the season of 1973, a year before harvesting, or immediately before or after harvesting during the harvesting season of 1974.

Our final entomological study design consisted of 5 combinations of harvesting and residue utilization treatments, and a control as follows:

Treatment #	Harvesting System Prescription	Block #	Residue Utilization Prescription	Residue Utilization Subunit #
1	Shelterwood	11 & 21	Intense fiber utilization	3
2	Shelterwood	11	Residues unburned	1 & 2
3	Shelterwood	21	Residues burned	1 & 2
4	Clearcut	13 & 23	Intense fiber utilization	3
5	Clearcut	13 & 23	Residues burned	1 & 2
6	Undisturbed forest	14 & 24	None	5

Another element in the overall study design that could influence the interpretation of entomological studies was the size and configuration of treatments. All treatments were rectangular in shape with the longitudinal axis parallel to the slope. The five treatments ranged in length from 155 m (510 ft.) to 930 m (3,050 ft.), and from 78 m (255 ft.) to 155 m (510 ft) in width (figure 1). Moreover, only the top, bottom and one side of each treatment was adjacent to undisturbed forests; the other side abutted subtreatment 4 which was not considered in this study.

It would seem that this configuration of units and treatments could create an "edge effect" where mobile arthropods could move in from the edges, or between treatments. However, this mobility is an arthropod behavioral trait that should contribute to the interpretation of treatment effect. If a treatment is antagonistic to a certain group or groups, the treatment would reduce the numbers of animals as well as discourage individuals from the surrounding areas to immigrate. On the other hand, if a treatment was favorable to a group, it would tend not to decimate them and may provide conditions favorable for immigration to the treated area. Moreover, if treatment effects were realized on these relatively small units, one would speculate that effects also would occur--perhaps even more dramatically--on larger treatment units. This would occur because most forest floor macrofauna are not able to, or usually do not fly.

FIELD AND LABORATORY PROCEDURES

To measure the treatment effects on forest floor arthropods, we installed a series of 196 pitfall traps throughout the study area. The traps were arranged in each cutting block and subunit so that they (1) gridded the units, (2) had equidistant plot centers, and (3) allowed a 31 m (100-foot) buffer along each edge of each subunit. There was one trap per 0.15 ha (0.37 acre). The number of traps per treatment and the sizes of the units were as follows:

Treatment No.	Block	No. of Traps	Size of Unit Acres	Size of Unit Hectares
1	11	24	8.9	3.6
	21	12	4.5	1.8
2	11	48	17.8	7.2
3	21	32	11.8	4.8
4	13	8	3.0	1.2
	23	8	3.0	1.2
5	13	16	6.0	2.4
	23	16	6.0	2.4
6	14	16	6.0	2.4
	24	16	6.0	2.4

The pitfall trap was made from a galvanized metal can with a diameter of 25.4 cm (10 inches) and a height of 30.5 cm (12 inches). Holes were punched in the bottoms of the cans to allow for drainage. A 237 ml (8-ounce) jar with a screw-type lid was placed on the bottom of the can and filled with 120 ml (4-ounces) of 70 percent ethyl alcohol, as a collecting container. A 25.4 cm (10-inch) tin funnel was positioned into the can, with the top of the funnel fitted snugly over the rim of the can and the neck suspended over the open jar. The funnel was secured to the can with three paper-binder clips. This entire assembly was placed with the open end flush with the ground surface.

The traps remained in position in the field for 2 weeks and were checked periodically for damage from wild animals, debris in funnel, jars filling with rain water, etc. At the end of the 2-week sampling period, the collecting jars were taken from the traps and removed to the laboratory for processing.

In processing the samples, the contents of each jar were poured into a flat pan and without magnification the debris was removed and discarded, and the larger arthropods removed from the sample. Then under magnification, the smaller remaining arthropods were removed from the sample. All animals were sorted and tallied by Class and insect Order. The Coleoptera were further categorized into the two most abundant families--Carabidae and Staphylinidae. Because of the nature of the pitfall sampling unit, smaller arthropods, particularly Collembola, were not considered in the sampling even though many were trapped.

We realize the hazards involved in categorizing such diverse groups of forest floor arthropods in major or higher-level taxonomic groups that could be too heterogenous to serve as bases for conclusions regarding responses to environmental change (Huhta and others 1967), and that taxonomic generalizations may be misleading (Ahlgren 1974). Notwithstanding the difficulties and time-consuming identification at the species level (Ahlgren 1974), species groups rather than higher taxonomic groups appear to be the most appropriate units of study (Tolbert 1975). No doubt, species respond differently to treatments than do larger taxonomic units; the abundance of a single species may be considerably altered while the overall abundance of a particular group might be unaltered (Huhta and others 1967).

Numbers of various taxa collected are expressed in terms of the mean number of individuals per trap per collection period for each treatment. As Allen (1977) has noted, expressing the data this way compensates for loss of traps or trap contents, illegible labels, and the fact that all treatments were not sampled at precisely the same intervals during the three years. Data so expressed also in part compensates for the under dispersion of animal communities in the forest floor.

A modified sampling schedule was followed during each of the three years of this study even though all 196 plots were sampled at each sampling period. In 1975, we sampled on seven consecutive 2-week periods, beginning in early July and continuing through the middle of October. No sampling was done in the prescribed burn units in September. In 1976, we sampled for one 2-week period each in June, July and August. In 1977, a single sample was taken during a 2-week period in mid-June.

RESULTS AND DISCUSSION

During the 3-year course of this study, we trapped forest floor macrofauna representing five classes of arthropods and eight orders of insects. The most abundant animals were Coleoptera, Hymenoptera, and Araneida. Four arthropod groups were identified to class; Insecta were identified to orders, and the Coleoptera to family. At this time, no determinations have been made below the family unit. The groups are as follows:

- Chilopoda
- Diplopoda
- Phalangidae
- Araneida
- Insecta
    - Thysanura
    - Orthoptera
    - Hemiptera
    - Homoptera
    - Lepidoptera
    - Diptera
    - Hymenoptera
    - Coleoptera
        - Carabidae
        - Staphylinidae
        - Cerambycidae
        - Scolytidae
        - Curculionidae
        - Elateridae
        - Chrysomelidae
        - Tenebrionidae
        - Coccinellidae
        - Lycidae
        - Silphidae
        - Cicindellidae
        - Buprestidae
        - Cucujidae

Many of the groups were trapped very infrequently. We will present here the results of forest stand and residue treatment on six major categories: total fauna, total Coleoptera, Coleoptera families Carabidae and Staphylinidae, Hymenoptera (mostly Formicidae), and Araneida (spiders).

Seasonal Trends

There was a downward trend in the number of macrofauna during the season regardless of year or treatment. The trend in the undisturbed control areas during 1975 (figure 2) is representative of the seasonal trends in all units during 1975 and 1976.

In 1975, we began sampling in early July, and the peak of macrofauna abundance coincided with that sampling date. Sampling in 1976 began in June, and in that year populations were significantly higher in June than in either July or August, when populations were the lowest. A higher peak may also have occurred in June of 1975; however, both seasons featured the same downward trend in the number of total macrofauna.

Populations remained relatively high through mid-August of 1975, but dropped significantly during the last two weeks of that month. Most populations resurged rapidly again in early September, almost to the July level, but in late September and early October dropped off significantly. The resurgence in early September may have been associated with rain that fell in late August.

In clearcut areas, regardless of residue treatment, total fauna populations decreased during the season much more rapidly than they did in the undisturbed forest, but generally followed the same trend.

Effect of Treatment

The effects of harvesting and residue treatments on six groups of forest floor arthropods are displayed in figures 3-8. In each figure, the six columns of bars and illustrations represent the five treatments and control described earlier in the study design section. The top row of columns presents the mean number of arthropods per trap from four sampling periods between early July and late August in 1975, prior to when some units were burned. The second row presents mean numbers of fauna from three sampling periods--June, July, and August--in 1976. The third row presents data from one sampling period in June of 1977. In the subsequent discussion of treatment effects the word "significant" means statistically different at the 5 percent level of significance.

TOTAL FAUNA

In general, neither silvicultural nor residue treatment had any significant effect on total macrofauna during the first season after treatment prior to burning. Populations in all treatments, with the exception of treatment 2, a lower elevation

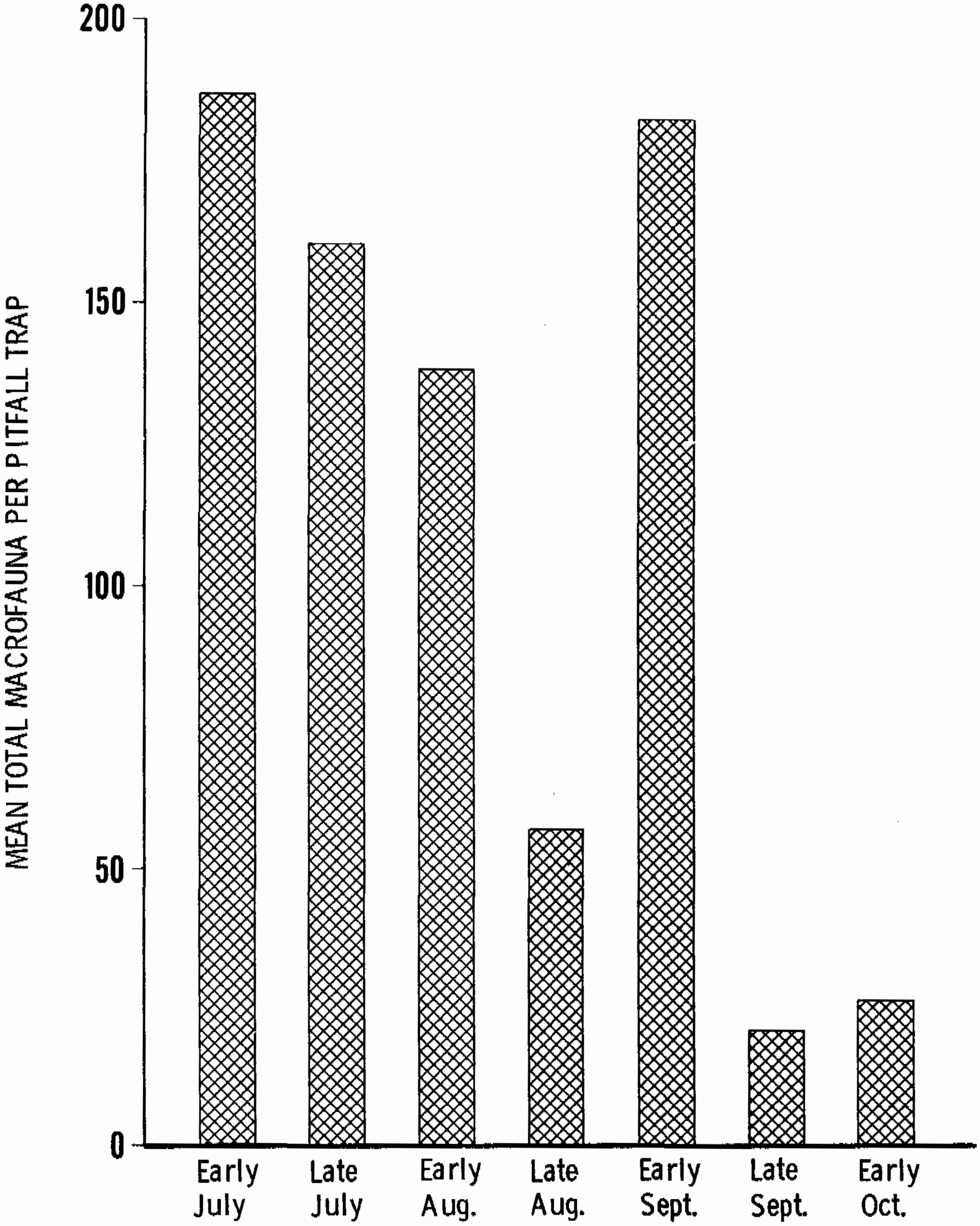

Figure 2.--Mean total macrofauna collected in pitfall traps during a portion of summer and early fall, 1975, in an undisturbed stand of western larch and Douglas-fir, Coram Experimental Forest.

shelterwood with residues, were significantly lower than populations in treatment 6, the undisturbed forest (figure 3, top). Though not apparent in figure 3, in September and early October, total faunal populations in treatment 4 were more than twice those in the undisturbed forest. Though not shown in the schematic in figure 3, with the exception of treatment 2 and one unit of treatment 4, total macrofaunal populations in all treatments and the undisturbed forest were significantly lower during the two sampling periods after the prescribed burn in early September. This population trend is shown for the undisturbed stands in figure 2.

In 1976, populations in the undisturbed forest, treatment 6, were significantly higher than those in any of the treatments; moreover there was no significant difference in populations between treatments (figure 3, center). It is of interest that in 1976, there was relatively no difference between treatment 2 and 3, where residues were either left or burned, respectively, in the shelterwood cuttings. Populations in 1976 were also very similar between treatments 1 and 4, where residues were mechanically removed in the shelterwood and clearcut, respectively.

Total macrofauna populations changed significantly in three treatments between 1975 and 1976. There was a significant and unexplained decrease in populations in treatment 2, where the residue remained in the shelterwood. Populations in shelterwood treatment 3 were significantly higher in 1976, while in the comparable treatment 5 in the clearcut, populations were nearly the same in both years. These data appear paradoxical, since the clearcut burned hot and thoroughly, while the shelterwood burned lightly and unevenly, due to an uneven distribution of residues. The other significant change came in treatment 4, where populations were about 25 percent lower in 1976.

In 1977, one begins to see what might be both a harvesting effect and a residue treatment effect. Populations in the undisturbed forest were still significantly higher than total macrofaunal populations in any of the 5 treated areas. However, there were some differences between the treatments. Regardless of residue treatments, populations in treatments 4 and 5 were significantly lower than those in treatments 2 and 3, but not significantly different from those in treatment 1. Populations in treatments 2 and 3, where shelterwood residues were left and were burned, respectively, remained about the same. In both the clearcut and the shelterwood, populations were not significantly different between areas where residues were mechanically removed or prescribed burned.

In comparing populations in June 1976 with those of June 1977, with the exceptions of treatments 2 and 3 and the control, populations in all treatments were significantly lower in 1977. However, when comparing all of 1976 to June 1977, populations in treatments 2 and 3 were not significantly lower. This is of interest since of all five treatments, treatment 2 was most nearly comparable to the undisturbed forest in terms of the impact of harvesting and residue treatments.

COLEOPTERA

In 1975, following cutting and prior to burning, Coleoptera populations were significantly higher in the undisturbed forests than in any of the treatments (figure 4, top); and there were only three significant population differences between the treatments. Where the residues were left, prior to burning, numbers were significantly higher in shelterwood treatment 2, than in shelterwood treatment 3, or clearcut treatment 5.

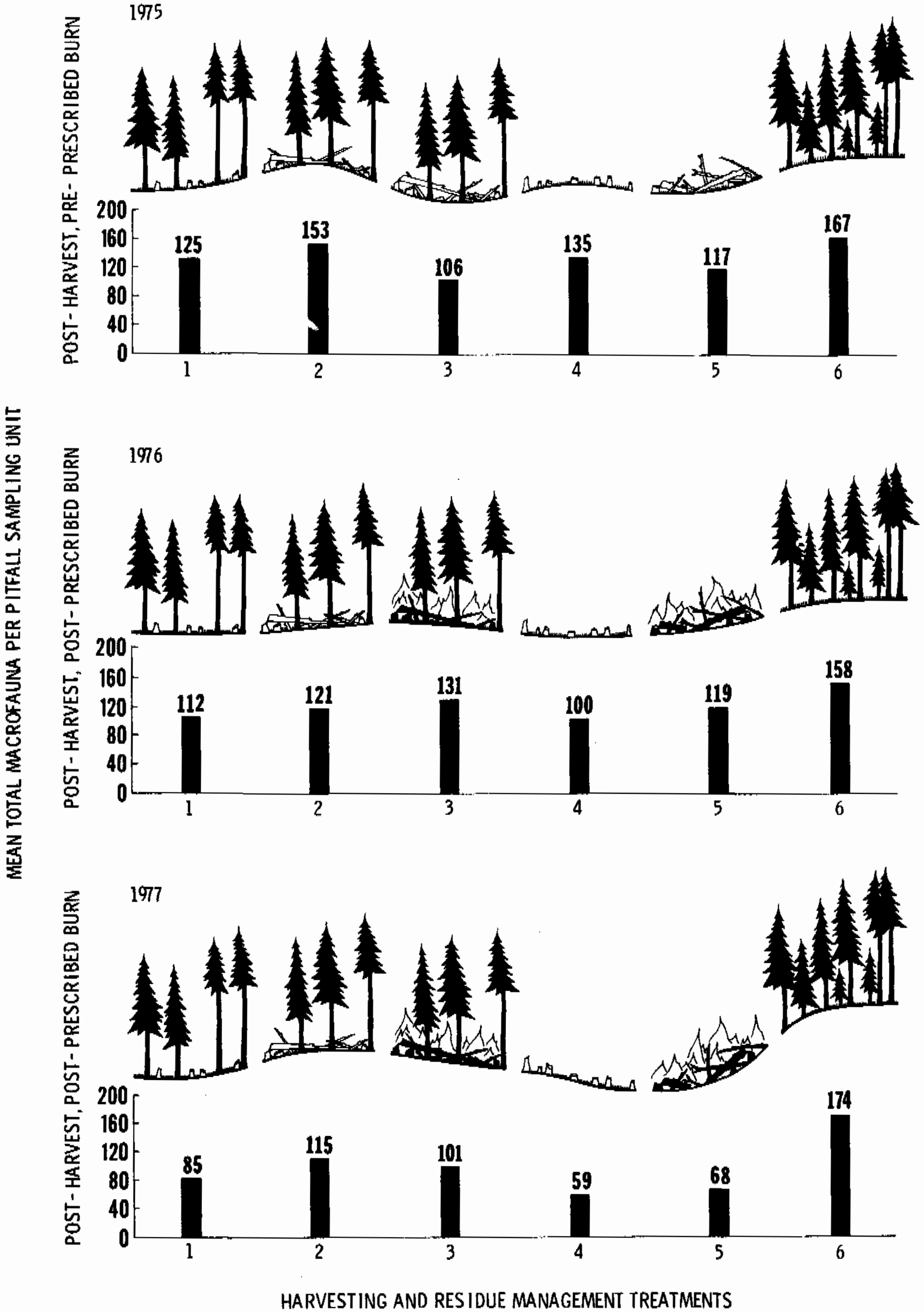

Figure 3.--Mean total forest floor macrofauna collected in pitfall traps in five harvesting and residue management treatment combinations and in adjacent undisturbed forests, Coram Experimental Forest.

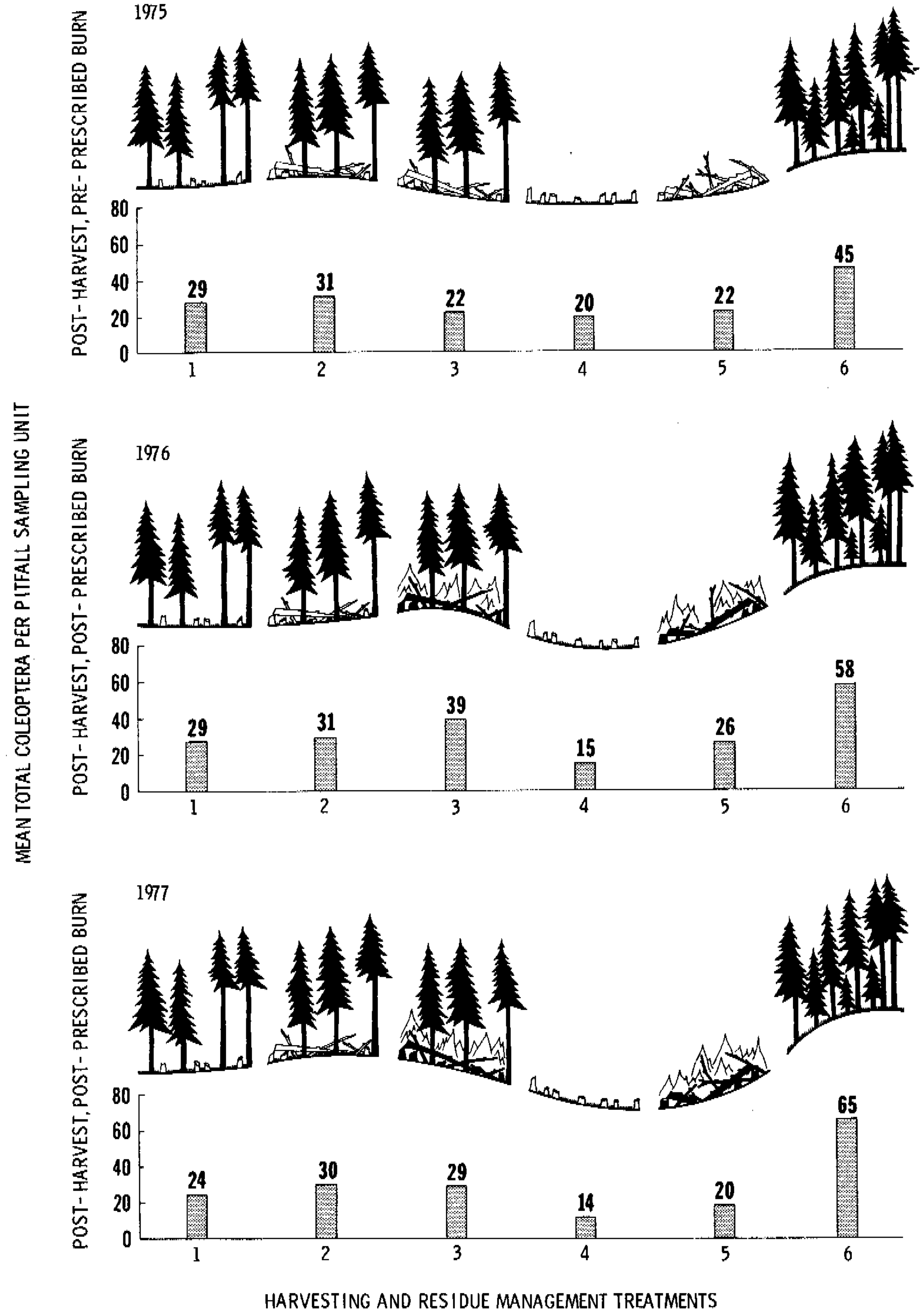

Figure 4.--Mean total Coleoptera collected in pitfall traps in five harvesting and residue management treatment combinations and in adjacent undisturbed forests, Coram Experimental Forest.

Mechanical removal of residues in the clearcut, treatment 4, significantly reduced total Coleoptera numbers as compared to mechanical residue removal in the shelterwood, treatment 1. Coleoptera populations were significantly lower in the two post-burn samples, compared to the last pre-burn sample in all six treatments, with the exception of treatment 4.

Populations remained significantly higher in the undisturbed forest than in any of the five treatments in 1976, with some population differences between treatments (figure 4, center). Populations in treatment 3 were higher than in any other treatment --significantly higher than in the shelterwood where the residue was not burned (treatment 2), the shelterwood with mechanical residue removal (treatment 1), and the burned counterpart in the clearcut (treatment 5). Treatment 4, where clearcut residues were mechanically removed had the most significant impact on Coleoptera populations in 1976.

Coleoptera populations remained essentially the same between 1975 and 1976, with the exception of significant increases in treatment 3 and the undisturbed forest (treatment 6).

Although for the third season in a row, Coleoptera populations in the undisturbed forests were significantly higher than in any of the treatments, there appeared to be a harvesting treatment effect, regardless of residue treatment in 1977. Both the shelterwood mechanical removal of residue (treatment 1) and residue burned (treatment 3) has significantly higher numbers of beetles than the clearcut counterparts, treatments 4 and 5, respectively. There was no significant difference in beetle populations between the residue treatments within the harvesting treatments.

For the most part, Coleoptera populations in all six treatments did not change significantly between 1976 and 1977. The most noticeable decreases were in those treatments (3 and 5) where the residues were burned.

CARABIDAE

Carabid populations did not differ significantly among treatments following harvesting and before burning in 1975 (figure 5, top). However, following burning, Carabids increased in the clearcut where residues were burned (treatment 5) and were significantly more numerous in the shelterwood where the residues had not been burned (treatment 2). There was no change in the shelterwood where the residues were burned (treatments 3).

Clearcutting and mechanical removal of residue had the most pronounced effect on carabid populations in 1976; populations in treatment 4 were significantly lower than in any other treatment. Treatment 2 had significantly higher populations than either of the other two shelterwood treatments 1 and 3. Between 1975 and 1976, populations in both treatment 2 and treatment 6, the control, increased significantly. Populations in the undisturbed forest were almost three times those in 1975.

The impact of clearcutting and intense fiber removal on carabid populations (treatment 4) was still pronounced in 1977. Populations in that treatment were significantly lower than in any of the other treatments. Although ground beetle populations in the undisturbed forest decreased in 1977, there was no significant change between 1976 and 1977 in any of the five treatments.

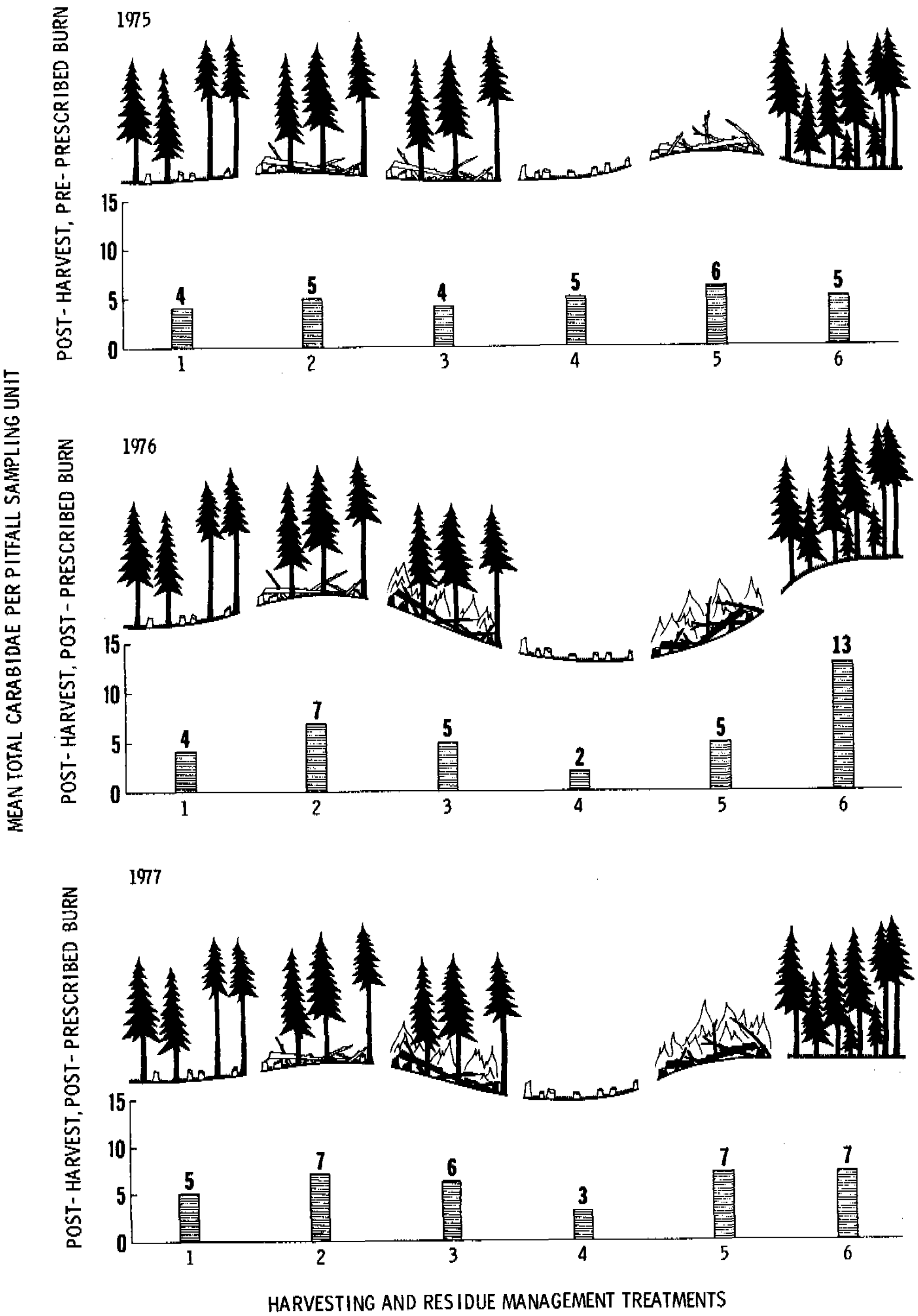

Figure 5.--Mean total Carabidae (Coleoptera) collected in pitfall traps in five harvesting and residue management treatment combinations and in adjacent undisturbed forests, Coram Experimental Forest.

STAPHYLINIDAE

As one might expect, population changes for staphylinids (rove beetles) were considerably different than for the ground beetles. In 1975, rove beetle populations in the undisturbed forest, treatment 6, were significantly higher than in any of the treatments (figure 6, top). Among the treatments, populations in the clearcut where residues were mechanically removed (treatment 4) were more severely and significantly impacted than those in the shelterwood counterpart (treatment 1). Among the treatments where residues were left, populations in treatment 2 were significantly greater than in either treatment 3 (also a shelterwood) or treatment 5 (clearcut).

In comparing staphylinid populations between the last pre-burn sample and the two post-burn samples in 1975, there were no significant changes in any of the treatments or in the undisturbed forest. In 1976, there appeared to be an effect of harvesting, though not of residue treatment on staphylinid populations. Rove beetles were significantly more numerous in all of the shelterwood treatments, especially treatment 3, than in either of the two clearcut treatments. There was no significant difference in populations between clearcut treatments 4 and 5.

From 1975 to 1976, populations increased significantly in all three shelterwood treatments but not in clearcut treatments 4 and 5; in the undisturbed forest (treatment 6) rove beetles increased by 50 percent. Because of the increase in the controls, the implications of increases in the three shelterwood treated areas is uncertain.

Effects of harvesting on rove beetle populations appeared to continue in 1977; populations in all three shelterwood treatments were significantly higher than the two clearcut treatments. However, a residue treatment effect was not apparent. There was neither a significant difference in rove beetle numbers among the three shelterwood treatments nor between the two clearcut treatments. In 1977, beetle populations were still significantly higher in the undisturbed forest (treatment 6) than in any of the other five treatments.

Between 1976 and 1977, populations in both burned treatments (3 and 5) and in the clearcut with mechanical residue removal (treatment 4) showed significant reductions. These population changes may have biological implications, since beetle populations in the controls remained stable between the two years.

ARANEIDA

Spider populations were relatively stable in 1975 (figure 7, top), but there were some treatment differences. Only two treatments (1 and 3) were significantly lower than the controls. In the intense fiber utilization treatments, spiders were significantly more numerous in the clearcut (treatment 4) than in the shelterwood (treatment 1). Spider population changes following burning in 1975 were inconsistent with respect to harvesting or residue treatments.

Population stability among the five treatments and the undisturbed forest continued in 1976, though there was an increase in numbers in all six treatments over 1975. Significantly higher populations in 1976 in treatments 3 and 5 would seem to

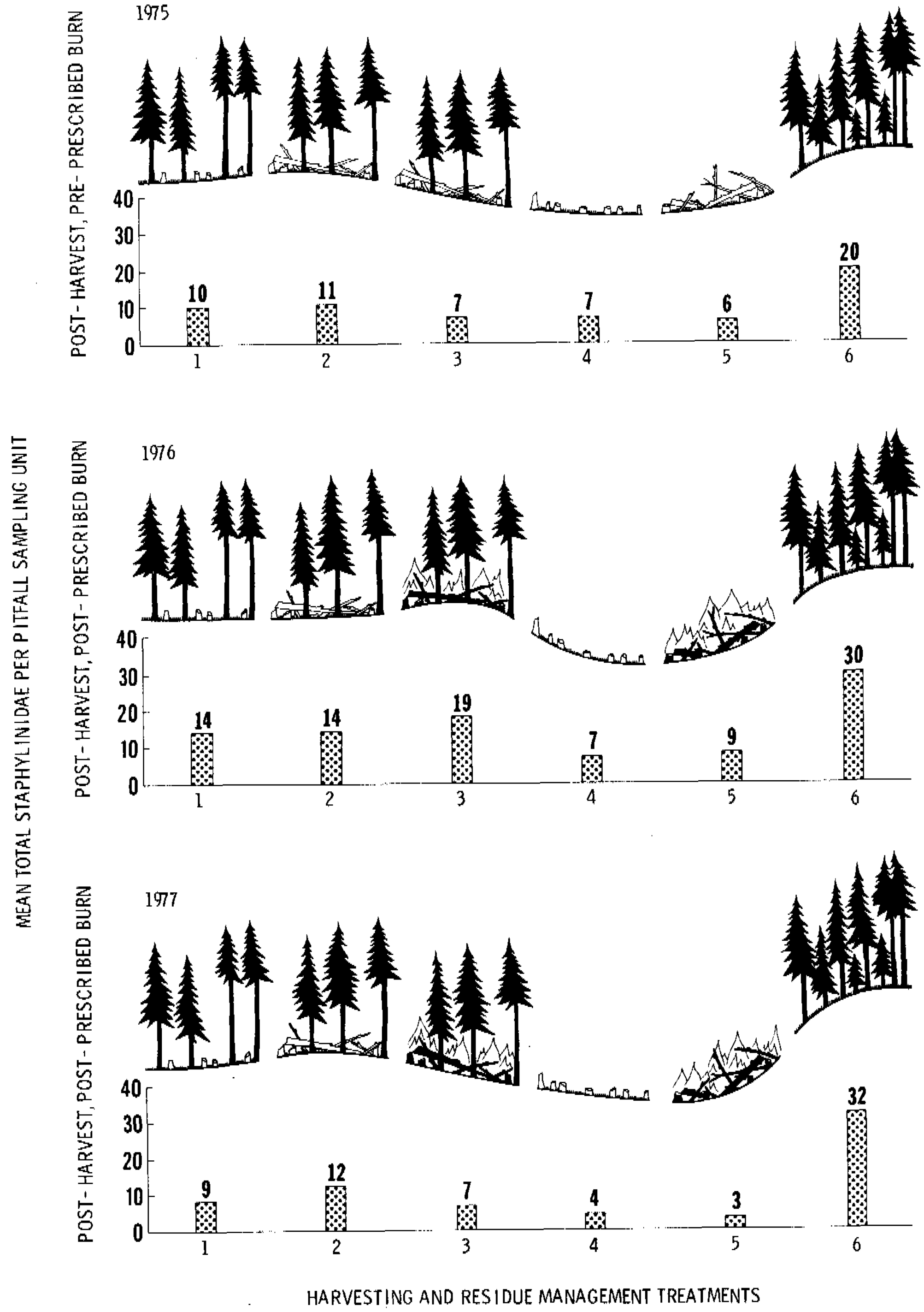

Figure 6.--Mean total Staphylinidae (Coleoptera) collected in pitfall traps in five harvesting and residue management treatment combinations and in adjacent undisturbed forests, Coram Experimental Forest.

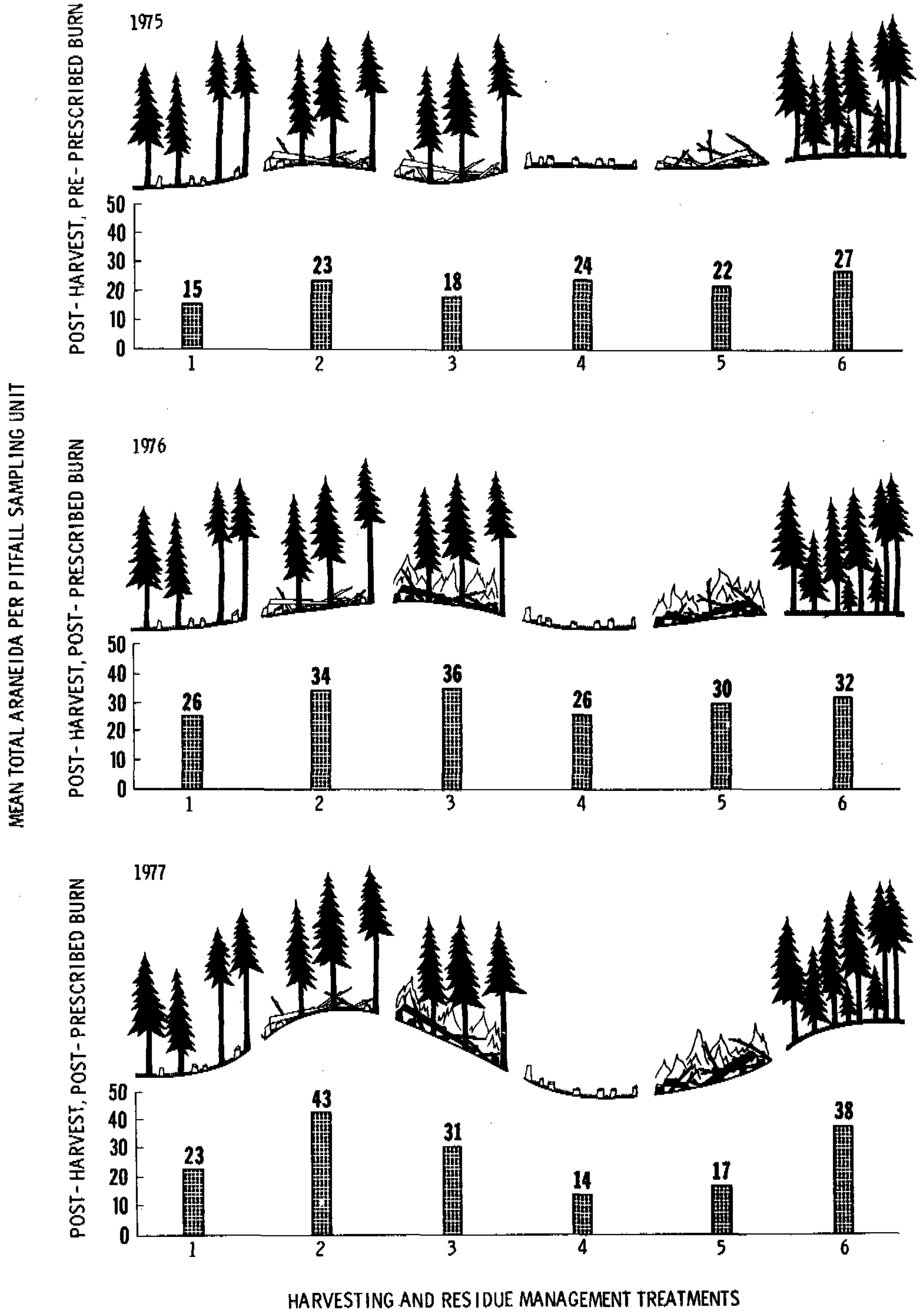

Figure 7.--Mean total Araneida (Arachnida) collected in pitfall traps in five harvesting and residue management treatment combinations and in adjacent undisturbed forests, Coram Experimental Forest.

indicate a treatment effect of burning. However, populations were also significantly higher in shelterwood treatments 1 and 2 which were not burned and where no other residue management had been effected between 1975 and 1976.

Both harvesting and residue management treatments seemed to have influenced spider populations in 1977. Populations in both clearcut units though not significantly different between them were significantly lower than those in any of the shelterwood treatments. Moreover, in both intense fiber utilization treatments (1 and 4), spiders were less numerous than in the respective residue burned treatments (3 and 5). As observed with other groups, the only treatments where spider populations were not significantly lower than those in the controls were treatments 2 and 3--the treatments that most closely resemble the undisturbed forest, especially treatment 2.

Clearcutting, regardless of residue treatments, effected the most dramatic change in spider populations between 1976 and 1977; in both treatments 4 and 5 spider populations decreased significantly by about 50 percent.

In the shelterwood, treatments 1 and 3 (counterparts of treatments 4 and 5 in the clearcut) also showed a decrease in spider populations between 1976 and 1977, though the change was insignificant and not nearly as pronounced as in the clearcut.

The significant decrease in spider populations on both clearcut units (and perhaps the shelterwood as well) between 1976 and 1977 may be indicative of a trend that could continue for several years. In a study in Finland, Huhta (1976) concluded that, "...for at least the first 7 years after felling, the succession of the spider community in a clearcut area continues to proceed in a retrogressive direction; i.e., diverging from the original state prevailing in a climax spruce stand."

HYMENOPTERA (FORMICIDAE)

Of all the animal groups, the Formicidae (ants) seemed to have responded most dramatically to some of the harvesting and residue management treatments.

Clearcutting and mechanical removal of residue (treatment 4) appeared to have affected ant populations most significantly the year after treatment (figure 8, top). In 1975, populations in treatment 4 were significantly higher than those in the undisturbed forest as well as those in all the other treatments. However, in the last two sampling periods in 1975, ant populations in treatment 4, as well as those in the shelterwood counterpart (treatment 1) decreased significantly.

In both the clearcut and shelterwood units, burning the residues (treatments 3 and 5) caused a significant resurgence in ant populations in the early fall following the burning; the most striking increase occurred in the clearcut treatment 5. Since this change is not graphically illustrated in figure 8 (top), figure 9 shows formicid populations throughout the season of 1975, pre- and post-burn for treatments 4, 5, and 6.

For these three treatments, ant populations remained relatively the same from early July to late August. Populations were most abundant in treatment 4, and nearly the same in treatments 5 and 6, at least from late July to early August. These same relationships can also be observed in treatments 4, 5, and 6 in figure 7 (top). In all three treatments, however, ant populations diminished steadily during the four

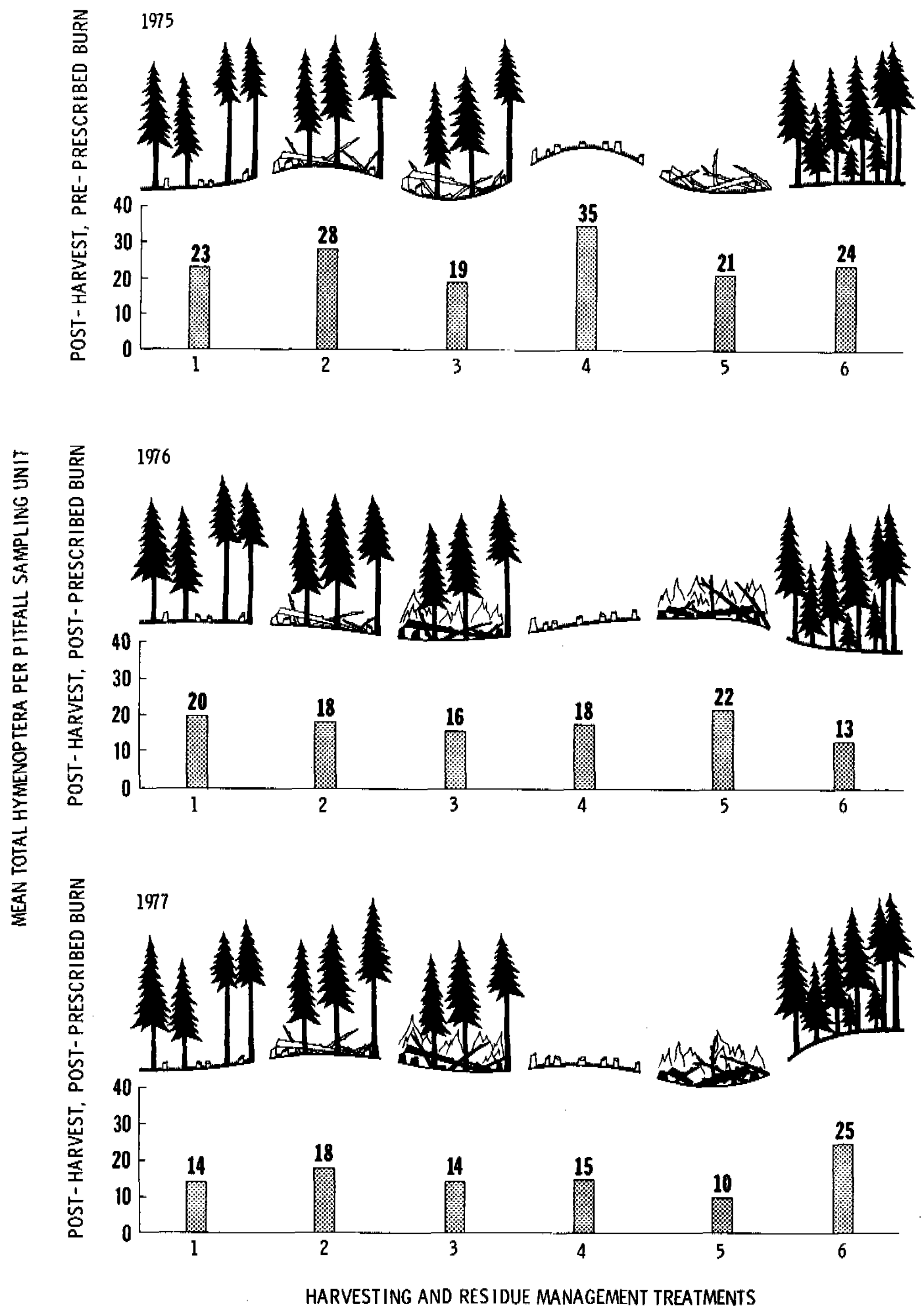

Figure 8.--Mean total Hymenoptera (mostly Formicidae) collected in pitfall traps in five harvesting and residue management treatment combinations and in adjacent undisturbed forests, Coram Experimental Forest.

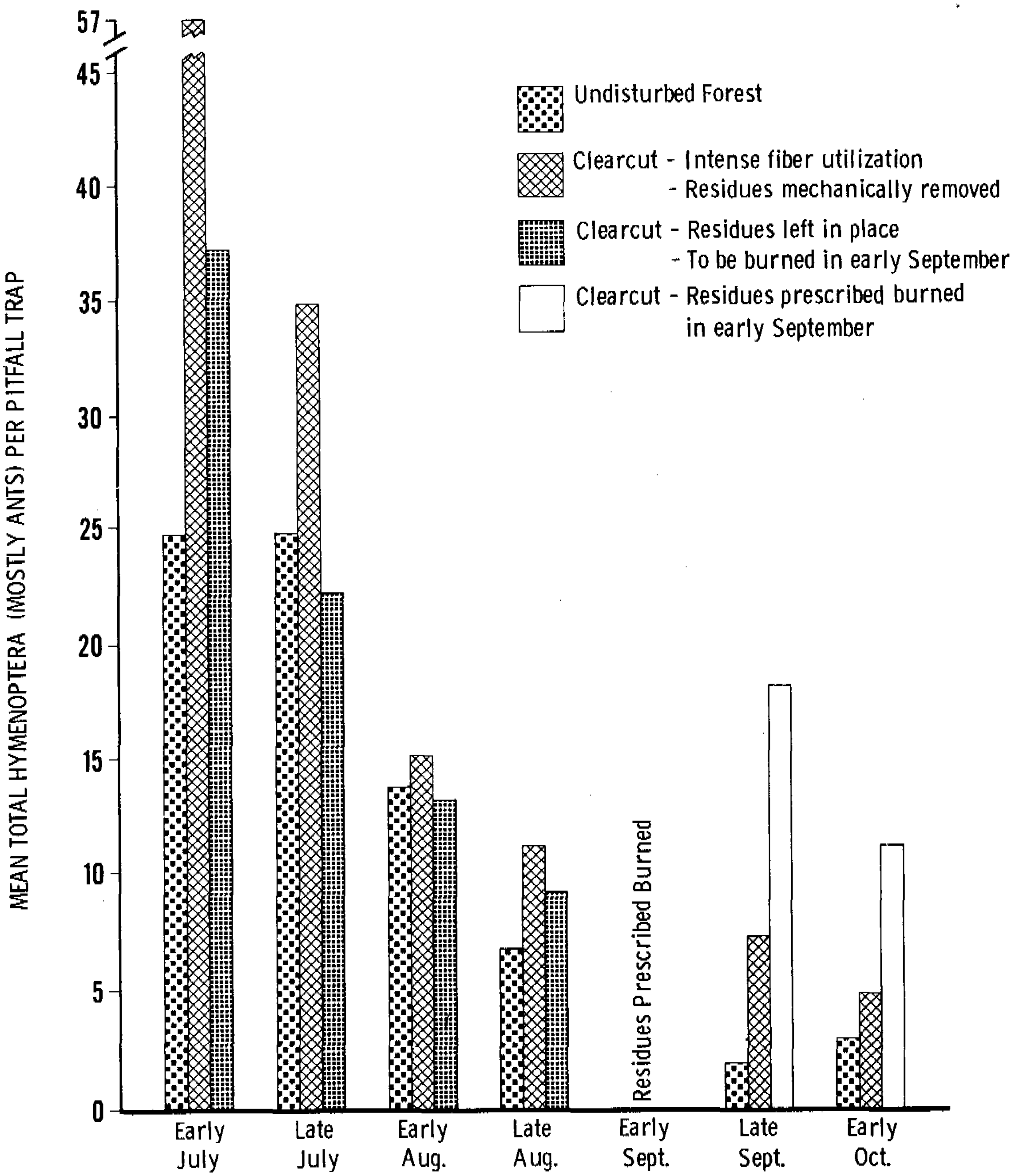

Figure 9.--*Hymenoptera populations (mostly Formicidae (ants)) in 1975 on undisturbed forests (treatment 6) and on clearcut forests where residues were mechanically removed (treatment 4) or where the residues were left in in place (treatment 5) until early September when they were prescribed burned.*

sampling periods, and by late August, were not significantly different. Residues in the clearcut were burned in early September, during which time no samples were taken.

The last two histogram sets in figure 9 show Formicidae populations in all three treatments after the prescribed burn in treatment 5 in early September. Ant populations in both the undisturbed forest and in treatment 4 decreased significantly between the pre-burn sample in late August and the two post-burn samples in late September and early October. However, in treatment 5, where residues had been burned, ant populations in the first sampling period after burning were 10 times greater than in the undisturbed stand, and 2.5 times more numerous than in clearcut treatment 4, where no burning had been done. Although not as striking, the same trend continued into early October.

The resurgence in formicid populations on the burned units was short-lived. Notwithstanding the significantly higher populations in treatment 5 compared to treatment 6 in 1976 (figure 8, center), populations of ants in 1976 on both treatments 3 and 5 were not significantly different from populations on these same treatments in 1975 (figure 8, top). Ant populations in treatments 3 and 6 were not significantly different in 1976, probably reflecting a less significant resurgence (as compared to that of treatment 5).

Besides a significant decrease of nearly 50 percent in ant populations between 1975 and 1976 in treatment 6, populations also decreased significantly in treatments 2 and 4 between the two years.

Clearcutting and burning residues, a practice that stimulated ant populations following burning in 1975, seemed to have the most debilitating effect of all the treatments 2 years later. By 1977, ant populations were less than half as abundant as in either 1976 or 1975 and significantly fewer than on any of the other treatments in 1977, including the shelterwood burned treatment 3.

Although we have not done it with other groups, it is interesting to compare ant populations in 1977 (figure 7, bottom) with those in 1975 (figure 7, top). The control populations are essentially the same (treatment 6). However, on all other treatments populations are lower in 1977; on the shelterwood treatments, they are down about 30 percent and on the clearcut treatments about 55 percent of what they were in 1975. Although populations are lower in 1977, the three shelterwood treatments and the two clearcut treatments have essentially the same relative population levels each season.

SUMMARY

The results of this study indicate that groups of forest floor macrofauna responded somewhat differently to the direct and indirect effects of harvesting and residue management practices. Although some populations increased between treatments or years, most treatments adversely affected most groups of macrofauna particularly noticeable the second and third year after burning and harvesting, respectively.

In 1975, one season after harvesting but before prescribed burning, populations of most taxa were significantly lower in the treatments than in the undisturbed forest, with three exceptions: (1) Carabid populations were essentially the same throughout all six treatments; (2) In only two shelterwood treatments were spider populations lower than those in the undisturbed forest; and (3) Formicids were equally abundant in all treatments with the exception of the clearcut, and intense fiber removal where numbers were significantly higher than all other treatments.

Prescribed burning in the fall of 1975 affected macrofaunal groups differently. Populations of some groups decreased, while others remained the same. Carabids were significantly more abundant in the clearcut following burning of residues; however, during the same period, they also increased on one shelterwood where residues were not burned. In the clearcut especially, but also in the shelterwood treatment, prescribed burning caused a significant resurgence in ant populations following the prescribed burning.

In many cases, populations of some taxa in shelterwood treatments where residues were left unburned on the forest floor, responded in a manner very similar to populations in the undisturbed forest. This may not be unexpected since this was the least "drastic" of the five cutting and residue treatments.

With the exception of spider populations which remained stable, and the numbers of ants that resurged on the burned units, populations of all taxa on the treated areas were significantly lower in 1976 than populations in the undisturbed forests.

In 1977, 3 years after harvesting and 2 years after prescribed burning, populations of all taxa were significantly lower on the treated areas than in the adjacent undisturbed forests. However, in all cases populations of all groups were higher in the shelterwood unit where the residues had not been burned (treatment 2) than in any of the other four treatments. Spider populations in treatment 2 were, in fact, more abundant than those in the undisturbed forest.

With some taxa, in both 1976 and 1977, there appeared to be both a harvesting effect and an effect of residue management. In many cases, populations in the three shelterwood units were higher than those in the two clearcut units, regardless of residue treatments. In other cases, populations in the treatments where the residue was mechanically removed (treatments 1 and 4) were significantly lower than in the two treatments where residues were burned (treatments 3 and 5) regardless of the harvesting system.

With most groups, arthropods are most adversely affected by those harvesting and residue manipulation practices that most drastically alter the forest environment. Clearcutting is a more disruptive practice than shelterwood cuttings and in most cases, the intensive and complete removal of residues from a forest have a more adverse effect than either leaving or burning the residues. In general, one could rank the 5 treatments from least harsh to most harsh in the following order: 2, 3, 1, 5 and 4.

The 3-year period covered by this investigation was too short to allow us to determine the long-term effects of these harvesting and residue treatments on the taxa studied. A complete understanding of the effects of these treatments and the length of time required for arthropod populations to stabilize at pre-treatment levels would require a detailed long-term study of all animal species in the forest floor.

MANAGEMENT IMPLICATIONS

The combined effects of residue management practices and harvesting systems in coniferous forests not only directly influence forest floor macrofauna, but also indirectly by modifying the environment in which these and other important forest insects live. The difficulties of analyzing treatment effect have been summarized by Huhta (1971) as follows:

> Catastrophes in an ecosystem, such as deforestation or burning, alter nearly every environmental factor, biotic or abiotic, interacting in such a complex way that it is very difficult to distinguish the factors which principally account for the changes in the animal communities. To discover the primary causes of the changes in the population densities of the different species or of the successional trends of the whole community, accurate information would have to be acquired about the habits and responses of each component species to each factor at the different stages of their life cycles, together with detailed long-term microclimatic records not only in the habitat in general, but also separately in the particular microhabitat of each species.

Such detailed studies were beyond the scope of the investigation reported in this paper.

Intense removal of fiber, especially in clearcuts, seems to significantly reduce the populations of some taxa, particularly two and three seasons after harvesting and residue removal, but we cannot now predict the complete significance of this reduction because so many groups are involved, and we have only determined the taxa involved to groups at the family level or above. Groups involved are those responsible for the mechanical degradation of residues and for providing entry courts for decay micro-organisms. Other groups are phytophagous, feeding on seeds and other plant tissues and others are very effective predators. Further complicating the complete interpretation of the treatment implications is a general lack of information on food chains, interorganism relationships and the biology and ecology of the species involved. Other investigators have reported that 100 percent tree removal and residue utilization ultimately leads to impoverishment of sites (Moore and Norris 1974). In Europe, some stands with a history of repeated removal of litter from clearcuts have been observed to be either chronically infested with forest pests or predisposed to recurrent mass infestations (Francke-Grosmann 1963).

Some investigators have reported that the most important factor influencing succession of fauna in clearcut areas is whether the felling residues are left on the site or removed (Huhta and others 1967).

Prescribed burning of residues, particularly in clearcuts, also severely impacts many groups of forest floor fauna by directly killing the organisms as well as removing the residues and forest litter required by these insects for food and shelter. In other coniferous forests "burning over" of residues is very destructive to all groups of forest floor arthropods because of the heat produced and the bulk of some populations may be destroyed (Huhta and others 1967). Some animals, depending on litter for food, have become "extinct" in burned over areas once litter remaining after burning had decomposed (Huhta and others 1967). Other investigators report that with the exception of mesofaunal species and spiders, population reductions do not seem to be directly caused by heat of fire (Ahlgren 1974). The direct effect of fire on forest floor macrofauna is greater in the forest environment than in grasslands, not only because of the more abundant fuel in forested areas (Ahlgren 1974), but because "grassland" species probably have evolved with more frequent fires.

Perhaps one of the more significant implications of harvesting and residue management practices on forest floor macrofauna is the indirect effect of these forest practices on the interrelationships of several groups of forest floor arthropods with the western spruce budworm, Choristoneura occidentalis Freeman, the most widespread and destructive forest defoliator in the northern Rocky Mountains. There are perhaps two implications: (1) many species of forest floor arthropods are predators of the spruce budworm, particularly in the egg, larval, and pupal stages; (2) some species of budworm parasites may be "forest floor" inhabitants for only a portion of their life cycle, perhaps using understory broadleaf vegetation or forest residues as an alternate host or substrate.

The role of predators and parasites as full-time or part-time inhabitants of the forest floor is not one of "controlling" outbreaks of the western spruce budworm (or any of the other coniferophagous Choristoneura species) but perhaps in regulating low-level populations. Although dozens of native insects and spider species eat spruce budworm (mostly their eggs and small larvae), none is recognized as a prospective agent for biological control (Miller and Varty 1975), and "there is little hope of using parasites and predators in a biological control context against the budworm species" (McKnight 1976). In full-blown epidemics parasites and predators do not seem to influence defoliation (Varty 1976) and have little influence in moderating explosive populations (Renault and Miller 1972; Allen 1968; Miller and Varty 1975). This is because predators and parasites (1) are unable to respond to changes in pest abundance, and (2) have critical habitat requirements and quickly reach population levels beyond which they cannot rise, no matter how easy it is to find budworm prey (Miller and Varty 1975).

Predators and parasites may help to regulate budworm numbers when there are only a few thousand larvae per acre--perhaps 5,000-50,000 larvae--or when budworm populations are just above the norms of epidemic status of about 100,000 larvae per acre (Varty 1976; Miller and Varty 1975). In non-epidemic years, the eastern spruce budworm is usually scarce, inconspicuous and totally harmless; evidently natural control mechanisms can be effective for decades (Miller and Varty 1975).

Of the forest floor arthropods influenced by harvesting and residue management that could be involved in naturally regulating spruce budworm populations, several species of ants, spiders, and ground beetles probably are the most significant. In the Lake States where the ant species Formica exsectoides is extremely abundant, it undoubtedly helps maintain low populations of the jackpine budworm (Allen 1968). This Allegheny mound ant is associated with the jackpine budworm only where soils are suitable (sandy and well-drained) for nest building and where stands are open enough to permit sunshine to reach the forest floor (Allen and others 1970). Another species, Camponotus noveboracensis, is a frequent predator of the jackpine budworm on the boles and branches of jackpine in stands where excessive ground vegetation and lack of insulation on the forest floor do not prohibit nest building (Allen and others 1970).

In a Montana study of ants and the western spruce budworm, Bain (1974) found nests of Formica criniventris located on the edges of clearings or other open spaces in stands in full sunlight, while nests of another species, F. obscuripes, were associated with more shady conditions. In the present study, the significant resurgence of ants following residue removal by prescribed burning could have some residue management impacts. Ants are apparently highly adapted to hot, xeric conditions of early postfire topsoil and their cryptic habits enable them to survive fire below the level of intense heat. Their rapid reestablishment on burned forests is also aided by their colonization habits and social organization. Miller and Varty (1975) report that it is remotely possible that in young stands, the introduction of European red ants might have some potential against the eastern spruce budworm.

Some species of Carabids have been recently reported as predators of spruce budworm larvae. In two white spruce plantations near Sault Ste. Marie, Ontario, a species of Calosoma has been observed crawling over the foliage and eating budworm larvae. Although no quantitative data is available on the impact of these carabids on budworm populations, investigators (Sanders and van Frankenhuyzen 1979) feel that the size, numbers and manner of searching the current foliage suggests that the beetles may have played an important role in reducing spruce budworm populations in these two white spruce plantations.

Another study indicates that some species of ground beetles are efficient predators of spruce budworm larvae that reach the forest floor (Krall and Simmons 1977, 1979). This happens most commonly when all the new foliage has been consumed and budworm larvae spin down to the ground or low vegetation.

Other investigators are continuing studies of carabids and the eastern spruce budworm. As a portion of a larger study of natural enemies of the eastern spruce budworm (Jennings and others 1979), Reeves and Jennings (1977) are studying carabid beetles associated with the spruce budworm. One of their objectives is to determine if stand composition and spruce budworm infestation can be correlated with carabid beetle populations.

Although invertebrate forest floor macroarthropods may be effecting only a regulatory effect on the spruce budworm when it is at low densities, perhaps their greatest impact, at all population levels, concerns predation on dispersing stage I and II larvae. In other phases of our research, we are studying the influences of various silvicultural and harvesting practices on the behavior of dispersing western spruce budworm larvae (D. G. Fellin unpublished research).

We are determining the relationships between types of cutting, aspects, slope and size of cutting units, and relationships of cuttings to sources of infestation and the dispersal of western spruce budworm larvae and subsequent impact on regeneration. We will soon be integrating the results of these budworm dispersal studies with the results of harvesting and residue management on forest floor fauna presented in this paper.

Indirectly, the effects of harvesting and residue management practices will affect forest floor fauna as they respond to changes in vegetation and the microclimate.

Forest floor vegetation will progressively have a greater influence on surface animals as treated areas begin to regenerate with both broad-leaves and conifers. In another paper in this proceedings, Schmidt (1980) reports on the response of understory vegetation to harvesting and residue management practices. However, he indicates that the significance of differential understory responses in relation to entomological and other biological systems will be the subject of further analyses.

New vegetation and the litter produced by it may differ considerably from that of the previous undisturbed forest, and an entirely new group of forest floor fauna may become established (Huhta and others 1967). As the new forest develops, forest floor fauna will progressively attain a "steady state"; however, a long time will pass before the forest floor fauna is quantitatively and qualitatively what it was prior to treatment. The return to a "steady state" or "normal association" between a forest and forest floor fauna depends on the relationship of the treated area to the undisturbed forests. Some research shows that the distance between treated areas and the undisturbed stand as well as the size of the area treated are both significant in the interpretation of treatment effects on forest floor arthropods (Newmann 1971). Others indicate that forests surrounding treated areas are important in retarding colonization by species of spiders from open habitats, which have to overcome the barrier as aeronauts, while species of semi-open habitats, occurring sporadically in surrounding forest stands, have the advantage that they can invade the area by land (Huhta 1971). A third investigator concluded that spiders move freely between burned prarie areas and unburned patches, and vice versa, since they collected more individuals in transects near the periphery of burned areas than in transects located toward the center (Riechert and Reeder 1972).

The indirect influence of changing the microclimate depends on the condition of the stand prior to treatment. The removal of all or part of either a dense coniferous stand or of the subsequent residues where the forest floor is heavily shaded will have more striking effects than the manipulation of a more open-grown stand, where more light reaches the forest floor and where understory vegetation may be more abundant. These harvesting and residue practices, particularly clearcutting, disrupts both diurnal and seasonal fluctuations of many physical factors, principally temperature, moisture, light intensity, wind, and humidity. Some animal groups, unable to tolerate the new microclimate, are at a disadvantage and disappear. Other groups, perhaps by their ability to reproduce rapidly, can survive the environmental change and may even benefit as a result of treatment.

In another paper in this proceedings, Hungerford (1980) discusses the micro-environmental response to harvesting and residue management. He indicates that following harvesting, on several sites surface conditions such as radiation load and temperature have reached lethal levels. In other cases harvesting has aggravated and created frost pockets. Both temperature extremes, and radiation load and other factors must certainly influence forest floor arthropods.

At this time we are only able to discuss some general management implications of the effects of harvesting and residue management on forest floor fauna, based on our own research and interpreting related research of others. The full management implications of these forest insect studies will only be completely realized when results have been completely integrated with the results of closely-related studies in other disciplines.

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POPULATIONS OF SOME FOREST LITTER, HUMUS, AND SOIL ARTHROPODS AS AFFECTED BY SILVICULTURAL PRACTICES, RESIDUE UTILIZATION, AND PRESCRIBED FIRE

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ABSTRACT

The combined effects of two silvicultural practices--shelterwood and clearcutting--and two residue management practices--intense fiber removal (utilization) and residue removal by prescribed fire--on forest litter, humus, and soil arthropods (mesofauna) are discussed. Arthropods most abundant on the study area and most affected by treatment were mites (Arachnida, Acarina) and springtails (Insecta, Collembola). These and other arthropods collected are listed and their seasonal and vertical distribution presented. Preliminary results of these four treatments are presented, and the management implications of the harvesting and residue utilization treatments discussed.

KEYWORDS: silviculture, forest residue, fire, arthropods, mesofauna

INTRODUCTION

Silvicultural practices modify the tree component of the forest by removing all or part of both the coniferous overstory as well as the understory. Management of the resultant residues, including prescribed fire, chiefly modifies the forest floor and forest soil component by removing or destroying both man-generated residues as well as natural forest residues, often eliminating or seriously influencing the litter and decomposition layers of the forest floor.

These silvicultural and residue management practices affect many species of insects and other arthropods involved in the initial breakdown of woody materials, a process vital to reforestation.

Recycling of minerals in forest residues is an intricate process that begins with the fragmenting of dead material into progressively smaller pieces, followed by decomposition into substances that enrich the soil. Although decomposition is largely a microbial process, its success depends heavily on the initial fragmentation of the material, which is largely done by arthropods, beginning with beetles and other macro-arthropods, and continuing with the mites, Collembola, and other mesofauna[1] (Mitchell and Sartwell 1974).

The forest floor and forest soil fauna include diverse species representing several classes of arthropods and orders of insects, each with its own unique, and not mutually exclusive role in the forest ecosystem. Because of their innocuous ecological niche, but also because other more dramatic and population-explosive species or groups of insects have had "higher visibility," literally and figuratively, relatively little is known of the identity, distribution, abundance and general ecology of that group of forest insects that inhabit the surface and decomposing layers of the forest floor and the upper layers of soil.

One purpose of the Forest Residues Research and Development Program that is the subject of this symposium was to determine the environmental consequences of the combined effects of harvesting methods, silvicultural prescriptions, and residue management.

Two entomological studies were conducted as part of that Program. A portion of the results of one study are presented in this paper (Fellin 1980c). This study is restricted to those soil surface and forest soil arthropods, mostly intermediate in size and often referred to as soil mesofauna (Metz and Farrier 1971). The primary objective of this study was to determine and evaluate the combined effects of harvesting methods, silvicultural prescriptions, and forest residue management, including prescribed fire, on quantitative and qualitative characteristics of arthropods inhabiting the soil surface and forest soil (soil mesofauna). Secondary objectives were to determine: 1) rate of population re-establishment following treatments; 2) vertical distribution of mesofauna and 3) seasonal changes in taxa in the various treated areas.

Reported elsewhere in this proceedings (Fellin 1980b) are the results of the other entomological study that was concerned with the effects of harvesting and residue management practices on forest floor macrofauna, which are larger arthropods usually greater than 10 mm in size (Wagner and others 1977).

This proceedings also includes a review of some relationships of harvesting, residue management, and fire to forest insects and diseases (Fellin 1980a). That review paper offers a summary of past and current research concerning the effects of forest practices on forest soil mesofauna and forest floor macrofauna.

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[1] Mesofauna, as defined by Metz and Farrier (1971) and Ahlgren (1974), are the intermediate size soil organisms and include fauna such as mites, collembolans and other small (100 µ - 1 cm) arthropods, as compared to microfauna which usually includes protozoa and nematodes (less than 100 µ) and macrofauna (generally larger than 1 cm) such as earthworms, snails, some spiders, beetles and ants. Soil mesofauna include those animals that reside in the forest floor and mineral soil, and spend their life cycle in either zone or move back and forth between the two.

STUDY DESIGN

The study area is located on the 3 019 ha (7,460 acre) Coram Experimental Forest, on the Hungry Horse District of the Flathead National Forest. It is accessible from U.S. Highway #2 at Martin City and lies about 40 km (25 miles) northeast of Kalispell. The cutting units were established along the main ridge facing east into Abbott Basin, sections 25, 35, and 36; T31N, R19W (48°25' north lat., 113°59' west long.). Timber was harvested in 1974 using one or more running skyline systems, and the residues broadcast burned in the fall of 1975.

The study area falls primarily in the Abies/Pachistima habitat type,[2] with a lesser amount along the bottoms within the Thuja/Pachistima habitat type. The mountain slope soils are from impure limestone underlying material of loamy-skeletal soil families.[3] Slopes on the cutting units range in steepness from 30 to 80 percent (17 to 39°) and average about 55 percent (29°). Elevation ranges from 1 189 to 1 585 m (3,900 to 5,200 feet) m.s.l.

Six cutting units or blocks were harvested, originally designed to provide two replications of three basic silvicultural systems as follows (figure 1):

(1)	Shelterwood	-- Block 11	12 ha	(30 acres)
		-- Block 21	9 ha	(22 acres)
(2)	Group Selection	-- Block 12	0.5 ha	(1.2 acres)
		-- Block 22	0.5 ha	(1.2 acres)
(3)	Clearcut	-- Block 12	6 ha	(15 acres)
		-- Block 23	6 ha	(15 acres)

In addition, two Control Blocks, 14 and 24, were established in the adjacent uncut mature forest.

Within each silvicultural treatment, four residue management treatments were superimposed. The residue subunits, designed to represent four basic levels of utilization, are as follows:

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[1] Based on a habitat type survey completed in 1969 by Robert D. Pfister.

[2] Based on a soil survey completed in 1969 by R. C. McConnell.

Subunit	Trees to be Cut	Utilization Standard	Site or Seedbed Treatment
1	All designated sawtimber; all understory trees.	Intensive log utilization. Remove all material (live & dead, standing & down) to 3" dia., 8' length, & 1/3 sound.	Broadcast burn.
2	All designated sawtimber; all understory trees.	Conventional log & tree utilization. Remove sawtimber material (live & recently dead) to current NFS sawlog merchantability standards--6"--dia., 10 bd. ft., 1/3 sound.	Broadcast burn.
3	All designated sawtimber; all understory trees. (All slash removed.	Intense fiber utilization. Remove all material (live & dead, standing and down) to 3" dia., 8' length, and 1/3 sound.	Leave as is. (All slash removed.)
4	All designated sawtimber.	Leave submerchantable understory. Remove all material in sawtimber trees (live & dead, standing & down) to 3" dia., 8' length, and 1/3 sound.	Leave as is.

The entomological study followed the overall study design as presented above and shown in figure 1, with three major exceptions:

1. Our study was restricted to one shelterwood unit, Block 21, one clearcut, Block 23, and one control unit, Block 24. We did not consider the group selections--principally because of their small size--nor shelterwood Block 11, clearcut Block 13, or control unit Block 14.

2. Within the shelterwood unit Block 21 and the clearcut Block 23, we considered only subunits 1 and 3. Although there were two utilization standards prescribed, as subunits 1 and 2, the amount of residues left in those units and the broadcast burning in the two units was very similar, so we considered these as a single subunit. Subunit 4 was not considered primarily because of the difficulty of removing residues in the clearcuts with the skyline harvesting system.

3. This entomological study did not begin until the fall of 1975. Therefore, no measurements were made prior to or during the harvesting in the summer of 1974, nor following harvesting during the summer of 1975. The first measurements were made in early September 1975, immediately prior to the prescribed burning.

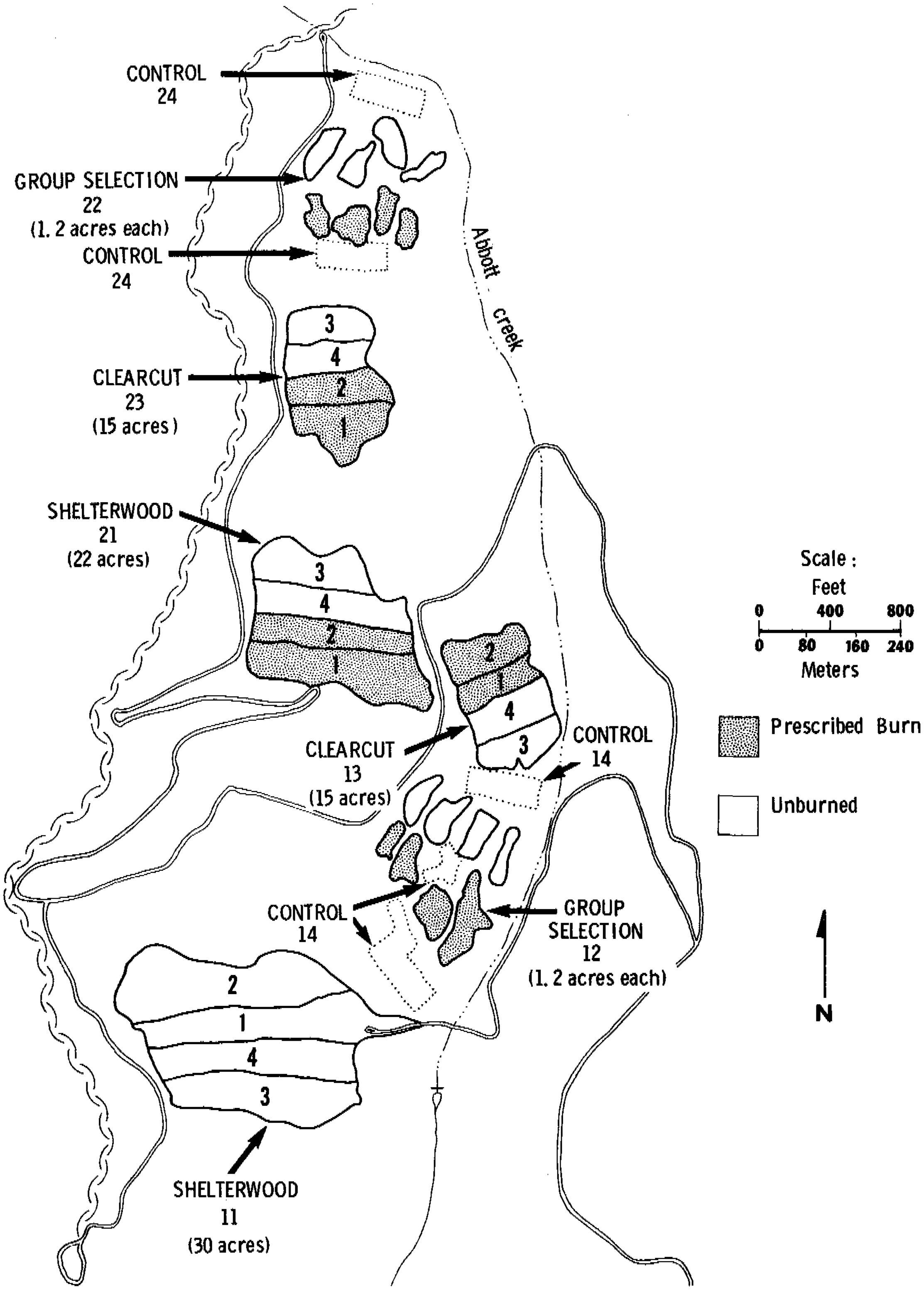

Figure 1.--Coram Experimental Forest Abbott Creek Watershed, a study area for evaluation of alternative harvesting and residue utilization practices showing: location of cutting blocks, residue management subtreatments within the cutting blocks, control areas, access roads, Abbott Creek, and main ridge.

Considering the planned and unplanned modifications to the study plan, our study design was based around four combinations of harvesting and residue treatments and a control, as follows:

Treatment	Silvicultural Prescription	Block #	Residue Treatment	Subunit
1	Clearcut	23	Residues burned	1
2	Clearcut	23	Residues mechanically removed	3
3	Shelterwood	21	Residues burned	1
4	Shelterwood	21	Residues mechanically removed	3
5	Undisturbed forest	24	None	5

Sampling Design and Plot Layout

To facilitate the pre- and post- harvest sampling activities of all the involved disciplines and studies, a permanent plot location system was established on each of the cutting blocks. Permanent points were systematically located at 30.5 meter (100 ft) intervals within each of the subunits in the clearcut and shelterwood blocks and at variable intervals within each of the eight group selection cuts. Twenty points were also established in each control area, Blocks 14 and 24.

For our entomological work, we randomly selected from the permanent plot location system three plots in each of the four treatments. The plots were randomly selected with the exception that in treatments 1 and 3, if the plot initially selected was missed by the prescribed fire, the random selection procedure continued until a plot was selected that had, in fact, been burned.

Field and Laboratory Procedures

Sampling began at the study area in September 1975 and continued through August of 1977. At each sampling period, one sample was taken from each of the plots, for a total of 15 samples over the 5 treatments. The sampling dates were as follows:

1975	1 September
1976	4 June
	20 June
	2 July[4]
	21 July[4]
	4 August
	19 August
	6 September
	14 September
1977	19 July
	29 August

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[4] No samples were drawn in shelterwood treatments 3 and 4 in July.

Sampling in 1977 was restricted to only two sampling dates as our efforts were being extended to related studies at another experimental forest.

The sampling unit consisted of a cylindrical core of litter, humus, and mineral soil, which was extracted from the forest floor by driving a hollow, hinged, metal cylinder into the ground with a sledge. The cylinder, 5 cm (2 in) in diameter, was driven deep enough to penetrate to at least 10 cm (4 in) into the mineral soil. The cylinder and its core were then extracted from the soil and the cylinder laid on its side. A hinged section of the cylinder was opened exposing the sample core.

The core was marked into four substrates--litter, humus, wood, and mineral soil. The temperature was taken with a thermistor probe and recorded for each of the substrates. The depth of each substrate was measured to the nearest centimeter, and beginning at a point 6 cm (2.25 in) deep (with some cores in the controls, the mineral soil was sampled to a depth of 18 cm [7 in] in the mineral soil), each substrate was sliced off in 2 cm (0.75 in) increments. Each sample was labelled as to: date, cutting method and subtreatment, plot number, core number, core substrate and substrate sequence, and placed in a 113- or 226-gram (4- or 8-ounce) soil tin for transport to the laboratory.

Once removed to the lab, each substrate core sample was weighed. The sample was then placed on a cheese cloth-covered hardware cloth screen in a split Tullgren funnel. The funnels were placed on shelves with an alcohol vial below the funnel and a 40 watt bulb over the top of the cylinder above the funnel. Once the apparatus was ready, the lights were turned on, beginning with just a glow, and by using a regulating rheostat, the light (and heat) intensity increased gradually each day. After 9 days, the vials, properly labelled, were removed. The substrate samples were oven dried at 60° C for 24 hours, weighed, placed in a muffle furnace for 24 hours at 600° C and weighed again for combustion analysis. Soil moisture and organic matter data were recorded.

As time permitted, the arthropods in the vials were separated from the debris that also precipitated into the vials, and were sorted and classified.

RESULTS

At this time, we are only able to present and discuss the 1976 data, without any statistical analysis, from our study area at Coram Experimental Forest. Therefore, these results must be tempered accordingly and interpreted as tentative. The complete results of this study, as well as a companion study conducted simultaneously and subsequently at another experimental forest, are not available at this time. When the analyses are completed for both of these studies, the results will be published in a subsequent paper.

Arthropods Collected

During the 3-year course of this study, we collected forest litter, humus, and soil mesofauna representing at least 7 classes of arthropods, including 3 orders of Arachnida and 12 orders of Insecta. By far the most abundant animals were Acari or mites (Arachnida). The next most abundant group, though far less than the mites, were three families of Collembola. All other animals, though represented in the collections, were far less numerous and only infrequently collected. At this time, no determinations have been made below the family unit. The arthropod groups are as follows:

- Arachnida
    - Pseudoscorpionida
    - Araneida
    - Acarina (Acari)
- Insecta
    - Collembola
        - Poduridae
        - Entomobryidae
        - Sminthuridae
    - Protura
    - Thysanura
    - Psocoptera
    - Thysanoptura
    - Hemiptera
    - Homoptera
    - Coleoptera
        - adults
        - immature
    - Trichoptera
    - Lepidoptera
    - Diptera
        - adults
        - immature
    - Hymenoptera
- Diplopoda
- Chilopoda
- Other unknown

Seasonal Distribution of Mesofauna

Despite the probability of within-and-between-treatment effects, and notwithstanding the absence of a sample in shelterwood treatments 3 and 4 in July, mesofaunal populations were generally higher in August and September and significantly less in June and July (table 1). This increase from June through September is probably a normal seasonal trend for these groups of soil animals. One might be inclined to attribute the seasonal increase to a response to, and resurgence following, the prescribed burn in the fall of 1975. However, mesofaunal populations increased as well during the summer of 1976 in the non-burned treatments 2 and 4, as well as in the controls, treatment 5. At this time I have no explanation for the low populations in the undisturbed forest in July nor treatment 1 in September.

Table 1.--Mean total mesofauna populations on four treated areas and in an undisturbed forest during the summer of 1976.

Treatment	June	July	August	September
1. Clearcut Residue removed by prescribed fire	6	18	63	15
2. Clearcut Residue removed mechanically	13	49	83	94
3. Shelterwood cut Residue removed by prescribed fire	41	--	103	178
4. Shelterwood cut Residue removed mechanically	84	--	167	229
5. Undisturbed Adjacent forest	84	26	238	217

Vertical Distribution of Mesofauna

Generally, animals tended to be concentrated in the organic layers of the soil, particularly the O_2 or humus stratum. Excluding the incomplete July samples, more than twice as many arthropods were found in the O_2 layer as in the surface layer of litter or O_1. The top 6 cm (2.25 in) of mineral soil contained only one-fourth as many animals as the humus and populations in the woody layer were less than one-tenth of those in the humus (table 2).

Table 2.--Mean total mesofaunal populations in the litter, humus, wood, and mineral soil layers in June, August, and September of 1976.

Month	Horizon			
	Litter O_1	Humus O_2	Wood	Mineral soil
June	64	123	23	24
August	130	350	63	116
September	202	451	0	89

This population distribution is probably attributable to several factors. The humus stratum no doubt contains an abundance of partially decayed plant and animal matter and detritus that serves as a source of food. Some of this may be found in the litter layers as well, but this surface stratum can be a rather harsh environment as it is partially at least exposed to widely fluctuating heat, moisture and other changes. A poor food source may account for the generally low arthropod populations in the woody stratum. The lignin, tannins and similar material found in the wood is unsatisfactory food for most arthropods. Fungi and bacteria flourish in this woody layer; the wood is also a haven for mycorrhizal fungi.

Another factor explaining this vertical population distribution is the occurrence of the various strata in the samples over the year. For example, not all strata, especially wood, were represented in all samples. Also the litter, and at times the humus, were at least partially consumed by fire in the prescribed burned treatments. Had they not been, populations in these strata would have been even higher than they were.

Effect of Treatment

The four treatments are discussed in order of decreasing severity or reduction of mesofaunal populations. Treatment effect is shown by month in table 1 and by month and forest floor and soil strata in figure 2 (June, July, and August) and figure 3 (September) during the summer of 1976.

CLEARCUT--RESIDUE BURNED

This treatment (#1) seems to have had the most dramatic effect on mesofaunal populations. As shown in table 1 and figures 2 and 3, populations in this treatment were not only significantly lower than those in adjacent check areas, especially in June, August, and September, but also lower than populations in the other three treatments, especially the two shelterwood treatments, throughout the summer. In treatment 1, populations were extremely low in June 1976, following the prescribed fire in September of 1975. They peaked in August and then tapered off in September.

CLEARCUT--RESIDUE MECHANICALLY REMOVED

Mesofaunal populations were relatively low in this treatment (#2) in June (table 1 and figure 2) but recovered as summer progressed and showed no decline in September (figure 3) as did populations in treatment 1.

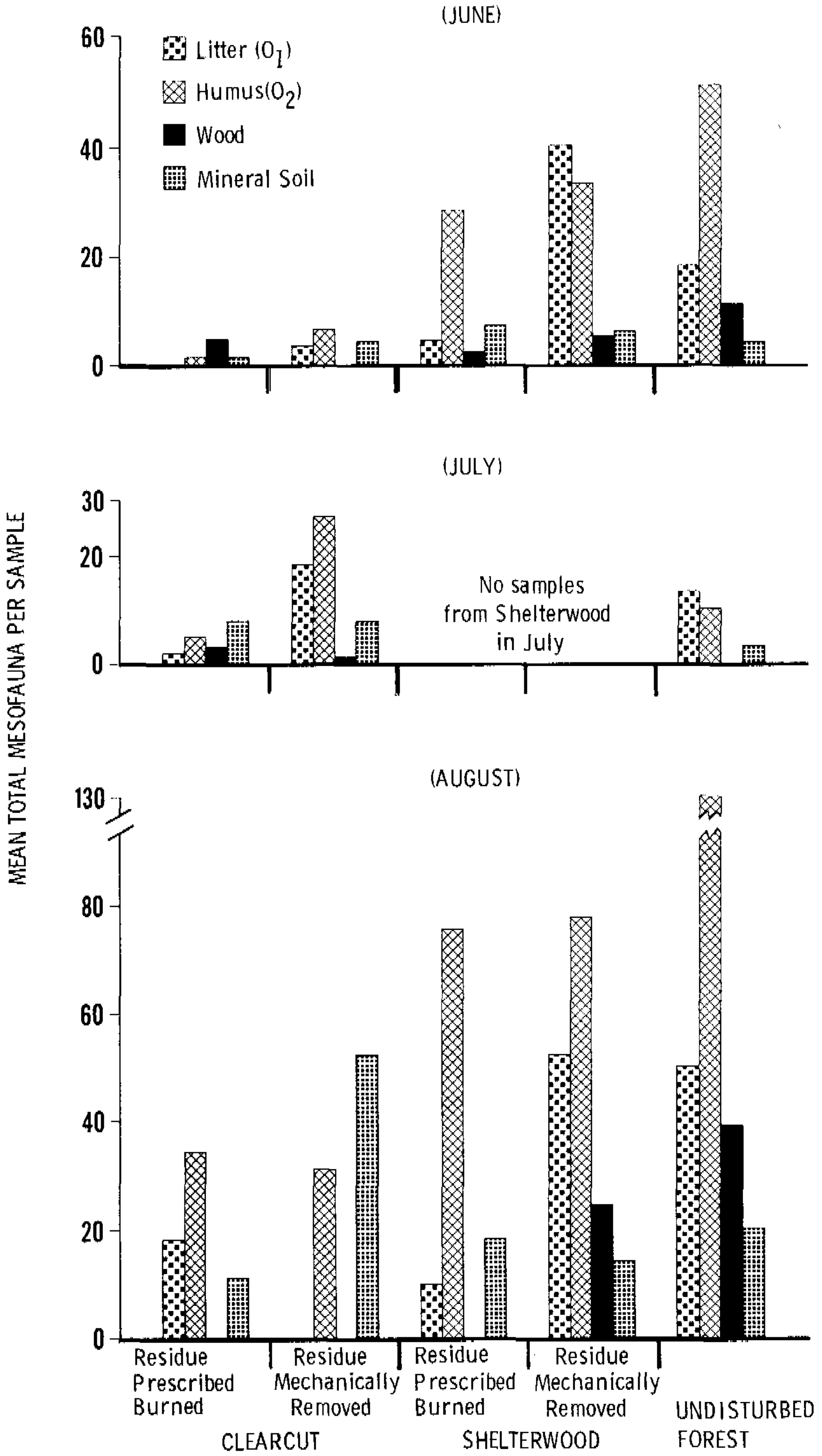

Figure 2.--Mean density of forest floor mesofauna in June, July, and August of 1976 in clearcuts and shelterwood cuttings where forest residues had been mechanically removed in 1974 and prescribed burned in 1975, and in undisturbed forests, Coram Experimental Forest. (For September data, see figure 3).

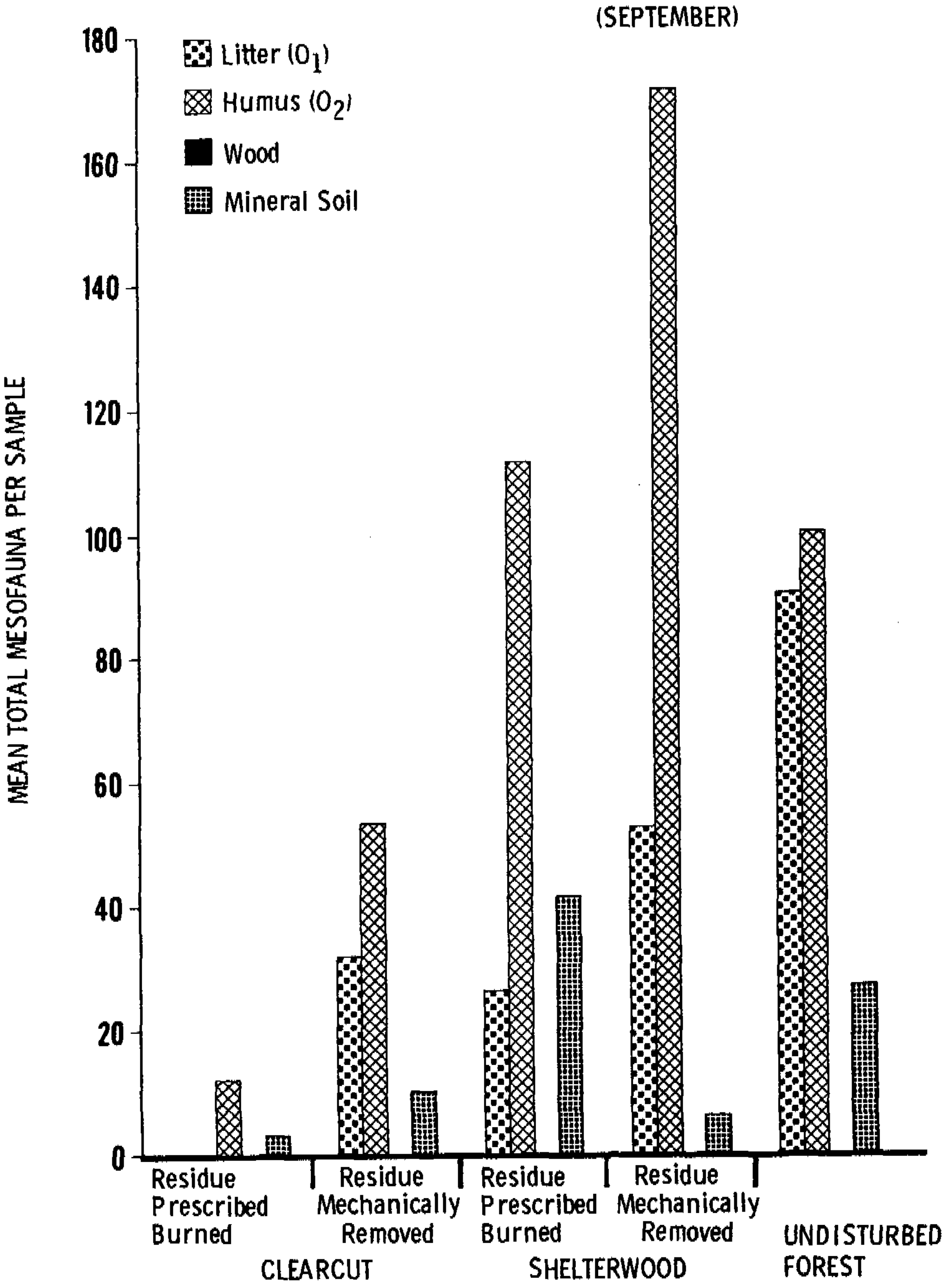

Figure 3.--Mean density of forest floor mesofauna in September of 1976 in clearcuts and shelterwood cuttings where forest residues had been mechanically removed in 1974 and prescribed burned in 1975, and in undisturbed forests, Coram Experimental Forest. (For June, July, and August data, see figure 2).

SHELTERWOOD--RESIDUE BURNED

The effect of this treatment (#3) on mesofaunal populations was generally intermediate between the clearcut and burn treatment (#1) and the undisturbed forest (treatment #5). Throughout the sampling period in 1976, mesofaunal populations on this shelterwood burned treatment (#3) were generally higher than on either clearcut area, but generally the abundance of animals was less than in the other shelterwood treatment (#4) or the undisturbed forest (treatment #5).

In this treatment, as one might expect, there were many unburned or partially burned areas where animals could have survived the prescribed fire and sample cores drawn from these areas may have been unrepresentative of the treatment. We selected our sampling plots in this treatment only on the forest floor where the residue had been effectively removed by the fire. Yet, as shown in figures 2 and 3, we still found mesofaunal populations in the litter strata (O_1) at all three sampling periods, June, August, and September.

SHELTERWOOD--RESIDUE MECHANICALLY REMOVED

This treatment (#4) was by far the least harsh of any of the four on mesofaunal populations. In June, populations in this treatment equalled those in the undisturbed forest (treatment #5) and in September were actually slightly higher than populations in the undisturbed forest, even though being concentrated in different strata than populations in the undisturbed forest (figures 2 and 3).

Mesofauna populations in the humus stratum (O_2) were similar in treatments #4 and #5 in June. In June and August, populations in the litter stratum in treatments #3 and #4 were nearly identical. But in June, August and September, populations in the litter stratum (O_1) were consistently and significantly higher in treatment #4 than in treatment #3--an indication that some litter was removed by prescribed fire in treatment #3.

DISCUSSION

In this study three elements might confound, or interfere with, the interpretation of treatment effects: direct effects of treatment, indirect effects of treatment, and the identification of taxa.

Huhta (1971) summarizes the difficulties as follows in what might be considered the idealized interpretation of treatment effect:

> Catastrophes in an ecosystem, such as deforestation or burning, alter nearly every environmental factor, biotic or abiotic, interacting in such a complex way that it is very difficult to distinguish the factors which principally account for the

changes in the animal communities. To discover the primary causes of the changes in the population densities of the different species or of the successional trends of the whole community, accurate information would have to be acquired about the habits and responses of each component species to each factor at the different stages of their life cycles, together with detailed long-term microclimatic records not only in the habitat in general, but also separately in the particular microhabitat of each species.

Direct Effects of Treatment

Considering harvesting and residue management procedures, prescribed burning is probably the only treatment that directly affects forest floor macrofauna. Some studies have concluded that the heat of the burning-over is very destructive to all groups, and that the bulk of some populations may be destroyed (Huhta and others 1967). Other investigators report that with the exception of mesofaunal species and spiders, population reductions do not seem to be directly caused by heat of fire (Ahlgren 1974). The direct effect of prescribed burning is not only in killing the organisms, but in the partial or complete destruction of the litter and humus, as well as the above-ground portions of low-growing surface vegetation. In such cases, only scanty material may be left on the surface of the mineral soil (Huhta and others 1967).

Indirect Effects of Treatment

In addition to direct effects, harvesting and residue manipulation practices have two general indirect effects: a change in the forest environment and microclimate and changes in successional development of vegetation.

Changes in the microclimate will depend on the condition of the stand prior to treatment. The removal of all or part of a dense coniferous stand where the forest floor is heavily shaded will have more striking effects than the manipulation of a more open-grown stand where more light reaches the forest floor and where understory vegetation may be more abundant.

Partial or complete removal of trees and residues alters the forest environment, hence indirectly influencing the forest soil fauna, by changing temperature, moisture, light intensity, wind, and humidity regimens. Of the harvesting methods, clearcutting no doubt has the greatest impact. However, all treatments disrupt both diurnal and seasonal fluctuations in these physical factors.

Some animal groups, unable to tolerate the new microclimate, are at a disadvantage and disappear. Other groups not only survive the environmental change but may even increase as a result of treatment. Some investigators have reported that the factor deciding the succession of fauna in clearcut areas is whether the felling residues are left on the site or removed (Huhta and others 1969). Some animals, dependent on litter for food have been known to disappear in a burned-over area after the unburned litter had decomposed.

In the first season or two following treatment, surface fauna probably respond to either the direct effect of treatment or the indirect effects on microclimate. However, forest floor vegetation will progressively have a greater influence on surface animals as treated areas begin to regenerate with both broad-leaves and conifers.

In another paper in this proceedings, Schmidt (1980) reports on the response of understory vegetation to harvesting and residue management practices. However, he indicates that the significance of differential understory responses in relation to entomological and other biological systems will be the subject of further analyses.

Identification of Taxa

In this paper, we have considered only total mesofauna, without regard to class, order, or family. Hence, any discussions, conclusions or resource management interpretations must recognize this overall lumping of all arthropod taxa.

We realize the hazards of categorizing such diverse groups of forest floor arthropods into major or higher-level taxonomic groups, and recognize that evaluating treatment effects by large composite taxonomic groupings can often mask the effects of treatment on specific groups (Wenz 1976). However, at this time the material collected in our samples has not been sorted into the lower taxonomic groups. Orders, families, and even genera are too heterogenous to serve as indicators of environmental change (Huhta and others 1967), and generalizations may be misleading (Ahlgren 1974). To determine the most meaningful effects of harvesting and residue practices on forest floor and forest soil mesofauna or another forest insect group, the analysis should be done at the species level, supported by detailed knowledge of the biology of each species and microbiological changes in the site (Huhta and others 1969).

Identification at the species level is often difficult and time-consuming (Ahlgren 1974), and a species-level analysis with all animal groups would be an extremely laborious task. Notwithstanding the difficulties, species groups, rather than higher taxonomic groups, appear to be the most appropriate units of study (Tolbert 1975). Species will probably respond differently to treatment than larger taxonomic units; the abundance of single species may be considerably altered, while overall abundance of a group is unaltered (Huhta and others 1969). Closely-related species (or genera or families) may, and often do, have different physiologies, dispersal habits, feeding behavior, ecological and habitat requirements, and diurnal and seasonal population vagaries. Hence, by grouping species, and genera and families, into larger taxonomic units, one risks masking the influence of treatment on the more definitive and meaningful taxonomic units. Still another consideration is the differences in requirements between life stages (larvae and adults) of the same species.

Subsequent papers are planned to deal with the influence of these silvicultural and residue management treatments on some fauna, particularly the Acari and Collembola, at the family, genera, and species level.

MANAGEMENT IMPLICATIONS

If we consider forest floor and forest soil mesofauna to be beneficial organisms --and we really have no evidence or reason not to--what we have learned so far suggests that some of our cutting and residue management practices may be more favorable to some arthropods than others.

Even though no data have been analyzed and only a few general findings have been presented, some preliminary recommendations can be made. These recommendations are solely entomological and based on the incompletely analyzed and interpreted data of this study. Of the four treatments studied, a shelterwood cutting accompanied by a near-100-percent removal and utilization of nonmerchantable residue and understory appears to be the most desirable treatment. The second best treatment would be a shelterwood cut followed by the burning of residues.

Preliminary data indicate that 1 year following burning under a shelterwood cut, mesofaunal populations already have recovered to the levels of those in adjacent undisturbed forests. With this prescription, apparently there are sufficient unburned refugia to allow recolonization of burned areas fairly rapidly.

Of the four treatments, the least recommended would be clearcutting followed by burning of residue. Clearcutting accompanied by 100-percent mechanical residue removal would be more favorable to soil mesofauna than clearcutting and burning residues.

In summary, the seemingly insignificant animals of the forest floor and soil should not be ignored in either the harvesting system or the management of residue. As noted by Wenz (1976), "Disruptions of soil microarthropods have potential long-term consequences to decomposition and nutrient cycling processes and should be weighed carefully when considering forest management options."

We should favor those resource and utilization practices that satisfy our increasing needs and demands for wood fiber while minimizing adverse impacts to, and insuring the continued functioning of, plant and animal forest ecosystems. Insofar as soil-litter animals are concerned, we have acceptable management options.

ACKNOWLEDGMENTS

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A REVIEW OF SOME INTERACTIONS BETWEEN HARVESTING, RESIDUE MANAGEMENT, FIRE, AND FOREST INSECTS AND DISEASES

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ABSTRACT

Many species of insects and diseases create residues that predispose forests to fire. Conversely, natural factors such as fire, wind-throw, and other agents create forest residues that predispose forests to diseases and insects, including bark and cambium beetles, wood borers, and others. Man-made residues also predispose forests to insects and disease.

Harvesting practices, residue management, and fire management not only influence the behavior and impact of forest insects, but also can be used to suppress some insect and disease populations. These practices also have a profound influence--mostly negative--on forest floor and forest soil arthropods, many of which (in concert with wood-destroying fungi) are involved in both the micro- and macro-deterioration and dispersion of forest residues. Opinions vary concerning the value of removing residues through prescribed fire to manage forest insects and diseases. Harvesting, residue management, and fire management are inextricably tied to forest succession.

The interactions between harvesting, residues, fire, insects, and diseases have many implications for the resource manager. Future research should provide a better understanding of these interactions and will likely enhance our opportunity to reduce the negative impacts of many species of indigenous insects and diseases in managed forests.

KEYWORDS: arthropods, disease, fire, residue, harvesting, silviculture

INTRODUCTION

Harvesting, residue management, and prescribed fire can have both positive and negative effects in the removal of standing green or dead trees, the removal of forest residues, which through natural decomposition and decay form the humus and forest soil, or the consumption of residues and the resultant effect on forest floor and forest soil flora and fauna.

The interactions between harvesting activities, residue treatments, fire (both prescribed and wild), and forest insect and disease behavior and activity are extremely varied, usually complex, and most often mutually inclusive and reversible. This paper is a review of the literature and an interpretation of some of these interactions, with a discussion of the management implications. Because of the breadth of these interrelationships, the contents of the paper is presented below:

INSECT AND DISEASE INTERACTIONS

Insects and diseases have many associations, often with the potential to stabilize populations or to alter the function of these organisms in the forest ecosystem. In addition to their often direct interdependence in dead plant materials, insects and diseases interact through their mutual or individual effects on live trees. In some cases, diseases predispose living host trees to insect attack (Miller and Keen 1960; Felix and others 1971, 1974; Thomas and Wright 1961; Rudinsky 1962). In other cases, insect attack predisposes living trees to diseases (Wagner and Mielke 1961; Lorio 1966; Molnar 1965; Partridge and Miller 1972). In still other cases, insects and diseases may combine to kill or damage trees (Shea 1971).

Many insects utilize fungi, usually sporocarps, as their primary food base (Fogel 1975). In the process of eating fungal sporocarps, the insects ingest spores, which sometimes survive passage through the digestive tract (Nuorteva and Lain 1972). Thus, the fungus-eating insect has the ability not only to destroy but also to disperse and build fungal populations. The fungi affected in these ways are frequently tree pathogens (Powell and others 1972; Molnar 1965; Willhouse 1919), ectomycorrhizae (Zak 1965; Weiss and West 1920), or major decay fungi (Ackerman and Shenefelt 1973).

Insects and fungi can be mutualistic. The ability of many insects to exploit either live or dead wood as a food source may be entirely dependent upon a beneficial association with specific fungi (Graham 1967). Moreover, many species of insects, principally bark beetles and wood borers, contribute directly to the dispersal and effectiveness of many decay fungi. By ingesting and macerating woody tissue (Witkamp 1975; Graham 1925), and by their tunneling and boring activities, insects not only introduce fungi (fig. 1) but also create avenues of entry or "infection courts" for staining- or wood-destroying fungi (Thomas 1955; Orr 1959; Graham 1922). In fire-injured or fire-killed Douglas-fir, Pseudotsuga menziesii Britton, in Oregon, pin hole borers (ambrosia beetles), and sap-staining fungi, Ceratocystis minor (Hedge.) Hunt introduced by the Douglas-fir beetle Dendroctonus pseudotsugae Hopkins (Kimmey and Furniss 1943) seriously degraded sapwood causing it to turn dark a few weeks after attack (Furniss 1937).

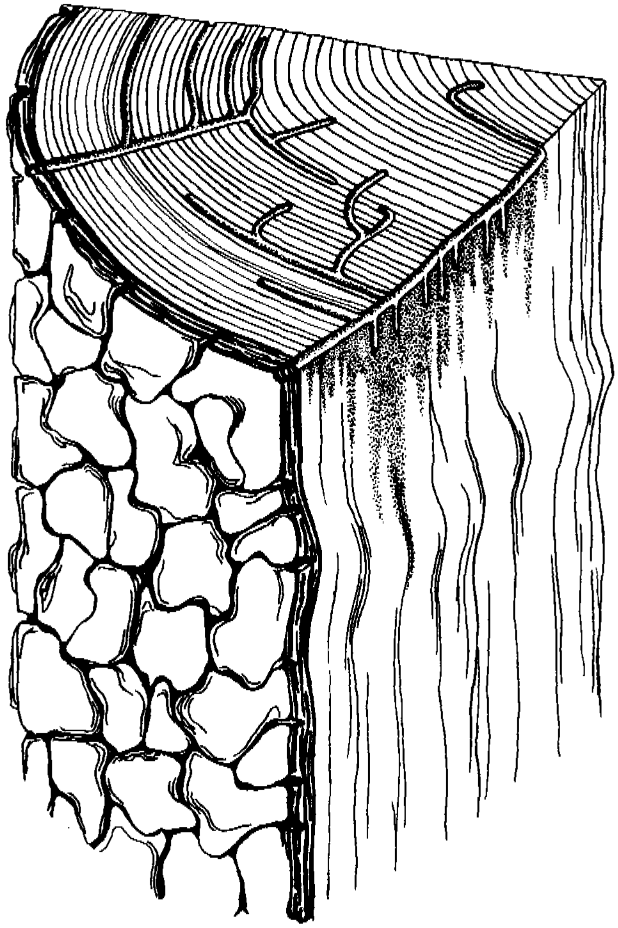

Figure 1.--Galleries of ambrosia beetles and associated stain. Beetle galleries and fungi cause degrade and hasten wood deterioration. Fungi also serve as source of food for these beetles.

Borden and McLaren (1970) reported that the year after Douglas-fir beetle attacks, hyphae of Polyporus volvatus Peck extrude through boring holes made by the beetles, suggesting the predator (Temnochila virescens var chlorodia (Mann.) (Ostomidae) as a likely vector. A few years later, Castello and others (1976) isolated P. volvatus from Douglas-fir beetles trapped in flight; their evidence suggested that the Douglas-fir beetle is the major vector of P. volvatus, a common cause of sapwood rot in beetle-killed trees. At other times, the brown rot fungus, Fomes pinicola (Schw. ex Fr.) Cke, is the most serious deteriorating agent in Douglas-fir killed by the Douglas-fir beetle (Wright and Harvey 1967). In some cases the blue fungus, Ceratocystis pilifera (Fr.) Moreau stains sapwood, and the red-rot fungus, Stereum sanguinolentum (Alb. and Schw. ex Fr.) Fr., causes decay in beetle-killed trees (Buttrick 1912).

In studying the rate of deterioration of Englemann spruce, Picea engelmanni Parry, killed by the Englemann spruce beetle, Dendroctonus rufipennis (Kirby) (=obesus Mann.), in Colorado, Mielke (1950) indicated that several root rot fungi may have weakened the trees before they were killed by beetles. An unidentified species of blue stain fungus that was probably carried into the trees by the beetles did not appear to be a serious defect. Although the rate of deterioration from decay in fallen trees was fairly rapid, Mielke anticipated that a high percentage of beetle-killed trees would remain standing and sound for at least 20 years.

On the Gaspè peninsula in eastern Canada, spruce killed by the eastern spruce beetle, Dendroctonus piceaperda, lost 8.7 percent of the merchantable volume to decay in 7 to 8 years (Riley 1940), while spruce killed by the European spruce sawfly, Diprion hercyniae (Htg.), lost 48.3 percent during the same period (Riley and Skolko 1942).

Insect-disease interactions also have been reported in wind-thrown white fir, Abies concolor (Gord. and Glend.), and California red fir, Abies magnifica A. Murr., in California. In one study (Gordon 1973), insects were attributed as killing many trees that were under physiological stress caused by root diseases or dwarf mistletoe, Arceuthobium americanum Nuttal ex Engelmann; mistletoe infections were judged to have severely reduced the vigor of 34 percent of the trees killed by bark beetles. Other trees physiologically stressed and mechanically weakened were wind-thrown; had they not been blown over, Gordoǹ feels they would have been killed by beetles. In another study, Wickman (1965) reports that blue stain introduced by bark beetles and flatheaded borers was the most important single cause of degrade effecting an estimated 50 percent deterioration in the first and second years after the blowdown (Wickman 1965).

There are several reports of diseases associated with trees damaged by one or more species of spruce budworm, Choristoneura spp. Decay in grand fir, Abies grandis (Dougl.) Lindl., top-killed by the western spruce budworm, C. occidentalis Freeman, resulted in a serious loss in volume, with young saw timber-sized trees suffering a higher percentage of loss than older growth trees (Ferrell and Scharpf 1979). Stillwell (1956) found balsam-fir, Abies balsamea (L.) Mill., top-killed by the eastern spruce budworm, C. fumiferana Clem., to have a high incidence of decay. Butt rot has also been reported in balsam fir defoliated by the eastern spruce budworm; the rot is apparently related to high rootlet mortality (Sterner 1970).

Insects and fungi also can be antagonistic. At times trees do not appear to be predisposed to disease as a result of insect attack, nor predisposed to insect attack when diseased. In the west, Wickman and Scharpf (1972) found that white fir damaged by the Douglas-fir tussock moth, Orgyia pseudotsugata McDunnough, failed to show the presence of typical decay, although in 2 out of 21 top-damaged trees, the common brown rot fungus was present. In the east, Basham (1971) found no significant heart rot in eastern white pine, Pinus strobus L., damaged by the terminal weevil, Pissodes strobi Peck. In a thinned red-pine, Pinus resinosa Ait., plantation in Ontario, stumps attacked by fungi appeared to be unsuitable or unattractive to insects, preventing the encroachment of bark- and wood-feeders (Martin 1965). Brown rots and carbonizing decays that attack cellulose seem to restrict insect activity, in contrast to white rots that do not seem to do so (Kimmey and Furniss 1943). Earlier in this Symposium, Dr. Mike Larsen discussed the relative significance of brown and white rots in the forest ecosystem. Some insect species parasitized by fungi reflect other cases of apparent antagonism (Roberts 1973).

Many insect and disease relationships in the forest ecosystem are very beneficial in that they contribute directly to the carbon and nutrient recycling process in dead plant residues and to the development of forest soil organic layers. Other insect-disease relationships are responsible for mortality and retarding growth in forest stands. An integrated insect-disease approach is often needed to fully understand the total forest pest impact (Wickman and Scharpf 1972). An excellent example of this concerns the need to very carefully consider the impact of dwarf mistletoe when contemplating partial cutting of lodgepole pine, Pinus contorta var latifolia Engelm., stands to manage the mountain pine beetle, Dendroctonus ponderosae Hopkins (D. Cole 1978).

INSECTS CREATE RESIDUES AND PREDISPOSE FORESTS TO FIRE

Insects and diseases kill forest trees and create dead plant bodies or residue. This material may decay, thus contributing to the recycling process by creating a reservoir both for nitrogen fixation as well as for pest inoculum. Or, these large accumulations of residues (fuels) may burn violently (fig. 2), consuming all or most of the residue as well as killing any living trees left in the insect or disease centers. Such wildfires affect the immediate recycling of nutrients as well as the removal of the pest inoculum; however, wildfires also increase genetic turnover because the survival potential of individuals with possible insect and/or disease resistant genotypes is negated by their increased probability of being burned. An ecosystem with these insect-disease-fire interactions may preserve endemic insect and disease activity, perhaps as a means of shortening the turnover time for available genes in long-lived trees.

Figure 2.--In August of 1961, a lightning ignited wildfire roared through 28,000 acres of jack-strawed lodgepole pine residue. The trees had been killed by the mountain pine beetle between 1926 and 1938 on the Bitterroot and adjacent National Forests in western Montana.

Bark Beetles

Of all forest insects that are reported to predispose forests to fire by creating residues, various species of bark beetles are perhaps the most significant. In the northern Rocky Mountains, as well as in the Pacific Northwest, the mountain pine beetle has been in the past and is currently responsible for killing millions of lodgepole pine. Dead trees, which as snags or windfalls, add to excessive residue (fuels) and increase the danger of devastating forest fires. Once ignited, the rate of consumption is magnified by these highly combustible fuels (Boag and Evans 1967).

Josef Brunner, an early day forest entomologist in the northern Rockies, recognized the predisposition of bark beetle-killed trees to fire. In 1917 he describes (Brunner 1917) the killing of millions of pine and Douglas-fir, by the mountain pine beetle and Douglas-fir beetle, respectively, and says, "These beetle-killed trees fall to the ground and form a veritable network of highly combustible material subject to ignition by lightning or other causes, which, other favorable conditions being present, result in conflagrations that kill all of the remaining living timber within its path." It was clear to Brunner that "there has been a most intimate interrelation of destructive bark beetles and forest fires in the denudation of the vast areas of once heavily forested lands in the Rocky Mountain region."

A classic example of this predisposition of bark beetle-killed forests to fire, and proof of Brunner's prediction, was the Sleeping Child burn (Mine Fire) on the Bitterroot National Forest in western Montana. Between 1926 and 1938, a mountain pine beetle epidemic killed lodgepole pine trees on 1.3 million acres on the Bitterroot and adjacent National Forests. In August of 1961, lightning ignited that residue, and the resultant fire consumed 28,000 acres of the beetle-killed, jackstrawed fuel (Lotan 1976). Earlier in the Symposium, Dr. Nellie Stark used this fire as a classic example of the impacts of wildfires on soil nutrient regimens.

The Sleeping Child wildfire and others like it also provide examples of the complex relationships between lodgepole pine and other conifers, the mountain pine beetle or other bark beetles, and wildfire. Many forests become predisposed to beetle infestations because of dense, overcrowded stands and competition between trees (Weaver 1961). At times, dense stands develop as a result of catastrophic fire, or because fire has not naturally thinned them; at other times overcrowding occurs in forests previously killed by insects (Weaver 1943). If bark beetle outbreaks occur during periods of drought, concurrent wildfires may check the excessive multiplication of beetles (Craighead 1925). Wildfires also provide a natural check on insects and disease; according to Lotan (1976), "the Sleeping Child burn will be relatively free of the mountain pine beetle and dwarf mistletoe for decades."

Fires, such as Sleeping Child, may serve to create lodgepole pine forests that may be predisposed to another mountain pine beetle outbreak in several decades, due to the ecological significance of the serotinous cone habit of lodgepole pine. Or, cone serotiny may lead to heavy overstocking and may actually delay beetle problems. Since the Sleeping Child fire, lodgepole pine has established itself over nearly all of the burned area, ". . . much of it with a density of tens of thousands of seedlings per acre" (Lotan 1976). In the first year of succession following the fire, lodgepole pine seedlings averaged over 8,500 per acre (Lyon and Stickney 1976).

The mountain pine beetle is now killing millions of lodgepole pine trees in Montana, particularly on the Gallatin, Beaverhead, Kootenai, Lolo, and Flathead National Forests and in Glacier and Yellowstone National Parks; more than 1.4 million acres of forests are infested. There is, however, disagreement over whether these beetle-killed forests will be predisposed to huge forest fires (Kuglin 1980). Some foresters feel as though "It's like a gasoline tank ready to explode out there" (Kuglin 1980). However, in 1979, concerns that the dead lodgepole could constitute an explosive fire hazard failed to materialize despite an unusually long and hazardous fire season (Schwennesen 1979). Cliff Martinka, research biologist in Glacier National Park, indicates that the relationship between fire and the mountain pine beetle is " . . . more complex than simply having an ignition source and a lot of dead trees" (Schwennesen 1979).

Early observations by Brunner (1917) might be an indication of what could happen on the Flathead and other National Forests where mountain pine beetle-killed trees are so numerous. In 1910 he observed the progress of two serious forest fires burning in beetle-killed timber. The first was in the Little St. Mary region, northeast of Belton, within Glacier National Park, where Douglas-fir had been killed by the Douglas-fir beetle between 1904 and 1910. In the second case, a fire burning in mountain pine beetle-killed (but still standing) western white pine, *Pinus monticola* Dougl., was so explosive that it jumped the north fork of the Flathead River and burned several sections of timber in Glacier National Park. Brunner's observations indicate that the length of time trees had been killed influence the potential fire danger. He says, "those which had been killed longest, previous to the fire, were burned to snags and those which had been dead but a season had the bark burned off to the very tops."

While National Park Service managers view the mountain pine beetle as just another protected species of wildlife (Kuglin 1980), Forest Service foresters are developing management plans to salvage beetle-killed trees as well as accelerate the harvest of green lodgepole pine. On the Flathead forest alone, 160 million board feet will be harvested between 1980 and 1982. According to Flathead Supervisor John Emerson, "It's time we start managing the beetle instead of letting it manage us" (Emerson 1979). The USDI Fish and Wildlife Service has recently been criticized by wildlife managers and conservationists for ruling that a proposed 22 million board foot salvage sale of beetle-killed lodgepole pine would not jeopardize endangered wildlife species such as grizzly bear and wolves (Schwennesen 1980).

In Oregon, the Forest Service is considering a 21-year, $133 million project to remove mountain pine beetle-killed lodgepole pine to lessen the chance that a massive fire will cause further economic and aesthetic damage (Baum 1976). Over the 21-year period, potential resource damage and fire suppression costs have been estimated at $260 million (Western Cons. Jour. 1976); the chance of a large fire is predicted to be multiplied 10 times if the dead tree residue is not removed (Baum 1976). Opponents argue that the expense of the salvage work is unjustified because the mountain pine beetle is nature's way of harvesting overmature trees (Western Cons. Jour. 1976; Baum 1976). It remains to be seen whether bark beetles have predisposed these forests to fire through the creation of some 1.4 million acres of lodgepole pine residue.

Defoliators

Some species of defoliating insects also produce forest residues that either decay and provide humus- and soil-building components, or--it is believed by some--fuel for wildfires. (Like bark beetles, outbreaks of defoliating insects also provide "fuel" for controversy.)

In the northern Rockies and the Pacific Northwest, the two insect species implicated in predisposing forests to wildfires are the western spruce budworm and the Douglas-fir tussock moth; transcontinentally, the entire spruce budworm complex is involved. In all cases, the insect-residue-fire interaction is inextricably related to the political, social, and emotional issues surrounding the use of insecticides.

In Canada Fettes and Buckner (1976) report that the eastern spruce budworm not only kills trees within 3 to 5 years of extreme defoliation--but also increases the threat of vast fires as an aftermath of epidemics. Others have also reported that many major forest fires have been associated with budworm outbreaks (USDA, FS 1975b). Notwithstanding these claims, I am not aware of any situations in the northern Rocky Mountains where either the forest residues created by defoliation or trees killed by the western spruce budworm have predisposed forests to major wildfires (fig. 3).

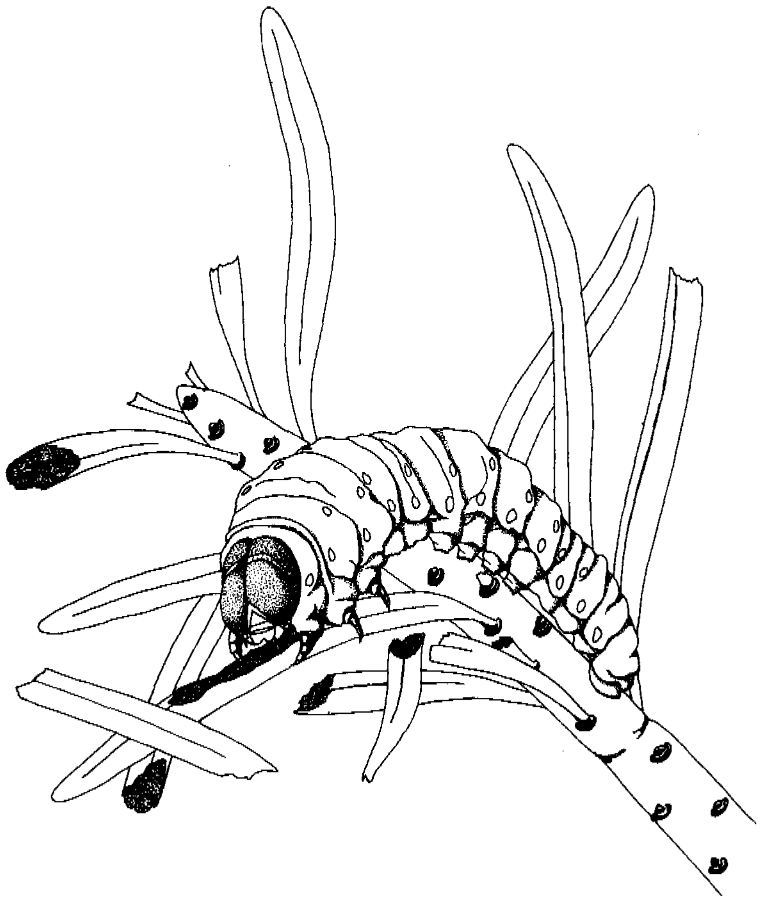

Figure 3.--A western spruce budworm larva feeding on Douglas-fir foliage. Though not substantiated in the northern Rockies, it is reported that many major forest fires have been associated with spruce budworm outbreaks (USDA, FS 1975b).

The large aerial spray programs against the eastern spruce budworm have been justified, in part, by the claim that not to take some kind of direct action would be to risk the development of thousands of acres of dead spruce-fir forests that when blown down could create a tangle, piled like criss-crossed matchsticks, that would not only create a tremendous fire hazard but also would make fire-fighting nearly impossible (Maine Forestry Dept. 1973). It has been said that "while such destruction has occurred historically and nature would in time heal the wounds, the risk in the present context of millions of Americans with all their needs and desires is quite unacceptable" (Maine Forestry Dept.1973).

Most of us are aware of the controversy generated by using DDT against the Douglas-fir tussock moth in Oregon early in the 1970's. Not so well known are claims that the residues created by that insect predisposed defoliated stands to wildfire. Heavily-damaged stands were reported to be especially susceptible to wildfire (USDA, FS 1975a), and increased fire risk and fire protection costs were listed among the several disadvantages to not using direct control with DDT or other chemicals (Ellefson 1974). In addition to 852 million board feet of merchantable timber killed by the Douglas-fir tussock moth (with a loss value of $28.1 million), an additional $30.8 million in losses occurred in the form of damage to immature trees, reduced growth, increased reforestation expense, and increased fire protection costs (USDA, FS 1975a). (One might interpret these as economic losses only if they actually reduced the allowable cut.) Senator Robert Packwood (Oregon) was quoted as saying, "had we used DDT last year, we would not have seen the awesome increase in defoliation and environmental damage leading to increased fire damage in the affected areas that we did" (Crisp 1974). And Oregon's State Forester, Ed Schroeder, estimated that the "total economic impact on Oregon in terms of timber and growth lost, rehabilitation cost, increased fire protection cost, and diminished land value is $9.5 million." He continued that "the esthetic and recreational appeal has been reduced, because of these forest residues and Oregonians will face increased fire danger for 20 years" (Crisp 1974). Again, as with the mountain pine beetle, it remains to be seen how serious the predisposition of Oregon forests to wildfires has been or will be, as a result of the Douglas-fir tussock moth.

Other Insects

In his unpublished manuscript, Brunner (1917) provides some interesting examples of insects contributing to the predisposition of trees to fire--less dramatic perhaps than the bark beetle and defoliator situations discussed above. He mentions several species of insects that feed in the cambium at the base of trees killing the bark in patches. In such cases, even light surface fires ignite and burn off the dead bark, especially of the resinous conifers, leaving basal wounds, which are often mistaken for fire wounds. He describes one situation where carpenter ants, *Camponotus* sp., often appropriate tunnels vacated by roundheaded wood borers, *Pachyta* sp., and " . . . so honeycomb the bark with their mines as to provide a draft through it for a fire which, on this account, is able to scorch the cambium underneath, even on trees with very thick bark."

RESIDUES PREDISPOSING FORESTS TO INSECTS AND DISEASES

Naturally Created Residues

RESIDUES CREATED BY FIRE

As recently as 1970, some researchers long-involved with fire ecology felt there was little knowledge of insect-fire ecology (Komarek 1970). Of the studies in the field of fire ecology that had evolved by the mid 1970's, those dealing with plants and plant by-products predominated almost to the exclusion of any other type (Clayton 1974).

Brown and Davis (1973) remind us that there are so many variables operating on a forest fire that generalizations on specific fire effects can be misleading if taken by themselves. Lyon and Stickney (1976) indicate that most fires are characterized as variable both in pattern and intensity. Further, they say that "only in large, intense wildfires does variability approach a consistent and predictable level. Given such a fire, the crowns of both overstory and understory vegetation are destroyed and the organic mantle is reduced to mineral ash."

Some fire effects are immediately apparent, and others only years later, reflecting both direct, physiological injury to trees and long-term changes in the forest environment (Brown and Davis 1973). When a fire passes through an area, it can radically alter both plant and animal elements, not only by direct kill but also through sudden changes in food, shelter, competition, light, territoriality, reproduction, radiation input and other factors (Komarek 1967).

Fires also may destroy habitats for natural enemies of insects, at times allowing populations of some insect species to thrive after burns (Ahlgren and Ahlgren 1941) (fig. 4). In a study of woodpecker populations in a Douglas-fir/yellow pine forest near Libby, Montana, Blackford (1955) found three species of woodpeckers-hairy, Dendrocopos villosus, black-backed, Picoides articus, and three-toed-, P. tridactylus, and red shafted flickers, Colaptes cafer, had locally fluctuating populations that were greater on a burned area than on unburned areas. One year following the burn, however, he was not able to find even one woodpecker. In another study, wood borers persisted in burned areas because charcoal, ashes, and related fire debris deterred potential competitors and natural enemies (Linsley 1943).

Figure 4.--Wildfires in undisturbed forests often create residues predisposing stands to a variety of insect species. Wildfire alters both plant and animal habitat as well as habitats for the natural enemies of insects, at times allowing some insect species to thrive following the fire.

Weakened living trees, or trees killed and reduced to residue by fire, provide a medium in which insects and disease can thrive (Ahlgren and Ahlgren 1941) and cause deterioration of the fire-created residues. The relationships between forest fires and disease or insect attack ". . . are exceedingly widespread, common and also complex" (Brown and Davis 1973), and are considered by some to be so intimately connected in causing deterioration of residues that they should be considered in combination rather than separately (Kimmey 1955; Kimmey and Furniss 1943).

Fire-Created Residues Predisposed to Diseases

The most comprehensive study of diseases in fire-created residues was conducted by Wallis and his colleagues (1971); they studied rate of decay in Douglas-fir, western hemlock, Tsuga heterophylla (Raf.) Sarge, and western redcedar, Thuja plicata Donn., after a wildfire, the Taylor River burn, in British Columbia. Three years after the burn, the upper bole of Douglas-fir, 8 inches and less in diameter, was of little economic value and 12 percent of the volume was decayed. Five years later, nearly all of the sapwood was decayed and significant deterioration of the heartwood had begun. By 7 years, salvageable material was usually limited to the lower bole and deterioration was complete after 11 years. They found no correlation between the extent of sap rot and insect attack in these three tree species 29 months after the fire.

The rate of deterioration in western hemlock and western redcedar differed from that in Douglas-fir. Deterioration of western hemlock progressed faster; nearly 3 months following the fire, 24 percent of the volume was decayed. In western redcedar, although some blue stain was found in most samples, no loss due to visible decay was present 3 years after the fire. Wallis and others (1971) concluded that fungal deterioration of mature, fire-killed western redcedar may not be significant for many years beyond that reported for Douglas-fir.

There were two reports in the 1930's of decay associated with fires. Three years after the Great Tillamook burn in Oregon in 1933, salvage of western hemlock was halted because of advanced decay and associated insect activities (Furniss 1937a). In an earlier study, investigators found that in the first year following a wildfire, the sapwood of Douglas-fir was stained by a fungus (Ascomycetes) that destroyed cell contents rather than wood fiber (Beal and others 1935).

Fire-Created Residues Predisposed to Insects

As a result of his research work with bark beetle problems in the northern Rockies in the early 1900's, Brunner (1917) wrote that "there is a current belief that outbreaks of serious insect devastations frequently follow in the wake of fires." He maintained that, in his opinion and that of his associates, this tenet cannot be maintained when subject to: 1) the "acid test" of careful observation, 2) a knowledge of the habits of the insects and 3) information concerning insect conditions prior to the occurrence of fires. He says that, "heavy killing near a burn after a fire . . .", usually taken as proof that the fire started the invasion, ". . . is but a centralization of an invasion which was already in existence before the fire occurred." Not only did he believe that serious invasions are not dependent on fires, but, in fact, that ". . . fire may be the means to end an impending infestation or at least to keep the killing of timber by the beetles at a nominal figure for many years."

In the more than 60 years since Brunner conducted his research, many investigators have reported on the interaction of fire and the predisposition of forests to a wide variety of insect species, principally bark and cambium beetles, wood borers, wood wasps, and other groups of lesser economic importance.

Bark and cambium beetles.--In the northern Rockies and other areas in the western United States, wildfires have predisposed forests to several species of bark and cambium beetles. In most cases, bark beetles, while present in large numbers, cause no direct damage (Gardiner 1957); they do, however, permit the entrance of wood-staining fungi that cause limited deterioration--changes affecting the original character of the wood but with the wood still being suitable for use as low-grade lumber--(Kimmey and Furniss 1943; Furniss 1937b).

The increased susceptibility of fire-injured Douglas-fir to the Douglas-fir beetle is probably the most notable example in the northern Rockies of fires predisposing forests to bark beetles. In a study in southern Idaho, Furniss (1965) found 70 percent of the trees on a burned area had been attacked within 1 year after the fire, but decreased abruptly with outright fire kill. The larger trees and those with most severe fire damage to the crown and cambium had the highest incidence of beetle attacks; however, trees killed by fire were less frequently attacked.

Elsewhere in the West, particularly in Oregon, the Douglas-fir beetle is the most important and abundant bark and phloem feeder in Douglas-fir predisposed by fire (Furniss 1937b; Kimmey and Furniss 1943). Beetles not only attack most of the fire-killed trees, but also scorched trees that survive the fire (Furniss 1937b), and at times healthy green trees surrounding the burn (Kimmey and Furniss 1943). Following the great Tillamook fire of 1933, many of the dead trees on the burn were attacked by that fall, more were attacked the following summer, and by the end of 1934 nearly all of the dead trees were infested by at least a few beetles (Furniss 1937a). Douglas-fir beetle populations developed in the scorched trees on that burn and killed some 200 million board feet of green timber in adjacent forests (Furniss 1941).

Following wildfires, tree killing of ponderosa pine by the western pine beetle, Dendroctonus brevicomis Leconte, usually increases (Craighead 1925; Connaughton 1936; Stevens and Hall 1960) and is often catastrophic (Miller and Patterson 1927; Salman 1934; Miller and Keen 1960). Although mortality of fire-injured trees varies with the amount of damaged cambium and foliage (Salman 1934), trees most often attacked are usually those that have lost more than 50 percent of their foliage (Miller and Pattersen 1927; Salman 1934). At other times, trees with light-to-medium fire injury attract more beetles than other trees in burned areas (Miller and Patterson 1927), and trees attacked are those that appear most likely to survive the fire. Fire-killed trees are not attractive to the western pine beetle (Furniss and Carolin 1977).

Most western pine beetle attacks in trees predisposed to fire occur during the first season after the fire (Miller and Patterson 1927), often accompanied by a decrease in the number of beetle attacks in the surrounding forest (Craighead 1925). Post-fire tree killing usually goes on at epidemic levels in the burned areas for 2 or 3 years (Miller and Keen 1960) and then wanes after 3 years (Connaughton 1936). The decline of attacks in burned areas has been attributed to high mortality of beetle broods (Craighead 1925). The cessation of beetle activity in the burned areas is often accompanied by an increase in beetle activity in the surrounding forest (Miller and Patterson 1927), often developing into outbreaks in the nearby green timber (Stevens and Hall 1960). With prescribed fire, the season when the burning is conducted is an important factor influencing the occurrence, the duration, and severity of beetle attack on fire-weakened ponderosa pine (Fischer In press).

The mountain pine beetle also is attracted to fire-killed or weakened western pines (Jaenicke 1921; Stevens and Hall 1960); in some cases beetle infestations are reported to have increased as much as 1,000 percent after "light burning" (Jaenicke 1921). More recently, Cronin and Gochnour (In Press) report two instances of increased activity of the mountain pine beetle following fire on the Kootenai National Forest in northern Idaho. They found: 1) a higher percentage of burned trees--lodgepole, ponderosa, Pinus ponderosa Laws., and western white pine--successfully attacked than trees that were not burned, and 2) that the larger diameter trees were more often successfully attacked. Craighead (1925) reported that the mountain pine beetle was not attracted to fire-scorched trees.

A few other species of bark beetles are attracted to pines predisposed by fire. Sizeable populations of the red turpentine beetle, Dendroctonus valens LeConte, are often associated with fire-scorched trees (Eaton and Lara 1967) and can hasten the mortality of severely defoliated trees (Herman 1950).

Southern pines injured by fire are also very attractive to bark beetles, resulting in concentrations of beetles in scorched trees, as well as the killing of live green trees surrounding burns (Beal and Massey 1945).

In addition to the bark beetles discussed above, at least one species of engraver beetles (fig. 5) is associated with trees predisposed by fire to attack. In the northern Rockies, the pine engraver beetle, Ips pini (Say), at least during years of limited activity, not only confines its activities to slash but also to the ". . . tops of mature trees and smaller groups of standing saplings-and pole size trees that often have been damaged by the fire or broken off by wind or snow" (Schmitz and Taylor 1969). Ips beetles are also becoming an increasingly important problem in connection with prescribed fire. If flame length is not carefully managed, crown scorch predisposes small, pole-sized ponderosa pine to attacks by pine engravers (personal communication with William C. Fischer).

The discussion above describes the predisposition of burned forests to bark and cambium beetles through the weakening, scorching or killing of standing trees, usually in mature forests. Fires may also predispose forests to bark beetles in an indirect way when dense forests of a fire-associated species, such as lodgepole pine, regenerate on the burned areas and become "beetle-susceptible" several decades later (Lotan 1976).

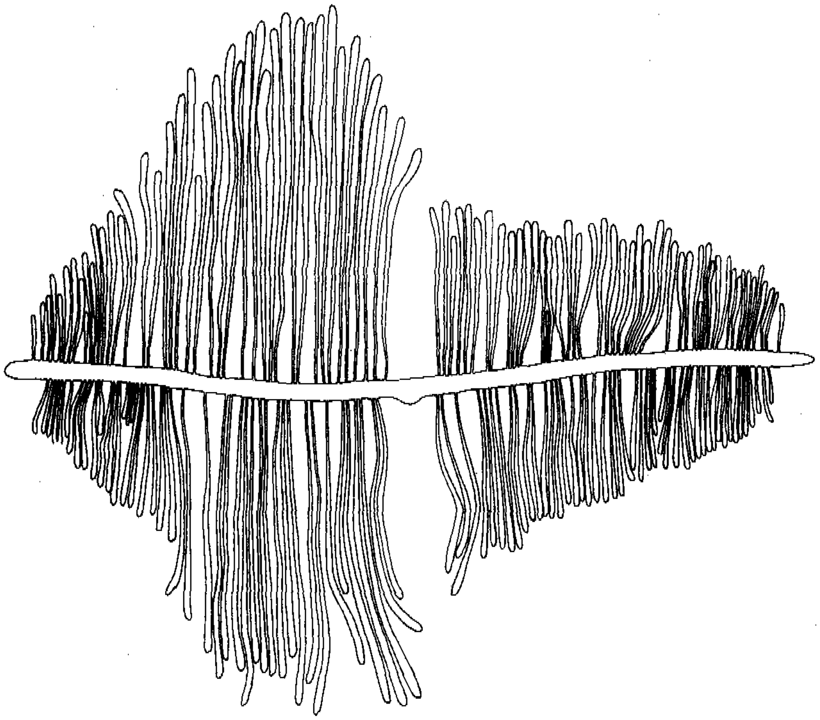

Figure 5.--Egg and larval galleries of the fir engraver Scolytus ventralis Leconte. Though not characteristically associated with trees and stands predisposed by fire, this engraver infests trees infected with root rot fungus and trees defoliated by the Douglas-fir tussock moth. The engraver also breeds in slash and windthrown trees (Furniss and Carolin 1977).

Wood borers.--In the Rocky Mountains and elsewhere in the West, wildfires create a residue of dead and dying trees that are often predisposed to a variety of wood-boring insects (Wallis and others 1974). Infestations of wood borers have been reported in, for example, (1) burned forests of Douglas-fir and ponderosa pine in California (Miller and Patterson 1927); (2) fire-killed pine in Ontario (Gardiner 1957); and (3) in fire-killed white spruce, Picea glauca (Moench) Voss, in Saskatchewan (Ahlgren and Ahlgren 1945). Most wood borers found in fire-killed conifers are "secondary" forms usually incapable of causing the death of the host; they usually infest only dead or dying trees (Gardiner 1957). The severity of attack by boring insects varies with the period of flight activity; due to the drying and subsequent detachment of bark, the further in time the fire is removed from the flight period the less severe the attacks (Buttrick 1912).

The galleries, or mines, of wood borers can seriously degrade some products, primarily peeler grade logs, but seldom become abundant enough to cause cull before fungi render the wood useless for lumber (Kimmey 1955). Wood borers related directly to the general deterioration of wood in fire-killed trees by providing entrance holes and galleries through which decay fungi can gain direct and early access to woody tissues (Basham 1956; Gardiner 1957; Stevens and Hall 1960; Wallis and others 1974).

"The most destructive wood borers belong to two families of beetles: the roundheaded borers and the flatheaded borers. Both groups contain a great many species, some of which are attracted to fire-killed timber even before the fire is out" (Stevens and Hall 1960).

Roundheaded wood borers (Cerambycidae).--Several species of beetles in this group attack sound heartwood, often of fire-killed or weakened trees. Roundheaded borers are usually the most important insects to consider in determining the salvability of fire-injured trees (Kimmey and Furniss 1943). Most heartwood damage to fire-predisposed trees is caused by a large roundheaded borer, _Ergates spiculatus_ Leconte (Beal and others 1935). Beetles of this species usually do not become abundant in fire-killed trees until 5 or 6 years following the fire; beetle attacks continue as long as the wood remains sound (Kimmey and Furniss 1943).

The roundheaded borer, _Criocephalus productus_ Leconte, causes considerable damage to the heartwood of Douglas-fir predisposed by fire (Kimmey and Furniss 1943). Adults of this group attack trees the first year after a fire (Kimmey and Furniss 1943), often while the trees are still smoldering (Furniss 1937b). By the third or fourth year after a fire, beetle larvae usually have not penetrated the heartwood of trees of average to large size, but in the smaller-to-medium-sized fire-killed trees, these borers will have done considerable damage (Furniss 1937b). Another borer, _Leptura obliterata_, along with several other wood-boring species and their associated fungi, destroy the sapwood and attack the heartwood of some conifers in the third year after fire has predisposed them to attack (Beal and Kimmey 1935).

Roundheaded wood-boring species of the genus _Monochamus_ also damage fire-killed conifers by excavating tunnels into the heartwood usually after feeding for a time on the inner bark and outer layers of sapwood (Gardiner 1957). In a study of _Monochamus_ damage to three species of fire-predisposed pine--eastern white pine, red pine, and jack pine, _Pinus banksiana_ Lamb.,--Gardiner (1957) summarized: 1) the effect of the fire on wood borer damage varies with the tree species; 2) the severity of the burn governs the spread and nature of the attack; 3) the severity of the burn, which influences the attack pattern, indicates when trees should be harvested. In British Columbia, _Monochamus oregonensis_ Leconte damage fire-killed white spruce (Ross 1960), and in New Hampshire _M. scutellatus_ Say attacks spruce as severly as it does pine (Bess 1943).

Flatheaded wood borers (Buprestidae).--Probably the most notable flatheaded borers associated with fire-predisposed conifers are various species of the genus _Melanophila_, or metallic wood borers (fig. 6). Although living, uninjured green trees are either resistant to (Linsley 1943) or not killed (Furniss 1937b) by _Melanophila_, these beetles are definitely attracted to trees predisposed by wildfire (Evans 1966, 1971).

Perhaps the most interesting relationship between beetles in the genus _Melanophila_ and fire-predisposed trees is how the insects are attracted to the fire. Some investigators feel that these beetles are attracted by volatile materials associated with smoke (Linsley 1943). Recent studies indicate that they are attracted to heat (Evans 1971), because heat is always a directional stimulus but smoke is affected by wind and is soon dissipated. _Melanophila_ beetles apparently are able to detect infra-red radiation for a distance of several miles through paired sense organs on the mesothorax (Evans 1964; Boag and Evans 1967); the organs are so sensitive that extraneous radiation from sources outside of the temperature range of wildfires is effectively filtered (Evans 1966). This feature allows Melanophila to be among the first insects to reach fire-killed trees--usually before competitors--and has resulted in the Holarctic distribution of at least one species, M. acuminata (Evans 1971). Buprestids of the genus Melanophila are known in some areas of North Carolina as "fire bugs," and have been observed landing on stumps that were still glowing (Linsley 1943). Another flatheaded borer, Asemum atrum Esch., infested the sapwood of the majority of fire-killed trees on the Great Tillamook burn in Oregon in 1933 (Furniss 1937b).

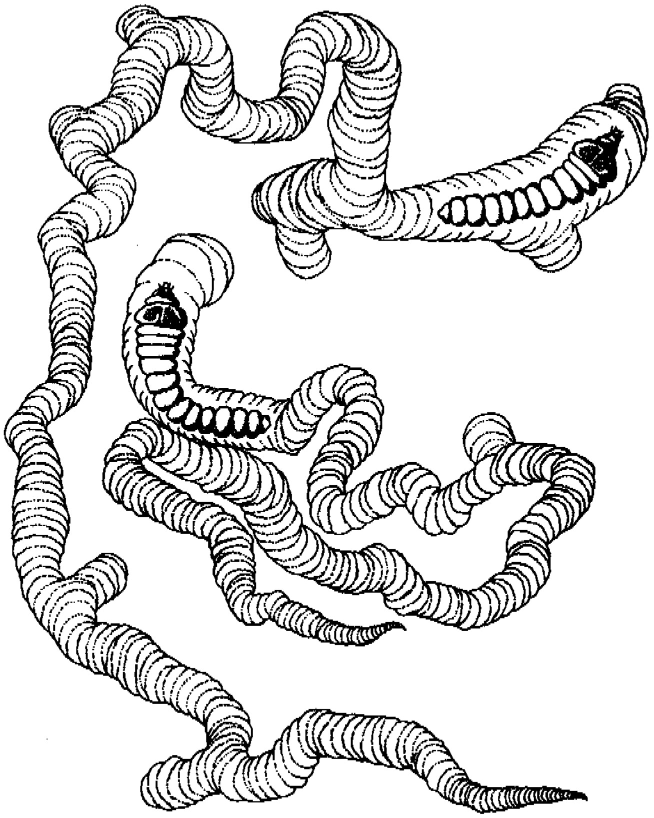

Figure 6.--Larvae and galleries of the flatheaded fir borer, Melanophila drummondi (Kirby). This species frequents fire-killed or otherwise injured trees. Larvae bore into the inner bark forming very characteristic frass-packed galleries.

Other wood borers.--Several species of ambrosia beetles, or pinhole borers, are associated with conifers predisposed by wildfire to beetle attack. Usually restricted to the sapwood, ambrosia beetles begin the process of wood deterioration (Beal and others 1935) through a combination of their galleries and an associated staining fungus (Kimmey and Furniss 1943); these beetles usually do not make wood completely useless (Furniss 1937b). In Colorado, some Engelmann spruce trees killed by the Engelmann spruce beetle showed evidence of ambrosia beetles, but most of the defect caused by these borers in the sapwood was removed with the slabs when the trees were cut into lumber (Mielke 1950).

Wood wasps (Siricidae) are also attracted to fire-killed trees, and may often severely damage the outer heartwood (Wallis and others 1971) (fig. 7). Siricids, along with roundheaded borers, produce larger holes than ambrosia beetles and are usually of more economic concern, even though their populations in the same tree may be lower. If lumber cut from fire-salvaged trees is not kiln-dried, siricids may emerge after the product is in use (Wallis and others 1971).

Other insect species.--Besides the more abundant and economically important bark beetles and wood borers, wildfires in coniferous forests attract a variety of other insects, some predatory, some scavengers (Boag and Evans 1967). Many species are attracted to fires by smoke and heat (Evans 1971); among those reported to be associated with fire are three species of Empidid or Platypezid smokeflies--_Hermopezasp_, and _Microsania occidentalis_ (Komarek 1969) and _M. imperfectus_ (Snoddy and Tippins 1968).

RESIDUES CREATED BY WINDTHROW

Windthrow represents a natural and often catastrophic event that, like wildfire, predisposes coniferous forests to insects and disease by creating tremendous amounts of residues. Throughout the West, as well as elsewhere on the Continent, several species of bark beetles and wood borers are known to degrade downed timber resulting from windthrow, and to threaten standing timber after breeding in the downed residues (Wickman 1965).

All known major outbreaks of the Douglas-fir beetle in western Oregon and Washington have been triggered by severe forest disturbances, particularly by residues created from extensive blowdown during storms (Wright and Harvey 1967). During the winters of 1949-1950 and 1950-1951, wind storms blew down some 10 million board feet of sawtimber and in the following 3 years another 3 billion board feet of standing timber were killed by beetles (Wright and Lauderbach 1958). A windstorm of hurricane force struck the Pacific Northwest on October 12, 1962, and in northern California alone blew down nearly a billion board feet of coniferous timber. Wickman (1965) caught, reared, or trapped at least 46 different species of insects degrading wood of those windblown trees. Species of _Melanophila_ were the most numerous wood borers, and several species of _Ips_ and _Dendroctonus_ were the most common bark beetles. As a result of that storm, Douglas-fir beetles attacked injured trees (those felled, broken off or leaning), and then spilled over into live surrounding trees (Johnson and Belluschi 1969).

Windthrown ponderosa pine-as well as logging residue--is also predisposed to attacks by the western pine beetle (Mitchell and Sartwell 1974). Usually there is little population increase in such residues (Patterson 1927; Beal 1935), however, and over the course of many years residue-associated beetle damage has been rather minor.

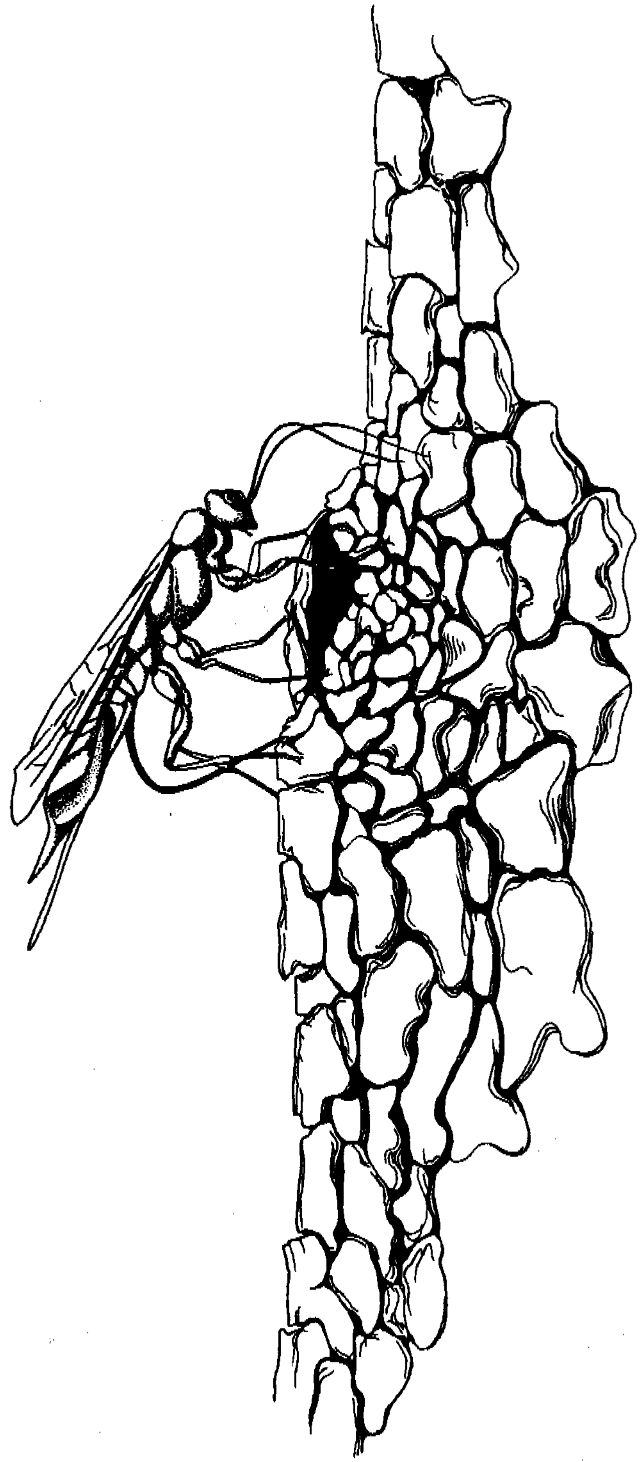

Figure 7.--An adult horntail (Siricidae) laying eggs in fire-killed tree. Eggs are layed deeply into the wood through the long, flexible ovipositor of the female. At times they are unable to extract their ovipositor from the wood and die in this position. Adult horntails are known to emerge from dimension lumber cut from fire-killed trees, at times creating emergence holes in walls, floor, and ceilings (Furniss and Carolin 1977).

Deterioration of spruce (Picea spp.) and jack pine blowdown in northern Ontario between 1969 and 1972 was caused by several species of wood borers, especially Tetropium spp. and sawyer beetles, Monochamus spp. (Gardiner 1975). Milling studies showed a 10 to 20 percent loss in all material combined, 1 and 2 years after the storm. In this case, trees left standing after the storm were not attacked due in part to rapid salvage of the windthrown material as well as the attraction of emerging beetle populations to fresh breeding material provided by further blowdown (Gardiner 1975).

In the central Rocky Mountains, major outbreaks of the Engelmann spruce beetle have generally been associated with residues created by windthrow, as well as residues created by logging (Massey and Wygant 1954; Schmid and Beckwith 1972). A severe wind storm in Colorado in mid-June of 1939 blew down groups of Engelmann spruce in which comparatively large populations of the Engelmann spruce beetle subsequently developed. Beetles spread from the windthrow residue to the surrounding forests, and by 1948, 4 billion board feet of spruce timber had been killed (Mielke 1950).

Perhaps the most notable occurrence of windthrown forests creating residues predisposed to insects in the northern Rocky Mountains involved the Engelmann spruce beetle. During the fall of 1949, hurricane-force winds whipped through northern Idaho and northwestern Montana, transforming countless stands of Engelmann spruce into large volumes of spruce residue. Severe epidemics of the spruce beetle developed in much of this downed timber during 1950 and 1951, spreading in 1952 to standing spruce throughout most of the Engelmann spruce timber type in the northern Rockies (fig. 8). As a result, approximately 2.5 billion board feet of spruce timber was attacked by this beetle between 1952 and 1956 (Tunnock 1959). During this same period, the forest management plan was modified on several national forests as thousands of acres of spruce forests were clearcut in northern Idaho and western Montana to salvage damaged and/or beetle-killed trees, both standing and windthrown. The outbreak steadily declined following its peak in 1953; by the late 1950's no infestations were reported in many forest compartments.

Figure 8.--Besides fire, windthrow is another natural and catastrophic agent that creates residues and predisposes forests to insects. In western Montana, between 1952 and 1956, 2.5 billion board feet of green spruce timber was killed by beetles developing in residues created by hurricane-force winds in 1949.

There are at least three interesting and significant residue management implications related to this Engelmann spruce beetle outbreak; the first involved the utilization of these wind- and beetle-created residues. While foresters were struggling to remove the standing and downed residual trees before they deteriorated too badly, several species of woodpeckers--known to increase their numbers in such outbreaks (Yeager 1955)--were feeding on the beetles in the infested standing trees. However, to reach the beetles in the cambium, the woodpeckers removed large quantities of the scaly bark. This accelerated checking and substantially reduced the period of time that residue trees could be salvaged for sawtimber (Fellin 1955). A similar instance was reported from the Gaspè Penninsula in eastern Canada, where beetle-killed spruce dried more rapidly when woodpeckers removed the bark in search of beetle larvae (Riley 1940).

The second residue management implication was both biological and socio-political; at issue was whether the removal of beetle-infested trees from the forest would effect some control--assuming that the beetles were still present in the trees--or would the removal be strictly a residue-salvage situation. This was an exceedingly volatile issue because forest pest "control" funds were available for access and removal of trees that were still beetle-infested, but not to remove the residue or salvage the trees.

One of the most controversial Engelmann spruce stands was in Bunker Creek, a roadless area about 15-20 miles from the Spotted Bear Ranger Station and contiguous to the western edge of the Bob Marshall Wilderness. Proponents argued that a road must be built to remove the beetle-infested trees; opponents argued that whether the trees were infested or not, a road in that area would jeopardize the wilderness. I personally spent 15 days in that forest in 1956 with a bark beetle survey crew. We determined that, in fact, the standing trees, though they had been infested, were now residue; and the beetles were gone. As a result of our survey findings, pest "control" funds, though requested, were not authorized to access those beetle-killed spruce. In 1971, 15 years later, a road was built and Bunker Creek was made accessible. The Engelmann spruce beetle residues were salvaged and ended up at the Hoerner-Waldorf pulp mill in Missoula, Montana. Payne (1969), in discussing the role of politics in the coniferous forests, cited the Bunker Creek controversy as a classic example of how pressure and political groups are involved in the management decisions in northern Rocky Mountain forests.

The Engelmann spruce windthrow illustrates a third implication of residue management: how our forest insect and disease problems change as old-growth forests are converted to stands of young trees. As the Engelmann spruce beetle problem diminished with the logging of progressively more mature and over-mature spruce during the past two decades, an increasing number of clearcuts have been planted to, or have naturally regenerated with, young Engelmann spruce. Damage to these young trees by the Engelmann spruce weevil, Pissodes strobi (Peck) (=engelmanni Hopkins) has steadily increased. These small weevils attack and kill or seriously injure terminal shoots of young trees, causing crooks in the trunk or a stunted, forked, and worthless tree (Keen 1952). By 1966, terminals destroyed by weevils were noticeable in most stands of spruce reproduction in the Northern Rockies; some were recurrently damaged (Tunnock 1966). By 1971, the weevil was distributed throughout young spruce stands in this region (McGregor and Quarles 1971) and terminal killing was prevalent in many areas. In some young trees, repeated attacks to live portions of the main bole killed the trees outright, or predisposed them to death by secondary insects. "In some areas," according to McGregor and Quarles (1971), "large blocks of young even-aged spruce offer ideal conditions for buildup and maintenance of weevil populations." No doubt this weevil will continue to be a serious problem in the management of young Engelmann spruce in the Northern Rockies.

The eruption of Mount Saint Helens has raised fears of windthrown residues predisposing forests to insects. High winds accompanying the 18 May 1980 eruption blew down millions of board feet of Douglas-fir timber growing on the mountain. Foresters are now worried that the downed residues may become infested with the Douglas-fir beetle, which may then spread to standing healthy trees farther from the mountain. Frank Kopecky, deputy regional forester in Portland, Oregon, says that the beetles could become "a major problem" in two or three years (Missoulian 1980).

RESIDUES CREATED BY OTHER AGENTS

Lightning may predispose trees and forest stands to insect attack when the struck trees do not ignite and burn. In the northern Rockies, Schmitz and Taylor (1969) document an instance where a 79-foot-tall, 24-inch-diameter (24 m, 0.6m) tree struck by lightning was infested along its entire length by bark beetles--the upper two-thirds by the pine engraver beetle, the mountain pine beetle at near mid-bole, and the western pine beetle and a pine engraver in the lower bole. Moreover, 76 percent of the immature trees within 80 feet (24.3 m) of the struck tree were attacked and became infested with pine engraver beetles (fig. 9). Schmitz and Taylor (1969) speculated that the infested trees surrounding the lightning-struck tree suffered lightning damage to their roots, predisposing them to pine engraver beetle attack. Schmitz (personal communication) believes that a lightning-struck tree is probably the most attractive of what we call "weakened" trees.

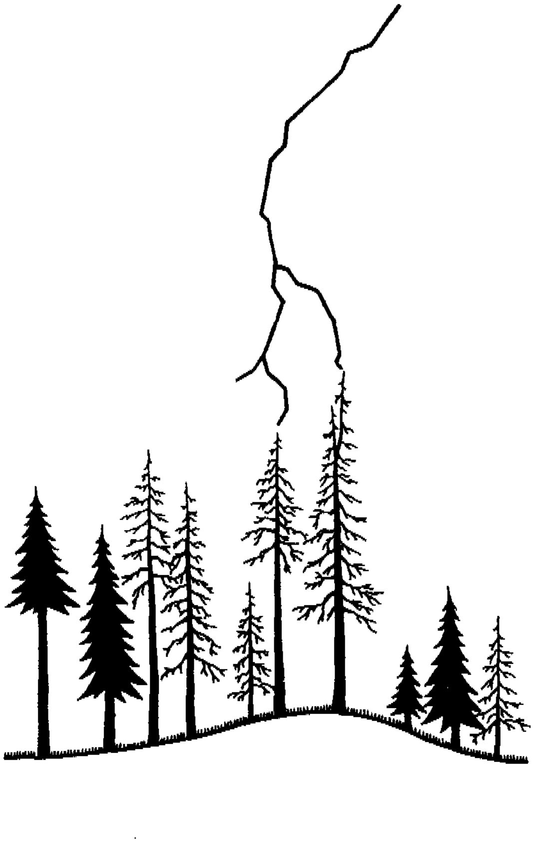

Figure 9.--Lightning, in addition to igniting fires predisposing forests to insects, often predisposes struck trees (when not ignited) and those surrounding them to various species of bark and engraver beetles. In the opinion of Dr. R. F. Schmitz (personal communication), lightning-struck trees are probably the most attractive to some insect species of those trees we call "weakened", by one cause or another.

In the South, the southern pine beetle, Dendroctonus frontalis (Zimm.), and Ips spp. are attracted to lightning-struck trees. Hodges and Pickard (1971) believe that lightning strikes are important in sustaining populations of the southern pine beetle. Hetrick (1949) has presented evidence that only when there is electrical injury to the roots of pines are the trees attacked by the southern pine beetle; electrical injuries confined only to the tops and trunks of trees are not followed by beetle attacks. In the West, Hopping (1925) found fire-scarred or lightning-struck pines to be more susceptible to insect attack than trees weakened by fungi or mistletoe.

Residues Created by Man

In the northern Rocky Mountains, the most significant forest insect problems associated with forest residues created by man's activities have developed as a result of precommercial thinning, particularly in species of pine. Probably the most widespread problem involves pine engraver beetles in ponderosa pine thinning slash.

In many cases, populations of engraver beetles, Ips spp., develop in thinning residue, often depending on the time at which residue is created. In the Northern Region (Tunnock, personal communication) as well as in the Pacific Northwest (Sartwell 1970; Mitchell and Sartwell 1974), thinning slash-residue deposited in the spring and summer is particularly attractive to engraver beetles. But if the material is thinned earlier, in March for example, the residue is unattractive by the time Ips begin flying.

Whether or not Ips broods that develop in the thinning residue "spill over" and infest crop trees or green trees in adjacent unthinned forests usually depends on the weather. If there has been a so-called "wet spring", residual crop trees are usually not infested. However, if the spring has been "dry", particularly during April-June, there will usually be significant mortality to residual trees. This latter situation has occurred in the northern Rockies, most recently in 1977. Also in the Pacific Northwest, residual trees are killed when drought accompanies thinning slash that is heavily infested with Ips engraver beetles (Dolph 1971).

In nearby Alberta, "flash insect outbreaks in lodgepole pine stands frequently result from the breeding of certain bark beetles..." (primarily several species of Ips) in slash remaining after logging operations (Reid 1955).

Graham (1922), in discussing insects that breed in residues and consequently are potentially injurious to standing green timber, cites Ips pini Say as a species that occasionally kills a few trees. Says Graham (1922): "...this species only kills living trees when it occurs in such large numbers that the attacked tree is quickly girdled, thus stopping the flow of resin."

Besides engraver beetles, some bark beetle populations develop as a result of residues created by man. In 1970 and 1971, populations of the Douglas-fir beetle built up in residues resulting from clearing operations associated with the construction of Dworshak Dam near Orofino, Idaho. Between 1972 and 1975, 111 million board feet of standing Douglas-fir were killed in forests adjacent to the reservoir (McGregor and others 1974).

In the interior of British Columbia, infestations of the Douglas-fir beetle are usually found where excess residue had been produced by logging operations, as well as in overmature stands (Walters and Graham 1952).

Bark and engraver beetles infesting thinning and logging residue are only a few of a series of insect species that successively inhabit and feed on slash and other forest residue until the wood has disintegrated completely (Adams 1915; Savely 1939). Thomas (1955) lists a series of four groups of arthropods that successively infest red and white pine logging slash: 1) bark beetles, 2) borers and weevils of the families Cerambycidae, Buprestidae, Pythidae, and Curculionidae, 3) parasites, 4) predators entirely dependent for food on the presence of insects in the first two groups.

In addition to bark and engraver beetles, thinning and logging slash predisposes forests to other types of forest insects (fig. 10). In Montana, Fellin and Schmidt (1966) observed a very close relationship between residues created by thinning young lodgepole pine stands and infestations of a needle-eating weevil, Magdalis gentilis Leconte. Although they were apparently neither feeding on or breeding in the residue, weevils were attracted to the thinned stands and fed on current year needles of crop trees, often resulting in a loss of 75 to 100 percent of the foliage. Fellin (1973) found that time of thinning was significant in determining whether these crop trees would be infested; when residues were not created before late July to mid-August, Magdalis infestations did not develop. In 1974, Magdalis populations were attracted to lodgepole pine thinning slash throughout 700 acres in the Moose Creek drainage of the Lewis and Clark National Forest in west-central Montana. There was heavy defoliation of the 1974 growth in most areas; in some stands 100 percent of the new growth was destroyed (Hamel and McGregor 1974).

Figure 10.--Although fire, windthrow, and other natural factors create substantial amounts of residue, predisposing forests to insects, man--through his own management actions--also creates vast amounts of forest residue through logging slash, precommercial thinnings, etc., predisposing forests to a wide variety of insect species.

In red pine stands in Ontario, Magdalis perforatus causes damage to young trees as a result of adult feeding, but population increases are usually related to pruning operations or mortality in young stands and not to thinning in older stands (Martin 1965).

In the Southeast, other species of weevils are influenced by forest residues, including stumps, also depending on when timber is harvested. In east Texas, Thatcher (1960) determined a relationship between the season in which pines were cut and emergence of the pitch-eating weevil, Pachylobius picivorus (Germar). Later, Speers

(1974) determined that the time of year in which timber is harvested affects the severity of killing of pine seedlings by both the pitch-eating weevil and the pales weevil, Hylobius pales (Herbst). In pine cuttings made after June and through the summer and fall, older weevils were attracted to the fresh stumps, from which they emerged to attack newly winter-planted seedlings.

Residues created by pruning in red pine forests also have been associated with populations of the pine root collar weevil, Hylobius radicis Buchanan, but were related to a decrease, rather than an increase, in populations and damage (Wilson 1967). Based on his previous research (Wilson 1966), and behavioral studies with the weevil, Wilson pruned the lower 3-5 whorls of branches from young red pines. This pruning, along with duff removal and soil scraping, allowed heat and light to penetrate the normally cool, dark daytime habitat of the weevil, reducing larval populations below an economic level for at least 1 year (Wilson 1967). Branch pruning to snow depth also has been reported (Miller 1967) to adequately and permanently control populations of the European pine shoot moth, Rhyacionia buoliana (Schiff).

The sequoia pitch moth, Vespamima sequoiae Hy. Edw., which infests pruned conifers, provides an interesting example of forest residues predisposing trees to insects through intense cultural practices. Fresh pruning scars, often associated with fuel-break pruning (Powers and Sundahl 1973), and associated resin flow where the living limbs are attached, attract the pitch moth (Weidman and Robbins 1947). Pitch moth attacks cause an additional accumulation of pitch, but larvae and pupae both tolerate it and are not drowned in the excessive amount of pitch exuded by attacked trees (Weidman and Robbins 1947). Although pitch moths usually do not kill trees, their attacks may weaken trees and render them more susceptible to bark beetles, Dendroctonus and Ips (Weidman and Robbins 1947). Aesthetic changes in trees, resin masses, and flowing pitch, may be the most important consequences of pitch moth attacks (Powers and Sundahl 1973). Pitch moths are also attracted to the large flow of resin at sapsucker drillings (Weidman and Robbins 1947) and to the wounds in the tree boles resulting from increment borings made by the investigators (Powers and Sundahl 1973).

In the stumps and slash of thinned red pine in Ontario, Martin (1965) found three groups of insects of potential economic importance--wood borers, bark beetles, and weevils. Although the wood borers are usually economically important because they downgrade sawn products, the red pine thinnings in this case were used for pulp, and wood borers were not of particular importance. One species of weevil, Pissodes approximatus, breeds in stumps, slash, logs, and dead standing trees; in Martin's study, this species killed many trees that may otherwise have survived drought, disease, planting shock, or other factors. Martin (1965) found that insects avoided or were not successful in establishing themselves in living stumps that were root-grafted to living trees.

In eastern Canada, many balsam fir trees damaged by the eastern spruce budworm are reportedly killed by the secondary attacks of the balsam bark beetle, Pityokteines sparsus Leconte. More trees are killed by the beetle in logging areas, indicating that logging residues are associated with an increase in beetle activity, since fewer trees were killed by beetles in areas where both logging and slash were absent (Graham 1922). In many areas of Montana and Utah, populations of Pityokteines and Pityogenes build up in logging and thinning slash, then move to the tops and branches of large residual ponderosa pine. In some areas, nearly every branch is attacked during the year when residues are created, with some branch killing the following year. Populations appear to wane after the second year.

In the northern Rockies, one conifer with minimal residue-insect problems, is western larch, Larix occidentalis Nutt. Though standing, live western larch has essentially no bark beetle (Dendroctonus) problems, long-butt residues are attractive to and suitable as a breeding substrate for the Douglas-fir beetle (R. F. Schmitz, personal communication).

HARVESTING PRACTICES INFLUENCE BEHAVIOR AND IMPACT OF FOREST INSECTS

Many species of forest insects are known to be influenced by the environmental changes brought about by silvicultural and stand management practices such as thinning, overstory removal, clearcutting, and prescribed burning. The ecological consequences of all types of cuttings--but especially clearcutting, which has been most intensively and most widely employed in coniferous forests of the northern Rocky Mountains--are incompletely or only partially understood and are the subject of increasing attention and debate. Changes in the forest alter micro (and macro) meteorological conditions such as light, wind, temperature (air and soil), evapotranspiration rates, and in turn affect nearly all flora and fauna either by outright killing of some plants or animals or by altering the environment, resulting in a modification of the behavior of the organism. The combined influence of all or some forest manipulations usually increases or decreases most species of forest insects by influencing the food supply, shelter, competition, vulnerability to predation, reproduction, and other behavioral habits, such as oviposition, dispersal, and feeding (fig. 11).

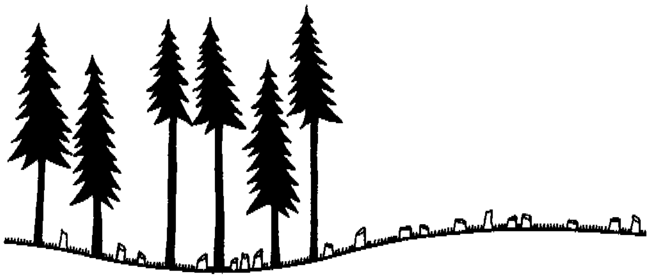

Figure 11.--A shelterwood and a clearcut with intensive residue utilization (mechanically removed). These harvesting practices, coupled with intensive fiber utilization, have varying effects on the behavior and impact of a variety of flying, surface, and soil insects.

In the northern Rockies, two widespread and destructive forest insects have plagued resource managers for decades--the western spruce budworm, principally in Douglas-fir and several other economically valuable species, and the mountain pine beetle, principally in lodgepole pine. Managers are interested in stand management practices that will reduce or ameliorate the impacts of either of these two, or any other insect species.

Western Spruce Budworm

In their most recent western spruce budworm management plan, resource managers in the Northern Region have chosen "silvicultural practices" over other alternatives, including the use of chemicals (USDA, FS 1977). This decision was largely intuitive because few studies have been made and little information exists relative to the relationships of stand manipulation and the behavior and impact of the western spruce budworm. Pursuant to the needs of resource managers, the entire western spruce budworm research effort in the northern Rockies is designed around silvicultural-entomological objectives. We are in our second year of three closely related and coordinated studies involving 1) the reciprocal relationships among the western spruce budworm and cone and seed production, 2) the influence of stand manipulations on behavior of the budworm, particularly dispersal patterns of both larvae and adults, and 3) the impact of the budworm on regeneration and residual stands within a matrix of variables involving cutting systems, forest series, size of cuttings, etc. (USDA, FS 1978a).

Mountain Pine Beetle

Based on empirical models that identify stand characteristics conducive to mountain pine beetle epidemics, W. Cole (1978) feels that harvesting or management strategies can be applied to prevent mountain pine beetle epidemics in lodgepole pine stands. Managers are faced with the challenge of lowering the probability that epidemics will occur within any given stand. W. Cole (1978) feels that managers can predict these probabilities from stand structure--i.e. principally diameter distribution and phloem distribution within diameters. In considering the alternatives presented, the manager must "...decide how much risk he is willing to accept if he desires large diameters, or be willing to accept and manage for smaller diameter stands" (W. Cole 1978). Amman (unpublished data) lists four main conditions that must be met for epidemics of mountain pine beetle to occur in lodgepole pine stands. These conditions are: 1) sufficient numbers of large diameter trees, 2) thick phloem in many of the large trees, 3) optimal temperature for beetle development, and 4) optimal tree age.

Other researchers agree that losses are related to tree diameter and phloem thickness, but feel that the most important factors in susceptibility are reduction of tree vigor and associated resistance; this, they feel, is why larger trees are successfully attacked. D. Cole (1978) recognizes the circumstantial evidence presented by both groups, but says "...neither has proved its case, especially as to whether managed stands will be more or less susceptible to attack than unmanaged stands and whether they will be susceptible sooner or later than unmanaged stands." Not unexpectedly, this research controversy presents the practicing silviculturist with a serious dilemma in determining the actual consequences of specific practices intended to minimize losses.

D. Cole (1978) discusses several silvicultural practices for reducing losses from the mountain pine beetle in lodgepole pine. He indicates that practices are available in each regeneration system for reducing losses either by lowering risk or recovering losses; however, the practices must be carefully selected and applied. He issues some reminders: 1) managers must be extremely cautious when using partial cutting, for any purpose, in lodgepole pine stands where sustained timber productivity is important; 2) practices implemented for reducing mountain pine beetle losses must be compatible with the major requirements of lodgepole pine silvicultural management systems; 3) "It is the forest that must be the <u>primary</u> focus of lodgepole pine management, and not the beetle." If we fail to recognize this, "...silvicultural recommendations may evolve that are too narrow in scope--perhaps solving some immediate problem, but creating greater long-term forest management problems" (D. Cole 1978).

At the present time, management of lodgepole pine stands in the northern Rockies is directed toward prevention, with emphasis on green stands and concurrently salvaging infested stands (McGregor 1979). In addition, research continues to develop methods 1) to prevent outbreaks from developing, 2) to obtain maximum wood and fiber production, 3) to develop knowledge of beetle-host tree interactions, and 4) to determine desirable stocking levels of insect and disease-free growing stock of desired species (McGregor 1979).

Researchers and managers in the northern Rocky Mountains and elsewhere in the West are also concerned with the mountain pine beetle in ponderosa pine forests. In Montana, McGregor (1973) indicates that thinning of second-growth ponderosa pine stands prior to beetle infestation will reduce susceptibility of individual trees to attack and decrease the number of attacked trees. As an example, on the Ninemile Ranger District in western Montana, second-growth ponderosa pine stands that were thinned to a basal area of 120 or less were not infested with the mountain pine beetle. At the same time beetles continued to infest stands with a basal area of more than 120, even more severly where the basal area exceeded 150.

In Oregon, Sartwell (1970, 1971) established that the severity of tree killing by the mountain pine beetle in second-growth ponderosa pine stands was related to stand density, and that thinning dense stands could be used to prevent outbreaks. He believes that beetles kill a larger proportion of trees in dense, overcrowded, and less vigorous stands, than in sparsely stocked stands. Sartwell (1971) and Sartwell and Stevens (1975) established that stands with well-spaced, thrifty trees can resist even the infestation pressures of an outbreak population.

Western Pine Beetle

Fifty-five years ago, Craighead (1925) recognized that each species of Dendroctonus presented a different problem in different regions as well as in different forest types, so that "control" methods could not be generalized to envelop the entire genus. Because the western pine beetle prefers overmature, slow-growing, decadent trees on poorer sites, Craighead suggested short rotations and cutting practices to encourage more rapid growth; light cutting in narrow strips, he said, "would largely prevent losses from the the beetle."

The Pine Engraver

In Alberta, Reid (1957) studied the bark beetle complex, especially Ips pini Say associated with slash created by five different cutting practices. He concluded that: 1) cutting to a diameter limit of 6.5 inches (16.5 cm) does not produce enough residue to constitute a beetle hazard; 2) clearcutting, or similar treatments, result in large volumes of slash and create the greatest beetle hazard; and 3) selection cutting, though creating large volumes of residue, provides environmental factors that favor predators and parasites of Ips, thereby reducing the beetle hazard to residual stands.

RESIDUE AND FIRE MANAGEMENT TO "CONTROL" INSECTS AND DISEASE

A multitude of interactions with several different diseases and a variety of insect species and groups (with different habits and economic impact) exist with both residue and fire management. In discussion some of these interactions, I use the word "control" with caution and interpret the word "residue" very broadly.

Diseases

The most noteworthy examples of fire and residue mangement involve three forest diseases: brownspot needle blight, Scirrhia acicola (Dearn.) Siggers, dwarf mistletoe, and root pathogens, principally Fomes annosus (Fr.) Cke.

As noted by Martin and others (1977) and Miller (1978), prescribed burning to control brownspot needle blight on long leaf pine, Pinus palustris L., seedlings provides a classic and outstanding example of the use of fire to control disease. Fire has been implicated in many aspects of the spread and intensification of dwarf mistletoes (Alexander and Hawksworth 1975), and fire is often used to burn the slash of infected trees in order to reduce the infection of new seedlings (Martin and others 1977). In discussing fire and dwarf mistletoe relationships in the northern Rocky Mountains, Wicker and Leaphart (1976) plead for planning management activities on the basis of habitat types. The authors are convinced that although fire, pests, and plants should be managed, "Man should strive to manage the total forest ecosystem and not to control or eradicate certain segments of it" (Wicker and Leaphart 1976). Repeated burning is known to have a suppressive effect on certain root pathogens (Froelich and others 1978). Prescribed fire reduces the incidence of Fomes annosus root rot (Martin and others 1977) and controls many other plant diseases (Hardisan 1976; Harvey and others 1976).

There are some other fire-disease interactions. Fire can act as a sterilizing agent in controlling some plant diseases by destroying insects acting as plant disease vectors (Ahlgren and Ahlgren 1960). Fire scars can serve as avenues of entry for many forest pathogens (Harvey and others 1976), and infested residues act as reservoirs that tend to propogate and increase pathological activity (Nelson and Harvey 1974; Mitchell and Sartwell 1974; Parmeter 1977). In some cases fire may favor the increase of disease by producing thick stands of the host plant, thereby inducing multiplication and spread (Ahlgren and Ahlgren 1960).

Insects

In the late 1800's and early 1900's, entomologists used prescribed fire to suppress insect populations (Komarek 1970), but fire prevention campaigns and insecticidal developments influenced later generations of entomologists to use methods other than fire. "Today, modern fire-use technology and renewed interest in alternative methods make fire attractive again as an insect management tool" (Miller 1978). Komarek (1970) summarizes the actions of fire on regulating insect populations and lists several variables that must be considered when studying or evaluating the effect of fire. Yet, he concludes that "...to what extent and how these changes occur has not been investigated," and "There appears to have been very little investigation regarding controlled burning and its effect on regulating forest insects" (Komarek 1970). Moreover, if an insect pest is to be controlled with fire, its life history must be known in detail in order for fire to be used at the most appropriate time (Lyon and others 1978). I will summarize a few fire-residue-forest insect relationships--bark and engraver beetles, wood borers, weevils and others.

BARK BEETLES

Of all the forest fire-forest - residue-forest insect interactions in the northern Rocky Mountains, probably the most interesting, controversial and sociopolitical event involves the tremendous amounts of lodgepole pine residues created by the mountain pine beetle and fire management related to those residue.

D. Cole (1978) recommends consideration of prescribed fire as an important long-range management alternative in integrated programs for controlling losses to the mountain pine beetle in commercial lodgepole pine forests in the northern Rocky Mountains. Stagnated stands, past the point of responding to cultural treatments, eventually will be susceptible to the beetle. In these kinds of stands, D. Cole (1978) indicates that "...prescribed fire can be a valuable silvicultural practice for bringing the stands under management by 'starting over'"--a different aspect of insect control through prescribed fire. Martin and others (1977) report that fire may be used to control spacing and thus reduce the severity of attacks by the mountain pine beetle.

Management of lodgepole pine residues--created by the mountain pine beetle--in Glacier National Park and the adjacent Flathead National Forest is at this time embroiled in controversy. One element of the controversy involves restraining the "spread" of the infestation. At this time there are some 30-40 million dead lodgepole pine trees--standing residue--killed by the mountain pine beetle on the east side of the Flathead River in Glacier National Park (Scott Tunnock, personal communication). Mark McGregor, a Forest Service entomologist, "is irritated because the National Park Service did nothing to stop the beetles from spreading..." from inside the Park to infest thousands of acres on the adjacent Flathead National Forest (Kuglin 1980). McGregor feels that "the infested stands could have been logged in an attempt to stem the infestation." National Park Service biologist Robert Hall responds that the national park manages its forests, not to produce timber but for people to enjoy. Hall said, "Tourists are curious when they see thousands of red-brown trees. We try to explain to people that this is a natural thing and that we don't log in National Parks" (Kuglin 1980).

Another element of the controversy involves the use of prescribed fire in managing the lodgepole pine residues. During the summer of 1979, park personnel planned to prescribe-burn patches of the residues to break up and diversify the stands. [One of the alternatives of the park's fire management plan is to introduce fire where a specific major need is demonstrated (Glacier Nat. Park 1978)]. The plan was not effected because of an extreme fire season. While some parks allow certain wildfires to burn under a pre-determined prescription--a "let burn policy"--some critics considered the Glacier Park burning plan tantamount to forest management, thus contrary to national park management philosophy.

In other fire-residue-insect relationships, Mitchell and Sartwell (1974) cite several authors who generally have supported the recommendation that tree killing can be prevented by burning or otherwise removing bark beetle-infested residues from which beetle progeny presumably emerge and attack live standing trees (fig. 12). Contemporary investigators, as well as some who worked in the 1920's, feel that this "build up" philosophy is too simplistic, that residues attract beetles and concentrates them in smaller areas where they can do more damage to standing trees than if widely dispersed. They support their contention by citing the behavioral patterns of the Douglas-fir beetle, when outbreaks of this beetle develop, "...many standing trees are killed during the time nearby residues are under attack" (Mitchell and Sartwell 1974).

Figure 12.--A shelterwood cut with intensive residue utilization (mechanically removed) and residues being burned. Removal and utilization of residues obviously eliminates the problems of insects developing in the residue. Prescribed burning of the residues usually prepares the site for regeneration, and kills most "destructive" as well as "beneficial" species inhabiting the residues.

An interesting twist to bark beetle control through fire has been reported with the western pine beetle in ponderosa pine. Miller and Patterson (1927) reported that although fire-injured trees attracted beetles to concentrate within trees in the burned area, the trees afforded a very unfavorable breeding ground for the insects and in the end contributed toward an actual reduction of their numbers. Nevertheless, Miller and Patterson (1927) concluded that fires do not markedly assist in eliminating populations of the western pine beetle unless the fires are severe enough to kill the trees.

ENGRAVER BEETLES

The philosophy that fire may be used to destroy infested residue or logs, aiding in the control of insects (Martin and others 1977), often applies to engraver beetles, especially Ips spp., in some pine species. If crop trees are only scorched, however, prescribed burning may merely predispose them to Ips attack. Some species of engraver beetles spend part of their life cycle in the forest floor (duff); the deeper the litter, the better the protection for the beetles. Eliminating prescribed fire in pine stands where slash has been created not only benefits beetles in the residue but also those aestivating in the forest floor (R. F. Schmitz, personal communication).

WOOD BORERS

Mitchell and Martin (In Press) suggest that prescribed burning to reduce fuel loads of residues serves two functions: 1) it not only consumes the residues, but also 2) attracts wood borers to the larger partially burned or unburned logs. Borers will initiate decomposition by loosening the bark, creating holes in the wood and introducing wood-destroying fungi. Evans (1971) suggests that the role of *Melanophila* wood borers should be considered in any prescribed burn program, not only because of their usefulness in residue deterioration but also because of their contribution to fire-induced increases in species diversity. Dahl (1971) found no relation between the mortality of *Monochamus* wood borers and the height of lodgepole pine slash above the ground in prescribed fires of low and moderate intensity, although at the ground level *Monochamus* mortality was increased.

OTHER INSECT SPECIES

Several species of weevils, some cone and seed insects and some other insect species that spend a portion of their life cycle in the forest floor, are also involved in the interactions of residue and fire management.

Earlier I mentioned that the killing of pine seedlings by two weevils, the pales weevil and pitcheating weevil, is influenced by the time of year during which timber is harvested. Fox and Hill (1975) studied the effects of prescribed burning in standing and cutover areas on the behavior of these two weevil species and found that: 1) the pales weevil showed a positive preference for cutover areas, but residues and debris burned after logging were a deterrent for this species; and 2) both burned and cutover areas were attractive to the pitcheating weevil. These differences in the relative attractiveness of burned and unburned areas can influence the management of pine forest land, especially when prescribed fire is used in preparing the site (Fox and Hill 1973).

Prescribed fire can aggravate damage to conifer seedlings by another species of weevil. In British Columbia, the weevil, *Steremnius carinatus* Boh. recently began causing significant damage to seedlings. Prescribed burning of surface residue, "...often necessary to reduce brush competition for seedlings, destroys the natural vegetation and materials the weevils normally eat, and focuses the attention of the weevils on newly planted seedlings" (Condrashoff 1969). "In some plantations, weevils have killed or damaged over 40 percent of Douglas-fir seedlings planted on recently logged and burned sites along the west coast of Vancouver Island (LeJeune 1962).

Logging and residue removal has been shown to kill sugar pine cone beetles, *Conophthorus lambertianae* Hopkins. In the laboratory, Bedard (1966), found high mortality rates in these beetles exposed to temperatures greater than 47° C, indicating that high temperatures from direct sunlight could have the same effect. Bedard (1966) noted that when logging operations open up the tree canopy, and when the residues have been removed, ideal conditions of radiation are established for high temperature mortality of this beetle. In seed production areas in the Lake States, burning is reported to be effective in controlling the red pine cone beetle (Miller 1978).

In the Lake States Simmons and others (1977) determined that prescribed burning to control the maple leaf cutter (Paraclemensia acerifoliella (Fitch)), which pupates in the forest floor, was more effective than insecticide treatments.

RESIDUE AND FIRE MANAGEMENT--SOME OPINIONS

Since the early 1900's, there has been an evolution in philosophy and strategy concerning the management of forest residues. Two issues are involved: 1) residue management and utilization as it involves protection from wildfire, and 2) residues triggering forest insect and disease outbreaks.

In the early 1900's, Mitchell (1913) indicated that in California the piling and burning of residue was the accepted method because of 1) a desire to render the cutover area as fireproof as possible, 2) the belief that protection of litter was not necessary to insure reproduction, and 3) a desire to make the area as sightly as possible. There was considerable controversy as to whether the increased protection from wildfire by prescribed burning offset the danger involved, the expense, and the damage to reproduction and standing timber.

The issue of the expense of burning forest residue was echoed the following year by Koch (1914) in the northern Rocky Mountains. Citing examples on the Lolo National Forest in western Montana, Koch 1) questioned the risk (to wildfire) of unburned residue, and 2) chided the Forest Service for "...piling brush just because we have always piled brush...," adding, "it is time for us to quit blindly following precedent and at least make a serious investigation of the possibility of less expensive methods of protection."

Shortly thereafter, Hopping (1915) acknowleged Mitchell's and Koch's concerns about protection and cost-benefits, but mentioned another protection aspect--the dangers of insect infestations that can result from destructive insects breeding in unburned forest residues. Citing several examples to support his point, Hopping concluded by saying that "...the consideration of the burning or non-burning of brush must be taken up from a broad protection standpoint and not from the standpoint of fire risk or cost alone."

Later, in studying residue management in the Lake States, Mitchell (1921) advocated intensive protection rather than prescribed burning. He felt that destroying the residue by burning did not materially reduce the fire hazard because 1) of the litter accumulation normally present and 2) the close utilization of cedar and spruce for pulp and posts resulted in little reside created. Moreover, Mitchell believed that prescribed burning actually increased the fire hazard by killing, but not consuming, reproduction, as well as damaging or destroying the soil organic layer.

The following year, Graham (1922) discussed the entomological aspect of the residue management problem, and pointed out that 1) "...we are burning up valuable humus in our slash piles," 2) smaller pieces of residues are unfavorable to insect development, while larger branches, tops and broken logs are the most suitable breeding places, and 3) larger pieces of residue are more difficult to burn, do not materially increase the danger of wildfire, and after burning usually remain on the ground uncharred. Graham (1922) concluded that in the Northeast prescribed burning is not the best way to manage residue, nor can it be recommended or is "...as effective a factor in forest insect control as has been generally believed."

Still, by 1938, there was a feeling that fire was commonly used for forest insect "control" (Haig 1938), and as recently as 1973 the disposal of forest residues by fire was often being prescribed to prevent insect populations from developing in forest residue, or to prevent insect populations from moving from the residue to green standing timber (Brown and Davis 1973).

Prior to concluding this discussion of fire and residue management opinions, I must mention that Mitchell (1913) not only had strong feelings of how residues should be managed in California, but also of the kind of labor that should be used. His words are rather strong and may be as controversial now as they probably were then. Sixty-six years ago, Mitchell (1913) wrote:

> "In California foreign labor, preferably Italian, for this class of work is, if properly supervised, probably the cheapest. There are two fundamental reasons for this aside from wages. In the first place, the foreigner is usually not afraid of work, and in the second does not consider his work beneath him. In addition, he is usually as quick to grasp the idea of how the work is to be done as the average "white man" and can generally be trusted not to soldier on the job. On the other hand, the average woods worker who has not raised himself out ot the "swampers" class is too often either lazy, incompetent, or both. As a rule, too, he is too good for his job, takes little or no interest in his work, and if left alone is pretty apt to spend his time in seeing how little he can accomplish."

In concluding these thoughts, observations, and opinions concerning residue and fire management in relation to insects and diseases, we are reminded that there are some who feel that fires have historically kept pest populations at low levels before the Forest Service existed (USDA, FS 1975c).

IMPACT OF HARVESTING RESIDUE MANAGEMENT AND FIRE ON FOREST FLOOR AND FOREST SOIL ARTHROPODS

Of all the interactions among forest residues, fires, and insects, probably none has received less attention and is as casually dismissed as the interaction among residues, fire, forest floor, and forest soil arthropods. Research scientists and land managers in the western States recently considered this as one of a dozen areas of fire ecology research needs (Kickert and others 1976).

It is a common practice in the northern Rocky Mountains and elsewhere to burn forest residues and unmerchantable trees after logging. Such fires consume varying levels of duff, exposing proportionate amounts of mineral soil. Partially or completely exposing mineral soil is desirable as a seedbed for germinating many species of trees and as a planting site for coniferous seedlings. Burning also removes vegetation that competes with developing young trees, and logging followed by prescribed burning usually provides desirable habitat for wildlife, particularly ungulates--a habitat that often is more favorable than that provided by dense forest cover.

While providing a desirable environment both for forest regeneration, and for many forest animals, fires also influence other forest flora and fauna, and fire variability makes generalizations concerning fire effects difficult (Lyon and others 1978). However, fires not only affect the flora and fauna within deteriorating residues, but also the habitat of the fauna that utilize the forest floor and the upper layers of mineral soil by altering the environment and food supply on and in the ground. Generally, invertebrates, often "undesirables," decrease in number following a burn (Reichert and Reeder 1972), usually because the animals or their eggs are killed by flame or heat, and their food supply and shelter are diminished. The effects of fire on invertebrate populations may be transitory or long lasting, as well as selective and varying among species; in some cases burning also destroys natural predators of pest species. Analyzing the effect of residue management and prescribed fire on forest floor and soil invertebrates is complicated by the fact that we still do not always know which are our friends and which are our enemies.

Most of the organisms that live in forest residues, the forest floor, and forest soil, are decidedly beneficial. The species and groups involved include not only natural enemies of pests, but also organisms that decompose residues. The series of events in the decomposition and fragmentation of residues is initiated by several species of beetles that loosen the bark on the residues as well as introduce wood-decaying fungi. As described by Mitchell and Sartwell (1974):

> "This is followed by a progression of other arthropods, each contributing to the fragmentation of the material (Wickman 1965; Elton 1966). Following bark beetles are wood borers such as ambrosia beetles (Scolytidae), flat-and round-headed borers (Buprestidae and Cerambycidae), termites (Isoptera), horntails (Siricidae), carpenter bees (Apidae), and carpenter ants (Formicidae). These insects bore holes deep into the wood and also introduce wood-destroying fungi (Boyce 1923, Shea and Johnson 1962, Wright and others 1956, Wright and Harvey 1967, Kimmey and Furniss 1943)."

Although decomposition itself is largely a microbial process, fragmentation of the material is largely an arthropod process. This fragmentation may increase the area of residues exposed to microbial activity by up to 15 times compared to unfragmented residues (Witkamp 1971). Moreover, the fecal material produced by these species of arthropod "fragmenters" encourages the growth of decomposing microbes, particularly bacteria (Crossley 1970).

Following the arthropod "fragmenters", forest floor and forest soil mesofauna (intermediate-sized organisms) are the next arthropod group in the decomposition process; most are various species of mites and Collembola with a wide variety of feeding habits. Many are saprophytes that feed on bacteria, fungal hypae, or other living plants or animals. Although they do not directly contribute to chemical decomposition of litter nor to the turnover of plant nutrients, they play a major role in the process by breaking organic tissue into smaller pieces. The smaller these particles become, the more susceptible they are to action by other organisms, such as bacteria and fungi, involved directly in the decomposition process (Metz and Farrier 1971).

"Harmful" forest floor or forest soil fauna can only be categorized as such insofar as they act or feed in a way that is in competition with, or counter to, what man wants out of the resource. For the most part, harmful insects include those that feed on seeds, seedlings, or sprouts of desirable coniferous and broad leaf species.

Different investigators have used several systems to categorize the arthropods in the forest floor and forest soil. In the following discussion, I will refer to those invertebrates that inhabit and move about in the forest litter as forest floor macrofauna, (surface arthropods) and to those that are generally smaller, less mobile, and occupy the humus and forest soil, as forest soil mesofauna.

Forest Floor Macrofauna

Many studies have been made throughout the United States concerning the impact of harvesting, residue management, and fire on forest floor macrofauna. Some of these studies were concerned with the effects of macrofauna on direct seeding. Though not designed to determine effects of residue and fire management, results of these studies could have implications in the management of residues and prescribed fire; the studies will be reviewed here.

RESEARCH IN THE NORTHERN ROCKY MOUNTAINS

In the northern Rocky Mountains three studies in the past 10 years have focused on the effects of forest residue and prescribed fire management or wildfire on forest floor macrofauna (Fellin and Kennedy 1972; Clayton 1975; and Fellin 1980b). These three studies were preceded by, and related to, several studies involving forest floor macrofauna and direct seeding and planting.

In the northern Rockies, most evidence that insects are involved in direct or indirect seeding efforts has been circumstantial (Kennedy and Fellin 1969). Wahlenberg (1925) summarized the results of past direct-seeding projects in the northern Rocky Mountain region and attributed the death of an undetermined number of western white pine seedlings to cutworm larvae. Haig (1936), and Haig and others (1941) noted that soil insects, chiefly cutworm (Noctuidae=Phalaenidae) larvae, were one of the most important direct agents of conifer seedling mortality in the western white pine type in northern Idaho. Schopmeyer (1939), and Schopmeyer and Helmers (1947), determined that either cutting or clipping were the major kinds of injury to direct-seeded western white pine during the first growing season. They observed several forms of cutting in both screened spots and unscreened spots; they speculated that "cutworms, grasshoppers, and other insects may have had a part" in causing the damage.

Fellin and Kennedy (1972) studied the abundance of some arthropods inhabiting the forest floor in three clearcut areas that were prescribed burned in 1960, 1961, and 1962, in north-central Idaho. Generally, they found more arthropods present and more taxa represented on the older burns, and attributed this greater relative abundance of individuals to movement from adjacent unburned forests, and repopulation from survivors within the burned areas. The most abundant arthropod in soil samples on the oldest burn was the carabid, Amara erratica (Sturm). A projection based on sample data from the 1960 burn indicated there could have been up to 100 carabids per square yard ($0.836m^2$) of soil surface. Because of the abundance of this carabid --and its seed-eating behavior-and because of one or more species of grasshoppers and cutworms, Kennedy and Fellin (1969) recommended that direct seeding of western white pine and perhaps other conifers be done the first or second season after prescribed burning.

The second research program on forest floor macrofauna in the northern Rockies was conducted by Clayton (1975). He studied forest floor insects where a wildfire had been allowed to burn as a "prescribed fire" in a wilderness fire management area. The fire was ignited by lightning on August 10, 1973, burned for 43 days and eventually covered 1,200 acres (486 ha). Although the fire did burn intensely in some stands of trees, most of the area was only lightly burned by surface fire. By summer of 1974 one had to look closely in places to see exactly where the fire had burned and where it had not.

Regardless of the light burn, Clayton (1975) found that 7 out of the 13 groups of arthropods studied showed a significantly greater number of individuals in the burned areas of hillsides and streamside than in unburned areas. On the other hand, four groups were more numerous in the control areas than in the burns. Clayton concluded that the effects of even a relatively light fire on the arthropod community can be easily seen a year later.

The third study of forest residues, prescribed fire and forest floor macrofauna was done between 1975 and 1977; results of that study are reported elsewhere in this proceedings (Fellin 1980b).

RESEARCH ELSEWHERE IN THE UNITED STATES

Probably the first research done in this country concerning prescribed burning and forest floor fauna was done by Pearse (1943) on the Duke University forest. He found that earthworms, centipedes, millipedes, ants, and nesting pollinators were "significantly--often seriously--reduced" in numbers after a prescribed fire. Moreover, mechanical removal of litter was even more detrimental to these organisms than was prescribed burning. One deficiency in Pearse's study was that samples were hand-sorted without magnification, so many small arthropods were no doubt overlooked in his sampling.

Several researchers have reported the effects of macrofauna on seeds and seedlings. The importance of soil-inhabiting invertebrates in the destruction of sown Douglas-fir seed in Washington was clearly demonstrated in a detailed study of the fate of 440 radio-tagged seeds by Lawrence and Rediske (1962). Soil-surface invertebrates were found to have destroyed 11 percent of the seeds observed over a period of 22 weeks. In a northern California study of 3,200 tagged seeds, 29 percent were destroyed by soil-surface-inhabiting invertebrates (Johnson and others 1966). Also in California, cutworms damaged pine seedlings (Fowells 1940), usually by clipping seedlings in groups. In Florida, tiger moth larvae Apantesis radians Wlk. (Arctiidae) damaged pine seedlings (Ebel 1967). In a study of seedspotting in Oregon (Franklin and Hoffman 1968), insects and other animals (rodents, birds, slugs, and shrews) were believed responsible for one-third of the mortality of western white pine germinants.

Several studies have shown that populations of surface arthropods (macrofauna) in the forest floor decreased after fire. Buffington (1967) compared populations of invertebrates in the forest floor and surface soil of burned and non-burned areas about a year after a wildfire in the pine barrens of New Jersey. His samples from unburned areas were usually richer than those from burns, in numbers of both taxa and individuals. In an area of shrub steppe vegetation in southeastern Washington, two species of beetles were significantly reduced by a wildfire (Rickard 1970). In Australia, both wild and prescribed fires reduce populations of phasmatids if the forest floor is completely consumed (Campbell 1961), and "fuel reduction fires" of low intensity substantially reduce populations of forest floor fauna (Leonard 1977). In African soils, burning destroys populations of termites and results in impoverishment of these tropical soils (Reichert and Reeder 1972).

Although most groups of macrofauna are reduced by fire, in some instances, prescribed burning, often in prairies and grassland, increases arthropod density and biomass. Following a prescribed burn in a grassland area (formerly a pine-hardwood forest), populations of herbivores (phytophagous) increased, presumably as a result of an increase in the food supply; at the same time, other groups such as predaceous spiders, flies, and scavengers showed less response to burning (Hurst 1970).

There are at least three reports of grasshoppers being more numerous in burned than unburned areas. In the northern Rockies, Clayton (1975) found the orthopteran family Acrididae to be more numerous in burned than in unburned coniferous forests, and Hurst (1970) reports grasshoppers to have increased in numbers after prairie and grassland fires. In a northern Minnesota jack pine burn, grasshoppers increased after a fire, possibly due to recolonization from adjacent unburned forests or from survival in patches of unburned ground (Ahlgren 1974). This recolonization from without or repopulation from within burned areas could be a very significant behavioral mechanism regarding the long-term effects of fire on forest floor macrofauna.

There are some interesting evolutionary adaptations and implications among some groups of insects surviving fires or inhabiting or recolonizing burned areas. In Montana, Clayton (1975) collected grasshoppers from burned and unburned areas, ranked them from dark to light and determined that out of 60 specimens, the 20 most darkest were from the burned area. Several investigators have reported melanistic forms of grasshoppers and other orthopterans, pentatomid bugs and noctuid larvae to inhabit burned areas in African savannas (Reichert and Reeder 1972). Many species of rodents and birds in grassland fire environments have color patterns that harmonize with burned or partially burned vegetation. Such camouflage is useful to these species, since some predators seem also to be adapted to fires, and will congregate at fires to feed on prey animals previously out of sight in the grass (Stoddard 1963; Komarek 1969).

RESEARCH ON IMPORTANT ARTHROPOD GROUPS

Of the forest floor macrofauna influenced by harvesting residue and fire management practices, at least three orders of arthropods deserve special attention because of their feeding behavior or their response to silvicultural or residue treatment. They are: Coleoptera (beetles), Hymenoptera (mainly ants), and Araneida (spiders).

Coleoptera

Of all the forest floor macrofauna, the beetles are probably the most abundant. Two to four families usually predominate. In a study of soil invertebrates in two aspen forests in northern Minnesota, Wagner and others (1977) collected 22 families of beetles in the soil litter environment. The numerically dominant taxa were rove beetles (Staphylidnidae), ground beetles (Carabidae), click beetles (Elateridae), and soldier beetles (Cantharidae). In a recent study in Montana (Fellin 1980b), carabids and staphylinids were the predominant families.

Some investigators have found that burning reduces beetle populations. Ahlgren (1974) reports that in forested areas fire reduced most beetle genera at least temporarily; she found fewer beetles on burned than on unburned land the first three months after prescribed burning in Minnesota jack pine stands. In southern pine stands, a 60 percent decrease in beetle populations was noticed in burned areas (Pearse 1943; Heyward and Tissot 1936). In the New Jersey pine barrens, four times more beetles were found on unburned than on burned land (Buffington 1967).

In other studies, researchers report that beetle populations increased following burning: 1) Tester and Marshall (1961) found beetle numbers to increase following burning in a Minnesota prairie, 2) beetles increased in number on burned transmission lines in Mississippi, and 3) in an Illinois prairie, after an initial reduction, beetles recolonized rapidly following burning (Rice 1932). Ahlgren (1974) reports that beetle populations in grasslands and prairies are not as affected by fire as they are in the forest, partly because of lower soil temperatures during fires and partially because of the safety in partially burned grass tussocks. It would appear that in prescribed burning in coniferous forests, particularly in partial cuttings where residue is not as abundant, that beetles, as well as other arthropods, could seek refuge from which burned areas could be quickly repopulated following burning.

In Finland, Huhta and others (1962) found the density of adult Coleoptera to be very high the first year after clearcutting and to remain high also during the second year, but to begin to decrease in the third year after clearcutting. Subsequent burning apparently had no serious effect on the beetles. These investigators felt that adult beetles are so swift that they can presumably escape danger by running into cracks and holes, which if deep enough, will allow the animals to survive until the fire passes by. Later, in comparing types of clearcutting, Huhta (1976) found beetles (other than Staphylinidae) to be most abundant in a young clearcut area stocked with pine seedlings and without a shrub layer. All clearcut areas harbored significantly lower numbers of beetle larvae than the untreated control site. Huhta (1976) cites other investigators who report a decrease in total density of Coleoptera after cutting.

Coleoptera (Carabidae).--Probably one of the most important groups of forest floor arthropods are the ground beetles, or carabids. Though a few species climb, fly, or both, most are restricted to the ground level (Kulman 1974) and are vulnerable to harvesting, residue, and fire management practices. Among the numerous species are those that are both "beneficial" and "harmful". I would like to review four aspects of carabid ecology: 1) as affected by fire, 2) as biological control agents, 3) as seed eaters, and 4) as influenced by the forest environment.

Carabids and fire.--As with some other groups of Coleoptera, some species of carabids are influenced by prescribed burning and wildfire. In an area where wildfire had been allowed to burn in western Montana, Clayton (1975) found carabids to be more numerous on unburned control areas than on burned sites. Within the burned area, he found more carabids in a riparian woodland along a creek bank than on a south slope ponderosa pine savanna. In a study of carabids in Florida pine forests which had either been burned annually or unburned for 10 years or longer, Harris and Whitcomb (1974) collected 85 percent of the beetles (representing 7 species in 4 genera) in plots that had not been burned for 10 years, and where leaf litter was present following fire, compared to annually burned forests. In Australian *Pinus radiata* plantations, French and Keirle (1969) found that carabids were reduced immediately after fire, but they were the first group of insects to recolonize burned areas.

Carabids as biological control agents.--Many species of carabids feed on other insects near, on, or in the ground, as well as larvae that drop to the forest floor from trees above (Kulman 1974). As such, they effect a certain amount of biological control against several species of forest insects, including the gypsy moth, Porthetria dispar (L.), the eastern spruce budworm, and a species of sawfly.

Kulman (1974) cites earlier investigators who report that in some areas the ground beetle, Calosoma sycophanta was the most important single control factor of the gypsy moth. More recently, however, Campbell (1967) considers that C. sycophanta probably can be an effective population influencing factor only in areas where dense host populations have persisted for several years.

Calosoma frigidum (Kearby), is reported as a predator of the eastern spruce budworm. In two white spruce plantations near Sault Ste. Marie, Ontario, these large black carabids were observed crawling over the foliage and eating budworm larvae; they also seized and ate larvae placed in front of them (fig. 13). Although no quantitative data is available on the impact of these carabids on budworm populations, investigators (Sanders and Van Frankenhuyzen 1979) feel that the size, numbers, and manner of searching the current foliage suggests that the beetles may have played an important role in reducing spruce budworm populations in these two white spruce plantations.

As a portion of a larger study of natural enemies of the eastern spruce budworm (Jennings and others 1979) Reeves and Jennings (1977) are studying carabid beetles associated with the spruce budworm. One of their objectives is to determine if stand composition and spruce budworm infestation can be correlated with carabid beetle populations. Other studies show that some species of ground beetles are efficient predators of spruce budworm larvae that reach the forest floor (Krall and Simmons 1977, 1979). This happens most commonly when all the new foliage has been consumed and budworm larvae spin down to the ground or low vegetation.

In a study of two jack pine stands lightly infested with Neodiprion swainei Midd., Tostowaryk (1973) found three species of Pterostichus preyed to a limited amount on sawfly cocoons, but the ground beetles preferred fly puparia. Tostowaryk (1973) concludes that these carabids are probably only of minor importance in the control of N. swainei.

Carabids as seed eaters.--Many species of carabids are phytophagous (plant feeders), often feeding on conifer seeds or seedlings. Johnson and Cameron (1969) list 159 species of Carabidae belonging to 33 genera that are known to use vegetable matter as food in varying degrees, with some species using it almost exclusively. Certain genera feed on berries, seeds, tender shoots, and pollen and foliage of plants (Essig 1942). Species in the genera Harpalus, Zabrus, Omophran, and Amara eat cereal and seeds of plants (Imms 1948). Of those species that use vegetable matter as food, species in nine genera are known to feed on coniferous seeds and seedlings.

In the northern Rockies, Kennedy and Fellin (1969) found the carabid, Amara erratica to be the principal insect destroying western white pine seeds after direct seeding in clearcut areas that had been prescribed burned in northern Idaho. They indicated that spring sowing of seeds treated with Endrin, Arasan, and aluminum powder prevented carabid damage to seeds. However, Johnson and others (1966) indicate that "apparently the protective coatings currently in use for reducing seed losses to birds and rodents have little adverse effect on the ground beetles."

In Washington, Johnson and others (1966) found the carabid, Amara sp. to be of minor importance as a seed-eater, but at least six other species of carabids were found to feed on conifer seed. One species was most abundant in open areas and recently logged habitats; another species ate seeds over which bark or wood chips had

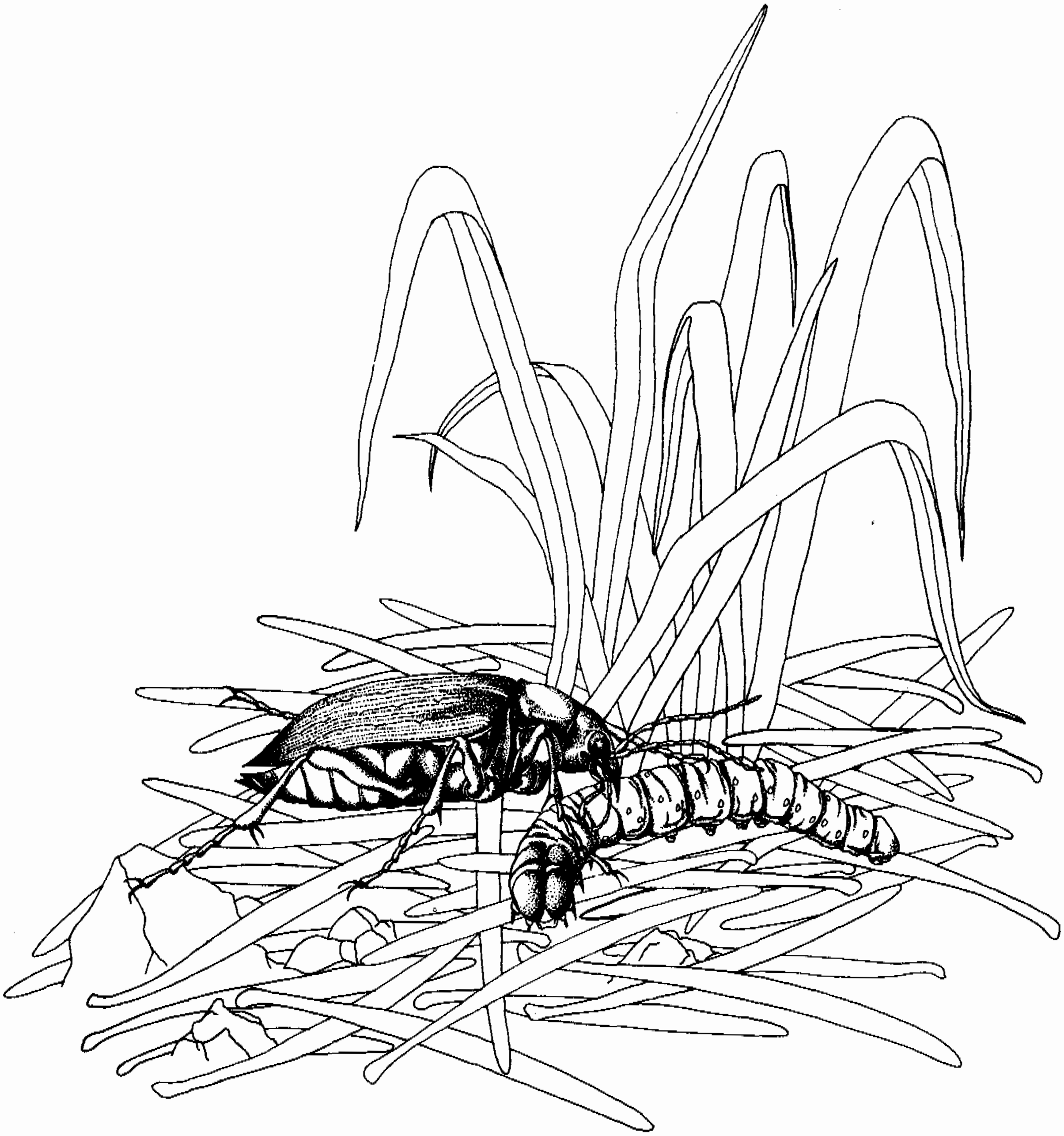

Figure 13.--Ground beetles (Carabidae) are one of the more important groups of forest floor arthropods. Some species feed on plant materials, including conifer seeds. Most species are predators, feeding on insects and other arthropods on the soil surface, as well as larvae, such as spruce budworm, that drop to the forest floor from trees above (Kulman 1974).

been placed for protection from rodents (Dick and Johnson 1958). One species, *Harpalus cautus* (DeJean) was often found under pieces of bark or wood lying on the ground, but quickly moved to a new place of shelter if the wood chip was removed. This behavioral trait, probably common to many carabid species, has implications in residue management practices and forest regeneration programs.

Seed caching has been reported for at least 3 species of carabids--*Harpalus pennsylvanicus* (DeGeer), *H. erraticus* Say (Kirk 1972), and *Synuchus* sp. (Manley 1971). Some species, even though they cache seeds, apparently do not eat them.

Carabid beetle damage to conifer seed is common in Europe (Nüsslin and Rhumbler 1922; Gäbler 1954). *Harpalus pubescens* (Müll) feeds on seed and seedlings of conifers (usually chewing seedlings off just above the ground surface). Species of *Pterostichus*, *Calathus*, *Poecilus*, *Bembidian*, and *Harpalus* feed on seed in nurseries (Nüsslin and Rhumbler 1922; Gäbler 1964.) Beetles in the genus *Harpalus* have destroyed up to 80 percent of the seeds and seedlings in nursery beds.

Carabids and the forest environment.--Several investigations have shown some important relationships between the forest environment and carabid behavior. Johnson and his colleagues (1966) studied the relative abundance and seasonal occurrence of six species of *Pterostichus*--all seed eaters--in three vegetation cover types near Chehalis, Wash. Of the six species, *P. algidus* (LeConte) was the most abundant, especially during October in an open grown and recently logged habitat. Another species, *P. vulgaris* was the most abundant from July to September and also more abundant in open stands and on recently logged land than in dense forest cover. Peak numbers occurred during the period of natural seed fall and prior to the time that direct seeding would take place.

From the results of a study of carabids in trembling aspen, *Populus tremuloides* Mich., stands defoliated by the forest tent caterpillar, *Malacosoma disstria* Hübner, Kulman, Grim, and Witter (In Press) speculated that several species of ground beetles preferred stands with less ground cover and greater humidity-both factors being related to less exposure of the forest floor in non-defoliated stands. Stands exposed and grassy from 4 years of defoliation were apparently unattractive to at least three species studied.

Studies in Minnesota show the relationships of tree species cover on carabid fauna. In northern Minnesota, Kulman and Cushwa (In Press) found *Synuchus impunctatus* Say to be most abundant in aspen stands and *Calathus ingratus* (DeJean) most abundant in jack pine stands. *Pterostichus adstrictus* was the most abundant beetle in all stands. In southern Minnesota, the abundance of several carabid species varied between stands of red oak, *Quercus borealis* Mich., trembling aspen, and sugar maple, *Acer saccharum* Marsh (Kulman, Witter, and Skalbeck, In Press).

Martin (1965) studied the abundance of carabids in red pine plantations of varying ages in four stages of development: 1) establishment, 2) transitional, 3) monoculture, and 4) young forest stages. He found four species to appear only in the open or semi-open conditions prior to crown closure (stages 1 and 2). Several species of *Harpalus* were abundant only prior to crown closure. Several species were found in all four developmental stages, though most common or extremely abundant in the latter stages of stand development.

In his treatise of carabids and their environments, Thiele (1977) notes that "characteristic societies of carabids can be assigned to some forest plant community", but that "it is not to be expected that a particular species be found exclusively in any one plant community." In Europe, carabid fauna in forests has little in common with that of adjoining fields (Thiele 1977).

Coleoptera-Staphlinidae.--Although probably not as important as carabids, some species of staphylinids (rove beetles) are influenced by forest management practices. In Finland, Huhta (1976) found the density of staphylinids to be very high in some clearcut areas where stocked pine saplings had failed to grow, but where spruce, birch, and mountain ash formed a sparse shrub layer. Ten years earlier, Huhta and others (1967) reported a strong but transitory increase in Staphylinidae soon after clearcutting. Huhta (1976) cites other authors who report a decline in staphylinid populations, accompanied by alterations in species composition, in clearcut areas in Poland.

Hymenoptera (Formicidae)

The formicids, or ants, are also an important component of the forest floor macrofauna. Like the carabids, ant populations are known to be influenced by fire, and many species of ants are effective predators.

Ants and fire.--Although most groups of forest floor arthropods are either decimated or reduced by burning, several investigators have reported ants to be more numerous in burned areas. According to Ahlgren (1974), ants are less affected by fire than many other groups because of their adaptations to hot xeric conditions of early postfire topsoil. Moreover, their cryptic habits enable them to survive fire below the levels of intense heat and their colonization habits and social organization adapt them to rapid re-establishment on burned land. Even though ant populations are destroyed by fire or are less numerous in burned areas, they are often the first to recolonize burned areas (French and Keirle 1969), at times within 1 hour after a fire (Komarek 1970).

Two studies in the northern Rockies report that ants were generally more abundant on burned than unburned areas. In his study in western Montana where a wilderness wild-fire was allowed to burn, Clayton (1975) found that by both numbers of individuals and species ants were more numerous on the burned than on the unburned areas. Of five genera studied, he found: 1) three genera to be more numerous on burned sites, 2) one genus more abundant in an unburned area, and 3) one genus with no difference in populations between burned and unburned areas. More recently Fellin (1980b) reported Formicidae were more numerous in burned areas after prescribed fire than in unburned areas.

Studies elsewhere also report ants to be abundant in burned areas. Although both Pearse (1943) in the long leaf pine region, and Buffington (1967) in New Jersey reported a reduction in ant populations following burning, Pearse reported an increase in the species proportion on the burned area and Buffington found two ant species strikingly more numerous on burned land. In the pine regions of the South, Heyward and Tissot (1936) found more ants in burned 0 to 2 inch mineral soil layers than in unburned soil. In grass and prairie habitats, both Rice (1932) and Hurst (1970) found ants to be more numerous following fire or on burned areas.

Ants as predators.--Several species of ants are reported to be associated as predators of both the eastern and western spruce budworm and the jack pine budworm. Ants also interact with both carabids and spiders in a predaceous or comptetitive-type relationship.

In his studies with the jack pine budworm, Allen (1968) found Camponotus noveboracensis (Fitch) to be a common inhabitant in all jack pine stands studied, and two species of Formica were also associated with jack pine budworm populations. At some sites, Allen found from 100 to 400 nests of F. exsectoides (Forel) per acre with every tree in the stand continually covered with ants. Budworm larvae falling to the ground were immediately attacked by a worker ant and dragged to a nest, and ants would commonly scurry down silk threads after budworm larvae spinning down from a feeding site. Allen and his colleagues (1970) report that both C. noveboracensis and F. exsectoides had little success preying on budworm larvae in the foliage because of the larval feeding tunnels and the silk surrounding them. This is probably why neither ant species was able to influence jack pine budworm populations. Jennings (1971) reports that 6 species of Formica actively preyed on late instar jack pine budworm when the larvae were dislodged from their feeding sites with long poles.

In a study of the introduced wood ant, Formica lugubris, McNeil and his associates (1978) found that large numbers of the eastern spruce budworm were removed from the population by the ants. They believe that this introduced wood ant could play a role in an integrated control program against the spruce budworm.

In Montana, Bain (1974) studied the relationship of two wood ant species, Formica obscuripes (Forel) and F. criniventris (Wheeler) with the western spruce budworm. He found that ants foraging in the foliage of budworm-infested trees was an important factor in causing larvae to fall to the ground where they were further preyed upon by ants. Bain estimated that during the period of larval development, as many as 12,000 budworm larvae could be gathered by the ants from a single nest. He acknowledges that while this pressure may not be sufficient to completely suppress the budworm population, predation by ants represents a formidable factor in slowing the rate of increase in budworm populations and reducing the overall economic damage caused by the budworm.

Populations of predaceous ants are also reported to influence carabid numbers in some habitats, but apparently to have little influence on spiders. Thiele (1977) reports that ants can exert a considerable influence on carabid populations and the habitats they occupy. Carabids are attacked and severly injured by ants; in the vicinity of Formica nests, there was a sharp decrease in numbers of both species and individuals of carabids. Although some investigators have reported a competitive-type relationship between ants and spiders, Van der Art and DeWit (1971) found no significant difference in the composition of the fauna of wandering spiders, or in the total number of spiders caught between a habitat in which ants were numerous and a comparable habitat without ants.

Ants and the forest environment.--In his studies discussed earlier, Martin (1965) lists five species of ants in four genera that generally occur prior to crown closure, while two other species only appeared in the last two stages of stand development, macroculture and young forest stages. Wagner and others (1977) observed 12 species of ants, mostly woodland species, in two aspen forests in northern Minnesota.

Araneida (Spiders)

A third group of important forest floor macrofauna are the spiders. As with the beetles and ants, many species of spiders are known to be predaceous. Some species are associated with forest development and populations of many species are affected by fire.

Spiders and fire.--Several studies of the effects of fire on spiders have been made in this country; however, the most exhaustive research on spider-fire interactions has been done in Finland.

In the northern Rockies where a wildfire had been allowed to burn, Clayton (1975) found spiders to be more numerous in areas that had been burned than in control areas. Within the burned areas, spiders were definitely more numerous and more species were represented in a riparian woodland than on a south slope ponderosa pine savanna. Elsewhere in these proceedings, Fellin (1980b) reports the results of a recent study of the effect of prescribed burning and harvesting practices on spiders and other forest floor macrofauna in western Montana.

Reichert and Reeder (1972) studied the immediate and long-term effect of burning on spiders in Wisconsin prairies. They found that species active on the surface at the time of burning were eliminated, while those occupying subsurface burrows, or sacs under rocks or clumps of dense vegetation escaped thermal damage. The greatest decrease in numbers was noticed two weeks after the burn, followed by a slow increase. Even after 45 days, however, the numbers in the burn were not equal to those in the controls.

Reichert and Reeder (1972) recognize that some spider species may be indirectly affected by a burn through changes in the plant cover and that "seasonal activity patterns largely determine the different response of spider populations to the immediate effects of burning." They concluded that the abundance and species composition of spiders are both relatively stable, and that species inhabiting the prairie have adapted to the effects of periodic burning.

In other studies, Pearse (1943) considered spiders, along with roaches and ants, to be well adapted for existence in a burned area; but Rice (1932), Buffington (1967), and Heyward and Tissot (1936) thought spiders to be one of the groups least well adapted to burning. Algren (1974) cites several authors in reporting that spiders, primarily surface dwellers, are drastically reduced by fire in most areas, with population decreases of from 9 to 31 percent. In one study, Hurst (1970) reported an increase, primarily ground and wolf spiders, following fire.

Huhta (1965, 1971) has intensively studied ecology of spiders in the litter and soil of Finnish forests, mostly in relation to silvicultural practices and prescribed burning. He found that after clearcutting, the abundance of typical species decreased, and species foreign to the original fauna spread into the cutover areas; though the species were varied, the total numbers of individuals were about 60 percent less than in the uncut area (Huhta and others 1967). Following burning, which almost totally destroyed most of the original populations (Huhta and others 1967), the number of individuals remained continuously low and the composition of the fauna was unstable; most species were markedly less frequent after burning and occurred only sporadically in the burned soil (Huhta 1965). Between years 7 and 13, following cutting and burning, the composition of the spider community reverted towards the original forest situation. In a more recent study, Huhta (1976) confirmed his earlier observations that the density of spiders decreased considerably after clearcutting, but in two of his clearcut areas, he was not able to show signs of spider recovery.

Elsewhere in Europe, Brabetz (1978) studied the effects of controlled burning in some uncultivated grasslands. In March and April of 1975 and 1976, two parcels of land (20 x 56 meters) were burned, and two parcels set aside as a control. In the spring and summer after the first burning, significantly more spiders were trapped in the burned area; however, after the second burning, spiders were more numerous in unburned areas.

Spiders as predators.--Studies have shown that several species and groups of spiders are associated as predators of the spruce and jack pine budworms. Though all of these studies have involved spiders in the arboreal, rather than the forest floor environment, many species do move from the duff and litter onto the boles and into the crowns.

Some studies began when it was discovered that spiders constituted about 90 percent of the total invertebrate predator fauna and that in New Brunswick spider populations may have been as high as 250,000 per acre. These early studies indicated: 1) a functional response of spider predation to budworm populations, 2) a seasonal pattern of predation, 3) the relative importance of various spider families, and 4) an explanation for previously unknown mortality. Investigators established that spiders may significantly influence budworm populations (Loughton and West 1962; Loughton, Derry and West 1963).

In a study of invertebrate predators of the jack pine budworm, Allen (1968) collected 51 species of spiders representing 15 families from the foliage and bark of jack pine; of those collected, nearly 75 percent were 5 families of hunting spiders with some potential as predators (Allen and others 1970). Several species of the important groups collected on the tree boles were actually ground dwellers that foraged on the boles and exerted some predatory influence. The spiders were commonly observed below tanglefoot barriers or scurrying around the bases of trees in the duff.

Although it has been reported that the selection of moving prey by spiders precludes their having any effect on the egg stage of the budworm (Loughton, Derry and West 1963), it has been recently determined that spiders do prey on spruce budworm egg masses (Jennings and Houseweart 1972).

The impact of spiders as predators of other soil-dwelling invertebrates is poorly known (Wagner and others 1977), but there are some data that spider predation is an important subtractive process acting on populations of some fauna. After removing spiders from enclosed experimental areas, Clarke and Grant (1968) found centipedes and Collembola, known spider prey, at higher densities than in the controls. Millipedes, not taken by spiders, were not consistently higher on areas where spiders had been removed. Although one spider species is reported to prey on certain species of carabids, ground beetles do not account for a large part of the prey (Thiele 1977).

Spiders and the forest environment.-Tolbert (1975) studied the preference of insects and spiders inhabiting the forest floor on one or more slopes and aspects on a small mountain in the Southeast. He found 20 of 34 species demonstrated shifts to slopes offering different exposures with time. Southfacing slopes were preferred by 50 percent of the species collected, while southeast and northwest exposures were least preferred. Tolbert (1975) recognized that since plants have distributional preference, the herbivorous arthropods may have been responding to specific food plants rather than slope conditions. Likewise, predaceous species may have been responding to the distribution and abundance of prey.

Physical aspects of deciduous forest litter habitat, either as structural micro-habitats or refuges from predation, are suggested as being important in regulating within-habitat species diversity with some species of wandering spiders (Uetz 1975). A distinct litter layer is important in the seasonal and daily activity of forest floor fauna in different habitats; the layer, in wooded areas, provided extra food and retreats during periods of inactivity (Williams 1959b).

During four stages in the development of red pine plantations, spider and harvestmen (Phalangida) made up about one third of the arthropod fauna during the first two stages--establishment and transitional. However, in the latter two stages--macroculture and young forest--of community development, spiders made up 50 percent of the total arthropod fauna (Martin 1965).

Forest Soil Mesofauna

Many studies, principally in North America and Europe, have dealt with the effect of harvesting, and residue management, and fire management on forest soil biota. Most of the research has involved the effect of fire, both prescribed and wildfire, on soil mesofauna, but some investigators have studied the response of mesofauna to silvicultural practices. There is a general feeling that harvesting stimulates the development of soil organisms, while prescribed fire substantially reduces populations, at least temporarily. Recovery is usually fairly rapid, especially in the upper layers of soil (Bell and others 1974). I will review the studies of harvesting, residue management and fire as related to soil mesofauna by geographic regions, and conclude the section by discussing soil and surface temperature during fires and its effect on mesofauna.

RESEARCH IN WESTERN UNITED STATES

In the northern Rockies, Fellin and Kennedy (1972) studied the relative abundance of forest soil fauna 1, 2, and 3 years after western white pine forests were clearcut and prescribed burned. Considering all taxa, the total number of individuals collected in samples from the 1962 burn was nearly half again as great as samples from either the 1961 or 1960 burn. Excluding the mites (Acarina), arthropods in samples from the 1960 burn outnumbered those from the 1961 burn by more than five times and were nearly four times more abundant than those from the 1962 burn. The Acarina--which comprised 77 percent of the total fauna--were most abundant on the 1962 burn, more than twice as numerous as on the 1960 burn, and 25 percent more abundant than on the 1961 burn.

A recent study investigated the effects of harvesting and residue management practices, including prescribed fire, on forest soil mesofauna in northwestern Montana. Partial results of that study are presented elsewhere in this proceedings (Fellin 1980c).

Vlug and Borden (1973) studied soil Acari and Collembola populations for 1 year in clearcut areas that were burned and not burned, and in adjacent unlogged areas, in a coastal British Columbia western hemlock and western redcedar forest. They found the density of mites, Collembola, and other arthropods was reduced by logging, and was even further reduced by slash burning. Population levels and diversity in the logged and burned areas was relatively high, however, indicating that neither treatment induced total mortality. Moreover, there was a rapid reinvasion of treated areas. The density of some mites and of one family of Collembola in the litter and upper two layers of soil was progressively reduced by logging and slash burning, but population densities increased in the third and fourth soil levels. This indicated that either migration to deeper levels or adaptation to conditions further below the surface had occurred.

At least two studies have been made of mesofaunal populations in California forest soils. Price (1973), in a study of the fauna in the organic and upper soil layers under a ponderosa pine stand near Grass Valley, Calif. showed a population density of about 200,000 arthropods per square meter of forest floor. About 150 species were encountered, mostly mites (primarily oribatids), followed by springtails (Collembola). Wenz (1976) investigated the effects of wildfire on forest soil microarthropod populations in California. He found that of two wildfires studied both reduced virtually all arthropod groups, and the effects were still evident 2 and 3 years after the fires.

RESEARCH IN EASTERN UNITED STATES

Some of the most comprehensive research in this country on the effect of silvicultural practices and prescribed fire on soil mesofauna has been conducted by Metz and his co-researchers (fig. 14). Metz and Farrier (1971, 1973) presented the first information concerning the effects prescribed burning of forest residues has on forest soil mesofauna under defined conditions and frequency. Metz and Farrier define the forest floor as all organic debris overlying the mineral soil, and divide it into three layers: the L, or litter layer, made up of freshly fallen undecomposed material; the F, or fermentation layer, consisting of partially decomposed L still recognizable as to origin; and the H, or humus layer, consisting of well-decomposed organic matter unrecognizable as to origin.

In their first study (1971), they found that mite populations were reduced more in the surface 3 inches (75 mm) of mineral soil than in the forest floor, while numbers of collembolans decreased in the forest floor with little change in the mineral soil. In 1973, Metz and Farrier studied mesofaunal populations in unburned areas and in periodically and annually burned areas. They found annual burns had the most serious impacts on animals, while the number of animals on the periodically burned plots was significantly greater. The number of animals in the controls was not significantly different from those in the periodically burned areas. They conclude that there are more mesofauna 1) in a coniferous forest floor than in the soil beneath it, 2) in the surface of the mineral soil than in the underlying layers, 3) in the lower layers of the forest floor than in the surface, and 4) when sampled immediately before and after burning on annually burned plots, the number of animals was reduced drastically. Metz and Farrier (1973) point out that there are no data in the literature to indicate that their results are applicable to other forest types or burning regimes.

Hill, Metz, and Farrier (1975) reviewed the effects of four silvicultural practices--fertilizers, insecticides, fire, and cutting--on forest floor mesofauna. With respect to fire, they note that when fire destroys much of the forest floor, the mesofauna are considerably reduced, either as a result of death from heat and suffocation or by the removal of much of their food supply and living space. They indicate that light prescribed burns where only the L and part of the F layers are consumed, and where there is no erosion problem, have no lasting effects on mesofauna, but that the effects of wildfire are more drastic and longer lasting. Metz and Dindahl (1975) report that species diversity of collembolans was increased by both annual and periodic fires. Concerning cutting (mostly clearcutting), Hill, Metz and Farrier (1975) after citing somewhat contradictory results of several studies, indicate that mesofauna usually are decreased after cutting, and slowly return to normal after a number of years.

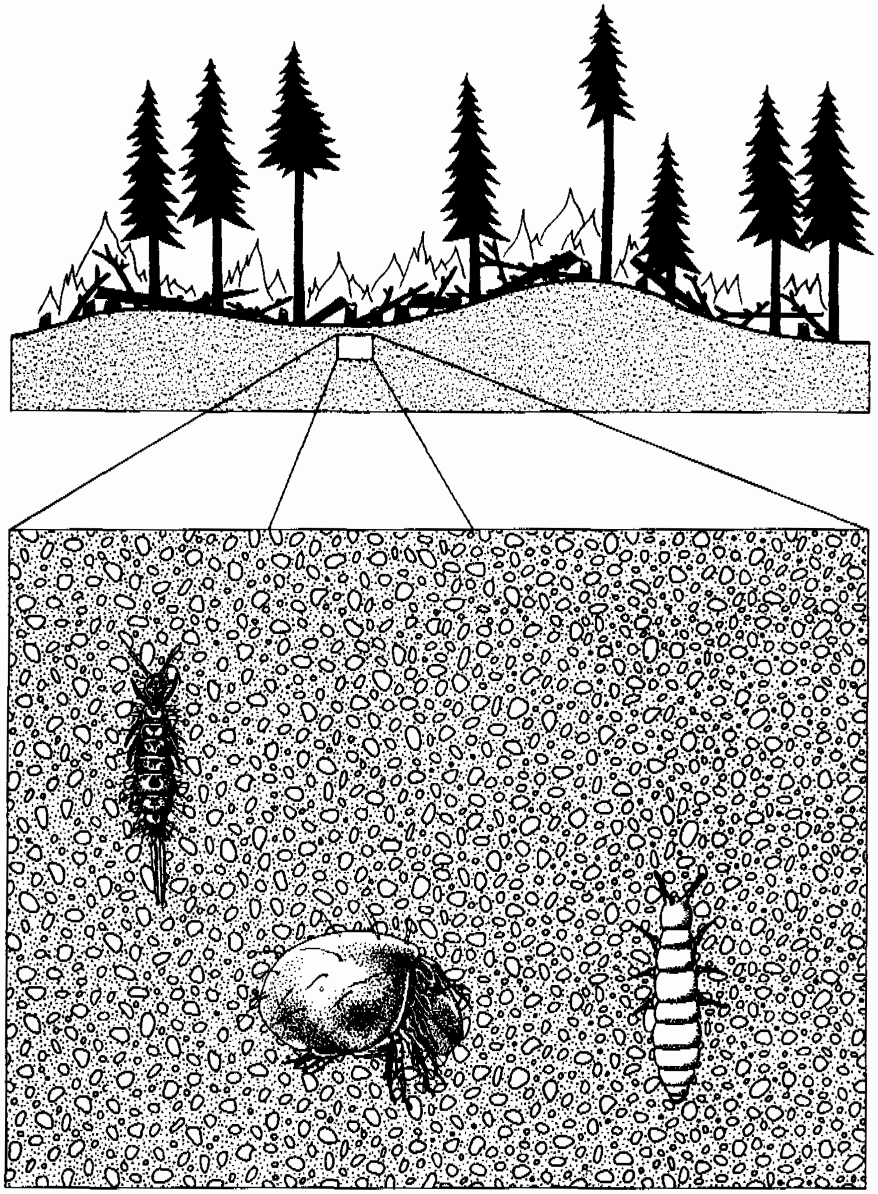

Figure 14.--Prescribed burning of forest residues under a shelterwood silvicultural system. Harvesting and silvicultural practices, as well as various residue management treatments, including prescribed fire, have differential effects on soil arthropods. Collembola and mites are the predominant groups of soil arthropods and most species are decidedly beneficial.

In the long-leaf pine forests in the southeast, Heyward and Tissot (1936) compared fauna from "areas protected from fire for 10 years or longer and similar soils subjected to frequent fires." They found 5 times more mites and collembolans in the forest floor of the non-burned than the burned-over areas. In both the A_0 horizon and the upper 5 cm of mineral soil, mites and collembolans were 11 and 3 times more abundant, respectively, in the non-burned than in the burned areas. They also found that mites made up between 71 percent and 93 percent of the fauna in unburned soil, and between 30 percent and 72 percent in burned soil, depending on depth. Rice (1932) also found that mites and Collembola are reduced by burning.

Pearse (1943) hand sorted samples taken every 3 months from sites where litter had been burned over, raked off, or left undisturbed in North Carolina. His samples were 36 feet square (3.3 m^2) and 6 inches (150 cm) deep. In all instances, he found the largest populations of both mites (90-95 percent) and collembolans (85-94 percent) in the forest floor and surface inch (2.54 cm) of mineral soil.

RESEARCH ABROAD

The majority of research concerning harvesting, residue, and fire management and soil mesofauna has been conducted by European (predominantly Scandinavian) researchers; one study is reported from Australia.

In Finland, Huhta and others (1967) found that the changes in the soil fauna as a result of clearcutting were not too significant. They found a decrease in the number of individuals, but the same species were dominant. The number of species, in fact, increased because of an influx of new species from surrounding areas. Huhta and others (1967) demonstrated that burning of the residues following tree harvesting was very destructive to all groups of soil animals, and that the soil and humus environment could be so changed that the reinvasion by soil fauna could be delayed. They found that many groups were permanently affected--oribatid populations were low for 7 years after burning--but they suspected that other animal groups might find conditions more favorable after the burning and would experience a more or less temporary population resurgence if the organic layer was deep enough to remain at least partly unaffected by the fire. In a later study, Huhta and others (1969) found the populations of some mites and Collembola to be greater in burned areas.

Burning has been shown to have some rather drastic effects on one family of mites--the Oribatidae. A year following the burning of residues on clearcut forests with thick, raw humus layers, populations of oribatid mites were greatly reduced (Karpinnen 1957), showed no signs of recovery 5 years after the burn, and were still at low levels 7 years after burning (Huhta and others 1967, 1969). The steep decline in oribatid mite populations following burning persisted. In deep layers of soil, oribatid populations were still below pre-burning levels 27 years after the burning (Karpinnen 1957).

In a more recent study of the effects of clearcutting, Huhta (1976) found that the biomass of soil invertebrates was at or even below original levels, 9 to 13 years after cutting.

Another Scandinavian investigator reported mites to be more numerous in unburned than in burned forests in northern Sweden, but ascribed the difference to normal population variation (Forsslund 1951).

In a study in Austria, mites were found to be less abundant in burned, than non-burned, areas (Jahn and Schimitschek 1950).

Following a wildfire in Australia, soil faunal populations in severely burned areas were reduced when compared to populations in lightly burned areas (French and Keirle 1969).

Summarizing essentially European research, Bell and others (1974) reported that all available research indicates that numbers of soil organisms (all biota) in general are greatly stimulated by cuttings. Often, in some Scotch pine, *Pinus sylvestris*, stands after both shelterwood and group selection felling, the stimulation increases with the intensity of the felling. However, the response of soil fauna to cutting, residue treatments, and fire treatments appears to differ from the response to cutting only, by *all* biota, as Bell and others have reported.

MESOFAUNA CAN SURVIVE SURFACE FIRES

Several investigators have reported that many soil-inhabiting animals can survive surface fires. In the Southeast, Heyward and Tissot (1936) indicated that even very hot surface fires rarely heat the underlying soil beyond 176° F to 194° F (80° C to 90° C) at a depth greater than 1/4-inch (0.62 cm) below the surface. According to Heyward and Tissot (1936), "...if either the animals themselves or their eggs were only 1/4- to 1/2-inch (1.2 cm) beneath the soil surface, they would stand in excellent chance of escaping harm during the fire."

A recent study on an experimental area where clearcut logging slash exceeded 100 tons/acre, prescribed burned in late July, during hot, dry weather in the northern Rocky Mountains, showed that an extremely hot surface fire can generate temperatures as high as 300° F (149° C) at a depth of 5/8-inch (16 mm) (R. C. Shearer, personal communication). No doubt, most insects would have to have been deeper than 5/8 inch under the soil to survive such temperatures. However, because the intensity of heat varied, average and maximum temperatures at a depth of 5/8-inch in parts of the burn were considerably lower, and soil insects in these portions of the burn could have survived.

Reichert and Reeder (1972) found surface temperatures during fires in prairies to be between 120° C and 200° C, and the duration of lethal temperatures was short--70 to 140 seconds. Subsurface soil temperatures at 0.5 and 1.0 cm (16°C to 20°C) were virtually unaffected by the brief heating at the surface. Reichert and Reeder (1972) suggested that spiders below the soil surface are well protected from direct heating, and usually could escape heat damage.

Brown and Davis (1973) noted that the heating of soil by fires to a level lethal to living protoplasm usually occurs only close to the soil surface. They continue, "repeated fires can reduce the number of soil organisms near the surface, while increased average soil temperatures following burning can increase the number of organisms present." Coults (1945) found that in the top inch of South African veld soil populations of a majority of the invertebrate species survived burning.

RESIDUES, FIRES, INSECTS, AND FOREST SUCCESSION

It is generally accepted that northern Rocky Mountain forests have evolved in the presence of repeated fires. The pattern of forest succession following fires in the northern Rockies has been defined as "...a sequential development of vegetation in which the more rapidly maturing and often shade-intolerant plants assume initial dominance, and, in turn, are dominated by taller, slower growing, and often more shade-tolerant species" (Lyon and Stickney 1976).

Natural fires have been a major influence on plant succession (Houston 1973). However, there is evidence that suppressing fires in areas managed for "naturalness" may be a serious disruption of natural processes (Mutch and Aldrich 1974). In Yellowstone National Park, a reduction in fire frequency through fire suppression has resulted in a greater expression of "climatic climax" vegetation, and forest succession has changed the relative abundance of species and increased the density and distribution of forests. Conifers have increased, but conifer succession could be returned to a more natural state if fire was either reintroduced (Houston 1973), or allowed to more nearly play its natural role; fire has always been present but its role has been seriously limited due to successful fire control (W. C. Fischer, personal communication). Early photographs in the Selway-Bitterroot Wilderness show numerous forest successional stages, attesting to the past incidence of fire, but more recent photos indicate "...a loss of lifeform diversity because of a gradual homogenous character resulting from fire suppression activities" (Davis 1977).

There is recent, growing interest in the natural role of fire as an influence on ecosystems, particularly in wilderness and other areas managed more for amenity values than for timber production. There is particular interest in the effect of periodic fires in maintaining stands of fire-dependent trees and in the diversity of the forest in general (Habeck and Mutch 1973). These interests are reflected both in the National Forest Management Act and in the revised Forest Service fire management policy, which has evolved from one of fire control to fire management (USDA, FS 1978b). The fire management policy allows that certain wildfires can be designated as prescribed fires if they burn under pre-selected conditions and in pre-determined areas--called fire management areas.

These interests and concerns, along with current fire mangement policies, have serious implications relative to forest residues and associated insect and disease interactions, to successional changes in our forests, and to our principal forest insect and disease problems in the northern Rockies. If we accept that natural ecosystems have evolved in the presence of fire and are at least partially dependent on fire for continued survival, we must also accept that animals, including forest insects, living in these fire-adapted ecosystems may also be adapted to the presence of fire (Clayton 1974). Hard (1974), in discussing northern coniferous forests in southeast Alaska, points out that the folly of indiscriminate control of all wildfire is analogous to the policy of "controlling" insect outbreaks, and says, "the lesson here is that it may not always be wise to attempt to control a factor that is an integral part of a natural system."

The most significant forest residue-fire-successional interactions with forest insects in the northern Rocky Mountains involve the mountain pine beetle and the western spruce budworm. The interaction of the role of fire, the succession of lodgepole pine, and the mountain pine beetle is very complex. In this region, light-medium fires and the mountain pine beetle are responsible for successional developments in lodgepole pine stands and for the maintenance of lodgepole pine as a widespread forest type (D. Cole 1978). Foresters trace the current mountain pine beetle problem in the northern Rockies to catastrophic (stand replacement) fires of nearly a century ago. They (the fires) triggered the growth of large stands of lodgepole which are now about the same age over vast areas of western Montana, northern Idaho and in Yellowstone National Park (Kuglin 1980). At this time, an appreciable percentage of logdepole pine stands, near and east of the Continental Divide in Montana, contain from two to several age classes, mainly because of the mountain pine beetle/fire history and severe conditions that excluded other species (D. Cole 1978) (fig. 15).

In many areas where natural fires have been suppressed, forest residues resulting from mountain pine beetle epidemics accumulate until hot fires occur. According to D. Cole (1978), "such fires are normally more destructive than ones that would have otherwise occurred if fires had not been suppressed, and they tend to perpetuate future extremes in the mountain pine beetle/lodgepole pine/fir interactions." Several opinions have been expressed that the bark beetle epidemics now rampant in the Rockies and Intermountain West may be a product of fire exclusion (Schwennesen 1979). In Glacier National Park, the mountain pine beetle epidemic took such a strong hold because fire suppression programs were so successful and trees that ordinarily might have burned are now mature and ripe for the beetles (Kuglin 1980).

Figure 15.--Along the Continental Divide in Montana, an appreciable percentage of pure lodgepole pine stands contain from two to several age classes, mainly because of the mountain pine beetle-fire history and severe site conditions (D. Cole 1978).

Western spruce budworm infestations in the northern Rockies are influenced not only by the interaction of forest residues, fire and succession, but also by the interaction of the budworm and the mountain pine beetle. One recommendation for ameliorating the impact of the western spruce budworm is to return the more xeric Douglas-fir sites to pine (Williams and others 1971). However, in many young ponderosa pine stands, the mountain pine beetle not only kills many desirable crop trees and creates understocking in the stand, but also appears to be converting the stands from ponderosa pine to Douglas-fir (McGregor 1973). This succession could predispose such stands to be more susceptible to the western spruce budworm. The same successional situation can be created by silvicultural practices that harvest pine and favor Douglas-fir or the true firs.

In the spruce-fir stands infested with the eastern spruce budworm in the Maritime Provinces, fire is also involved in the successional relationships. In the absence of fire the budworm kills primarily shade-tolerant trees, and these species tend to regenerate. If fires occur often within the regeneration period, the shade-intolerant species regenerate instead, and these species are less preferred hosts of the eastern spruce budworm (Flieger 1970). Essentially, then, in eastern Canada, in the Lake States, and in other areas where the spruce budworm occurs, outbreaks may have been less prevalent in primeval times because fire may have curtailed the expansion of shade-tolerant climax species.

In the West, the fire-residue-insect-successional interaction also influences outbreaks of the Douglas-fir tussock moth. Forest managers and investigators have been concerned that fire exclusion in some coniferous forests may have increased the susceptibility to the Douglas-fir tussock moth by allowing the number of true fir understory components to increase (Kickert and others 1976). In studying the last two tussock moth outbreaks in Oregon and Washington, Williams (1978) found infestations most common in stands, where fire was excluded. There, fir stands developed under the pine and eventually dominated the site--a site ordinarily too dry for either Douglas-fir or true firs. Recently, research has begun to see if fire could, in fact, be used to reduce Douglas-fir tussock moth damage by preventing growth of susceptible Douglas-fir and true firs on sites more suitable to pine (Martin and others 1972).

Fire, understory, and residue created by beetle attacks are also involved in the successional interactions of the western pine beetle and ponderosa pine. Weaver (1943) believed that fires, in combination with pine beetle attacks, frequently controlled the density, age classes, and composition of ponderosa pine stands. He also seems to have answered a question asked by land managers: "Would fire exclusion in ponderosa pine stands yield denser stands and more host material for bark beetles?" (Kickert and others 1976). Weaver (1951, 1955) indicated that as a result of fire exclusion, more intolerant white fir, incense cedar, Libocedrus decurrens Torr., and western larch increase and develop into densely reproducing stands that compete with the overstory pines for moisture, thus predisposing the overstory pines to bark beetle attacks.

In other situations, wildfires in forest residues created by beetle-killed pine have killed reproduction, changing the pine habitat to an aspen type. The pines eventually return, along with fir and spruce; the pines eventually are killed by the western pine beetle, leaving only the fir and spruce (Craighead 1925).

Another interesting fire-forest residue-successional interaction involves insects causing deterioration in fire-killed trees in the Pacific Northwest. Excessively dry or wet fire-killed trees do not attract insects. In a normally dry forest, recurring fires keep down regeneration, allowing fire-killed trees to become too dry. In normally wet coastal forests, fire-killed trees protected by the cover of a green forest are too wet for the deterioration causing insects; however, if recurring fires destroy the cover, the dead trees will dry out enough to become attacked (Kimmey and Furniss 1943).

In a longleaf and slash pine, Pinus caribaea Morelet, forest in the southeast, the only known epidemics of engraver beetles, Ips spp., occurred in a stand that had not been burned annually for over 70 years. Transpiration by mixed hardwoods that in other areas had been removed by prescribed burning apparently weakened the pine, predisposing them to attacks by the engraver beetles (Komarek 1970).

The use of prescribed fire to disrupt normal succession patterns and control understory vegetation (Martin and others 1977) often has beneficial effects on forest insects, such as described above, with _Ips_ problems in pine and aspen stands in the southeast. The use of fire in itself, besides reducing shrubs and herbaceous plants to increase tree growth (Martin and others 1977), has serious implications for forest insects. Fire exclusion could influence the incidence of parasitism in some cases by altering the species composition of flowering and fruit-bearing ground cover which is important as as food source for adult parasitoids, such as the ichneumonids. In other cases, fire exclusion could influence cone-seed or other "harmful" insects that spend part of their life cycle in the litter (Kickert and others 1976).

SOME MANAGEMENT IMPLICATIONS

Throughout this paper, I have described some of the interactions and relationships between harvesting, forest residues and fire management, and forest insects (to a lesser extent, diseases), particularly in the northern Rocky Mountains. I also have selected and described some classic, or at least representative, examples of some of these interactions. I will discuss three management implications of these varied interactions: management of forest residues, fire management, and silvicultural practices.

Management of Forest Residues

From the discussions above, it is apparent that forest residues constitute a habitat, substrate, and food for a wide variety of insect species-some "harmful", and some "beneficial"-as well as for a variety of decay organisms, many symbiotically associated with one or more insect species. In the northern Rocky Mountains and elsewhere, there are management implications associated with both natural and man-made residues that involve what we may call "harmful" insects.

NATURALLY CREATED RESIDUES

At least four significant natural factors create residues in the northern Rockies--insects, windthrow, fire, and diseases. I will discuss the first three.

Residues Created by Insects

Without a doubt, at this time the most serious and far-reaching management problem attributable to insect-created forest residues concerns the millions of dead lodgepole pine (standing and prone) killed by the mountain pine beetle.

Recently, Senator John Melcher (Montana) sponsored a controversial bill to encourage better utilization of forest residues. The bill would encourage the sale of wood residues left after harvesting, all of which would be hauled to a central collection yard and sold. Melcher's bill was prompted by the fact that many western forests are infested with the mountain pine beetle. Melcher has said, "that wood should be harvested now so we can get on with forest regeneration." He has emphasized that there are markets for dead trees, and "I believe the Forest Service should expedite the harvesting of these trees before rot, wind, or fire further diminish their value" (Hodges 1979). "Beetle-killed lodgepole can be harvested for several years but there is substantial devaluation" according to Jack Usher, former Timber Management Chief in the Northern Region of the U.S. Forest Service (Kuglin 1980). Dead lodgepole produces sawlogs with splits, and the beetles also stain the wood with a fungus which reduces the value.

The harvest-salvage of mountain pine beetle-created residues in lodgepole pine forests may have far-ranging resource management implications. Although the Forest Service is in some areas responding to the problem by accelerating timber harvest to salvage beetle-killed timber and making uninfested stands "beetle-proof", "this means more roads, more clearcutting and more complaints from environmentalists" (Kuglin 1980). On the positive side, foresters say that the beetle "epidemic gets rid of old trees and permits regeneration of other species, opens meadows which provide elk and deer forage and even provides housing for snag-nesting birds" (Kuglin 1980).

Residues Created by Windthrow

Should Melcher's bill pass and become law, its effect on forest management plans in the Northern Region would be similar to that created by the thousands of acres of Engelmann spruce that were windthrown and relegated to residue and to subsequent infestations by the Engelmann spruce beetle in the northern Rockies in 1949. I have discussed the residue utilization, biological, socio-political, and forest successional aspects of this Engelmann spruce beetle problem, as well as other implications in the Rocky Mountains of windthrown Douglas-fir, Engelmann spruce, and ponderosa pine. I have also discussed some of the entomological and management implications of windthrown timber in the Pacific Northwest.

Although at this time there are no serious, widespread insect problems associated with forest residues caused by windthrow, any future windthrow-created residues will have even more significant forest insect management implications because of the economics of residue utilization, and current markets for forest residue.

Residues Created by Fire

The most important management implication related to fire-created residue concerns the prompt salvage, or harvest, of fire-killed or fire-weakened trees. The early removal of these trees is necessary for two reasons. Fire-killed or fire-weakened trees are more likely to be attacked by a variety of wood borer species; subsequent riddling of wood and the associated deterioration-causing fungi can rapidly degrade these trees for lumber and other products. In one sense, woodboring species are very beneficial in that they are the primary fragmenters in the natural cycling process that tranforms residues into humus and soil. It is only when wood borers compete with man for material having economic value that they become "harmful." Because of a drier climate, neither the borer nor the associated deterioration problem is as acute in the northern Rockies as in the Pacific Northwest.

The second reason for promptly removing fire-weakened trees is to prevent the buildup of bark beetle populations that often spill over to attack and kill green trees in surrounding forests. Oftentimes, the speed at which fire-killed or fire-weakened trees need to be removed is determined not only by the species of insect involved, but also by the tree species involved. The problems of insects in fire-killed or fire-weakened trees is of increasing importance since more prescribed burning is being done in partial cuttings (W. C. Fischer, personal communication). Fischer (In Press) discusses in detail the fire management implications of bark beetle problems in ponderosa pine stands.

RESIDUES CREATED BY MAN

Although usually not as serious or widespread as residues created by natural factors, man at times has created management problems for himself in the form of residues generated by harvesting or thinning operations. With some conifers, particularly ponderosa and lodgepole pines, managers need to be aware of potential problems with engraver beetles and to pay particular attention to weather conditions and the time of year when thinning or harvesting creates residues.

Entomologically speaking, there is still some disagreement, and apparently always has been, concerning the hazards of forest residues in attracting large numbers of tree-killing insects-often serving as a breeding medium for some pest species--and the use of prescribed fire in managing those residues. We have already pointed out some of the varying philosophies of using prescribed fire to manage residues in the late teens and early 1920's. Recently, Mitchell and Sartwell (1974) pointed out that according to some and in some regions, the threat of outbreaks posed by insects breeding in residues is generally overrated. They went on to say:

> "Conclusions are that certain residues in Douglas-fir and ponderosa pine often create serious pest problems that should be considered in residue management programs. But the beneficial aspects of insects associated with residues may have more significance to man's objectives in the long run."

In terms of the impact of residue management on beneficial organisms, our concerns at the present time seem to be 1) the relative merits or drawbacks of removing all or most forest residues from a site, either mechanically or by prescribed fire, particularly in terms of impact on forest soil biology; and 2) how silvicultural treatment, superimposed on residue treatments would affect insect and disease relationships.

Most research has shown that fires reduce the populations of most soil and forest floor fauna, the majority of which are generally beneficial. Complete utilization, or removal of residue by prescribed fire, both act indiscriminantly and nonselectively on beneficial organisms. The disruption of beneficial arthropods would have potential long-term consequences on all phases of residue decomposition and nutrient cycling; these consequences should be considered in residue management plans. Since fire, too, is a decomposing and nutrient cycling agent, the need for decay and nutrient cycling organisms could be diminished for a short period of time following fire.

The decimation of beneficial insects could be prevented, or at least ameliorated, if burning were done so that patches of material could be left, from which the burned areas could be repopulated. Partial utilization and/or light burns under a partial cutting, shelterwood, or selection prescription, may achieve the manager's objectives as well as provide more optimum conditions for beneficial forest insects and fungi.

Fire Management

Our past preoccupation with attempting to suppress all wildfires may have had some subtle, but serious, influences in predisposing some of our northern Rocky Mountain forests to insect and disease infestations, through the disruption of natural fire, insect, and disease, successional processes.

Recently, researchers have expressed concern and have attached considerable importance "...to the problem of genetic response of plants to changes in natural fire frequency and the form taken by adaptations to fire to sustain species diversity and ecosystem stability" (Kickert and others 1976).

Howe (1974) presents examples of how some trees and shrubs cannot assume their natural ecological roles in the absence of fires because of mechanisms that have developed specifically in response to the selection pressure of fire. One possible adaptive mechanism (though perhaps less obvious than others) concerns the control of native insect and disease pests, which may prevent the development of strong genetic resistance in trees. "That is," Howe (1974) states, "fire may have consistently removed the selection pressure of an insect or disease pest before enough host generations were exposed to it to build genetic resistance."

"Forest protection" usually and historically encompasses fire, insects, and diseases. It appears that our past wildfire control policy, though necessary to prevent serious economic loss, may have predisposed forests to insect and disease problems, the other two targets of our forest protection efforts. The implications for management are that the diversity of ecosystems as a result of past wildfires has been gradually replaced by more homogenous forests because of fire suppression activities.

D. Cole (1978) suggests that a deliberate program of fire management and prescribed fire can be instituted to moderate the mountain pine beetle-lodgepole pine-fire interaction cycle. His premise is that both wildfire and prescribed fire management plans can be developed to use fire to "create a mosaic of regenerated stands within extensive areas of large timber that have developed." D. Cole (1978) believes that prescribed fires can create these ecosystem mosaics more effectively than wildfires. With the recent change from fire control to fire management, managed wildfires will be, in fact, prescribed fires.

Silvicultural Practices

Five years ago, one researcher summed up the implications of silvicultural practices on insect and disease problems; in my opinion those implications are equally applicable today. The discussion that follows is essentially from Hard (1974).

The forest manager's current, most realistic approach to insect and disease management in virgin stands, based on biological and economic considerations, may be to do nothing to suppress widespread outbreaks. Perhaps we should let outbreaks run their course, but establish a flexible harvesting policy that permits salvaging good quality timber in damaged areas and converting non-productive old growth to more productive even-aged stands (Hard 1974). In their most recent plan for the management of the western spruce budworm in the Northern Region, resource managers have, in fact, selected the alternative of "current management" (interpreted by some as "do nothing") in many western budworm-infested forests (USDA, FS 1977).

Silvicultural practices and other stand manipulations are a desirable alternative in averting potential pest problems. However, "since many of the requirements and limiting factors for the potential pest species are as yet unknown, effective silvicultural practices cannot always be prescribed" (Hard 1974).

Notwithstanding these unknowns, the manager's goal in insect and disease management in intensively managed stands should be prevention, and, if necessary, suppression. As Hard (1974) has said, "Probably the least expensive approach in the long run, environmentally as well as monetarily, is to anticipate pest problems and attempt to forestall them through cultural manipulations of the forest and natural control factors."

There are several elements of silvicultural practices that have implications in resource management. Two of them are 1) insect and disease resistance and 2) changing forest insect problems.

INSECT AND DISEASE RESISTANCE

In some respects, knowledgeable harvesting can replace pests and fire in accomplishing desired genetic turnover. Pest resistance can be encouraged through prescribed fire management procedures that promote consumption of infested residue while protecting potentially resistant trees. Where non-infected residues have accumulated in sufficient quantity (Harvey and others 1979), they represent an opportunity for increasing fiber production from our forests. Therefore, through intelligent harvesting, prescribed fire, and residue management, we have an opportunity to increase productivity of our forests and possibly raise the pest resistance level of second- and third-generation forests.

Accumulation of resistance can also be enhanced through planting resistant stock and protecting this resistant stock from wildfire. Geneticists and managers must realize, however, that in accepting pest-resistant strains or increased productivity of genetically improved varieties, we are substituting artificial for natural evolution, and because of this artificiality, we must watch for unforseen problems in the future. Until we know more, extensive plantings of an improved or resistant strain should be avoided, and some mix of varieties maintained, even if growth potential or pest resistance is sacrificed (Shea 1971).

CHANGING FOREST INSECT PROBLEMS

Insects, diseases, and their host trees have evolved together for centuries, each responding to changes in the other. Though antagonistic to individual trees, insects and diseases may be beneficial to the virgin forest ecosystem, acting not as intruders, but as a natural, and necessary component of the system.

As more virgin forest is harvested and converted to managed stands, what once were only potential insect and disease pests may become real pests for a variety of reasons, primarily because of increased competition with the forest manager for a resource in which he is investing time and money and expects maximum return (Hard 1974).

One might concur with Heinselman (1970) that fires have destroyed many old forests and kept a significant proportion of each region in young stands, and that these young stands are less susceptible to certain insects and diseases. However, it is equally important to point out that young, intensively managed stands are much more susceptible to some pests than are old-growth forests.

Young, intensively cultured forests differ markedly from the natural forests. Therefore, it is not surprising that new insect and disease problems are arising. In the past, managers have focused their attention primarily on pests that kill trees; now and in the future, we must place greater emphasis on pests that reduce growth or predispose trees to other damaging agents (Shea 1971).

RESEARCH NEEDS

The most significant and widespread forest insect problems in the northern Rockies at this time are the western spruce budworm and mountain pine beetle. Nearly all of our entomological research efforts and a sizeable silvicultural research effort is being directed toward these two pests. The entire spruce budworm effort, and a sizable portion of the mountain pine beetle research, is entomologically-silviculturally oriented. The research needs for these two insect species are, compared to the overall insect research effort, relatively well-covered.

Two other areas related to residue and fire management merit additional research: forest floor and soil arthropods, and insects affecting regeneration.

With respect to forest floor and soil arthropods, we need information on 1) specific habitat requirements, life histories, and interspecies relationships of key faunal species or groups; 2) group systematics; 3) roles and importance of groups in nutrient cycling and conversion of residue to humus and soil; 4) influence of physical factors on reinvasion and reporduction rates in burned areas; 5) effects of various residue management and silvicultural practices; and 6) the ways in which soil, litter, or residue can be treated to reduce or ameliorate the impact of "harmful" insects or disease organisms that complete at least a portion of their life cycles in one or more of these substrates.

We know very little, in some cases nothing, of the role forest insects and diseases play in the management of young forests of seedlings, saplings, and pole-sized trees in the northern Rocky Mountains. If we wish to minimize damage and losses caused by these agents in young coniferous stands, where much of our forest management effort is directed, more research must be devoted to the study of the biology, ecology, and impacts of insects and diseases affecting forest regeneration.

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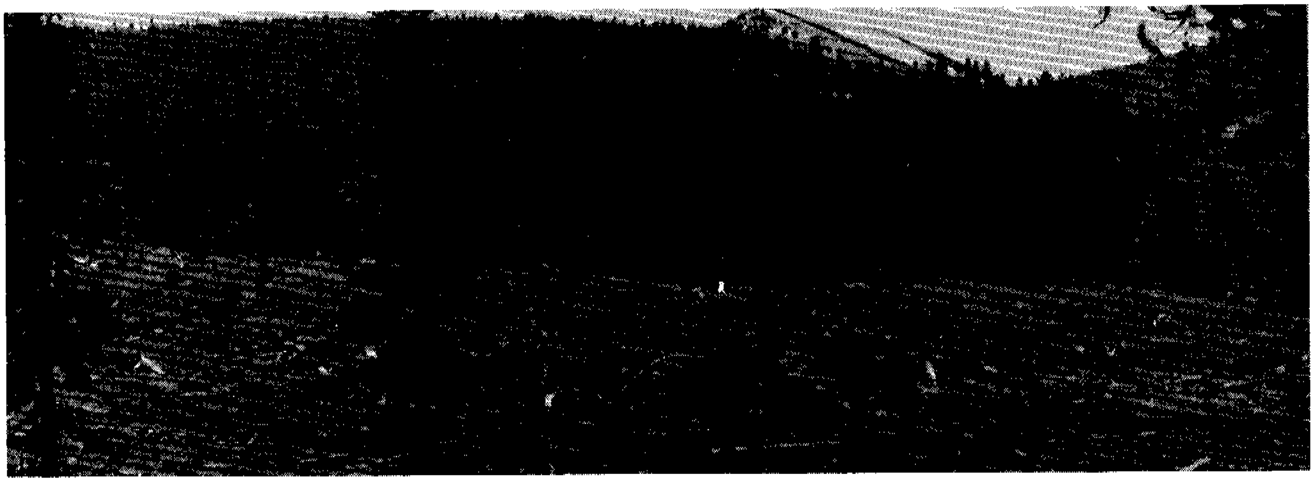

RESOURCE MANAGEMENT IMPLICATIONS

The need to recognize and avoid unacceptable environmental impacts is one reason for pursuing research that will better define and quantify effects of harvesting. A more compelling reason, however, is the fact that properly prescribed timber harvesting can be the most effective tool available to manage forested lands for a variety of resources and uses. Timber is rarely harvested from public lands simply to obtain wood fiber. Principal management objectives for the site are more likely to relate to insect and disease control, fuels management, wildlife habitat, recreation potential, or watershed potential.

Harvesting systems and practices -- especially intensive levels of wood utilization -- must be compatible with broad multiple resource management objectives. Beyond the immediate post-harvest influences (1st order responses), and short-term biological effects (2nd order responses), there is a need to develop reliable predictions for longer periods of time. The manager's ultimate concern is to protect on-site resources, and to produce a specified mix of resources and use opportunities over time. The extent to which timber harvesting activities can be prescribed to meet these long-term resource management goals is of critical importance.

In this section, researchers and land managers explore the implications of alternative timber harvesting and residue management treatments for broad resource management. Researchers are faced with integrating and extrapolating from site-specific "case" studies: land managers extrapolate in a similar fashion from trial and experience.

INFLUENCE OF HARVESTING AND RESIDUES ON FUELS AND FIRE MANAGEMENT

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ABSTRACT

Fuel and fire behavior potential in clearcut lodgepole pine and in Douglas-fir/larch under clearcutting, group selection, and shelterwood silvicultural systems were compared after logging to near-complete and conventional utilization standards. Fuels and fire behavior potentials were unaffected by silvicultural systems but varied substantially by utilization standards and method of skidding. Predicted rates of spread on conventional units were 3-4 times greater than on near-complete units. Predicted fireline intensities were 6-10 times greater on the conventional units. Conventional utilization left fireline intensities exceeding capabilities for direct fire control for 3-5 years up to 20 years or more. Whole tree skidding without slashing reduced hazard to acceptable levels by trampling and transporting material from the site. Fuel less than 0.25 inches in diameter was reduced to 0.4 of that created by cutting while all fuel less than 3 inches in diameter was reduced to 0.7 of that created by cutting. Whole tree skidding coupled with slashing left unacceptable hazards for 3-5 years. Near-complete utilization left acceptable levels of hazard but also left insufficient fuel for prescribed burning. Methods with which land managers can appraise fuel and fire behavior potentials on specific cutting units are presented. Deciding "how much fuel is acceptable" is discussed.

KEYWORDS: Fuel appraisal, fuel management, slash hazard, residue, utilization standards

INFLUENCE OF HARVESTING AND RESIDUES ON FUELS AND FIRE MANAGEMENT

Timber harvesting produces forest fuels with fire behavior potentials of great concern to land managers. Fires involving slash fuels can be particularly difficult to control, generate high costs of suppression and threaten resource values. Fuel quantities from harvesting vary substantially and can be excessive, depending on volumes cut and methods of harvest (Howard 1973; Benson and Johnston 1976). Utilization standards and methods of skidding offer the manager opportunities to modify fuel hazards, because they influence fuel loading, size distribution, continuity, and compactness.

Little has been documented on the extent to which harvesting methods can alter fuel characteristics and fire potentials. However, techniques developed over the past few years for measuring and predicting fuels and fire behavior have made it possible to appraise slash fuels. This paper describes how different harvesting methods altered fuels and fire potential on two study areas and discusses how managers can appraise fuels on any cutting area before slash is created.

CASE STUDIES AT UNION PASS AND CORAM

Study Procedures

Effects of harvesting on fuel and fire behavior potential were evaluated at two locations: Union Pass on the Bridger-Teton National Forest in Wyoming, and Coram Experimental Forest on the Flathead National Forest in Montana. Forest conditions and study designs were different.

UNION PASS

Two mature, even-aged lodgepole pine stands were studied. In each stand, two 20-acre harvesting units were established. One unit was clearcut to "conventional" utilization standards, the other to utilization standards that were called "near-complete". On both the conventional and near-complete harvesting units all sound trees to a merchantable top diameter of 6 inches were removed. In addition, on the near-complete units chips were produced from: (a) tops of all merchantable trees; (b) all remaining live and dead sound standing trees with a d.b.h. of 3 inches or larger; and (c) all material remaining on the ground that was more than 6 inches in diameter at the larger end, more than 6 feet long, and sound enough to permit skidding. On the conventional units, trees were limbed and bucked where felled, then skidded by crawler tractor to the landing. On the near-complete units, trees were felled and then bunched and skidded to a central point where the sawlog material was removed. The remaining top material was then skidded to the chipper.

CORAM

Mature Douglas-fir/larch stands were divided into six cutting units. Clearcut, shelterwood, and group selection cutting methods were each applied to two units. In addition, each unit received four levels of utilization ranging from current standard utilization ("intensive tree" and "sawlog") to near-complete removal of tree material (fig. 1) as follows:

Utilization level	Treatment and utilization standards
Intensive tree	Trees down to 5 inch d.b.h. cut; all material (live and dead, standing and down) 3 inches in diameter and 8 feet long or larger removed; smaller trees slashed.
Sawlog	Trees down to 7 inches in d.b.h. cut; logs to a 6 inch top diameter (live and recently dead) removed; smaller trees slashed.
Intensive log	Trees down to 7 inches d.b.h. cut; logs (live and dead, standing and down) to a 3 inch top diameter and 8 feet long removed; smaller trees protected (no slashing).
Near-complete	All trees down to 1 inch d.b.h. cut; all material (live and dead, standing and down) to 1 inch removed.

Harvesting was accomplished using a running skyline system that provided lift and travel to the suspended load. Trees up to 8-10 inches in d.b.h. were skidded whole. Larger trees were bucked before skidding; their tops were left in the woods consistent with utilization standards.

Downed woody fuels were inventoried before and after logging using the planar intersect method (Brown 1974b). Additionally, at Coram, loadings of slash fuels were predicted from an inventory of trees and crown weight relationships (Brown 1978). This permitted a comparison of worst possible fire potential and actual fire potential created by the harvesting. Sampling design and procedures are described in detail for Union Pass by Brown (1974b), and for Coram by Benson and Schleiter.[1]

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[1] Benson, Robert E., and Joyce Schleiter. Volume and weight characteristics of a typical Douglas-fir/western larch stand, Coram Experimental Forest, Montana. USDA For. Serv. Gen. Tech. Rep. INT (in process).

Figure 1.--The sawlog treatment (above) and near-complete treatment (below) illustrate the range in fuel quantities and size encountered in the Coram Douglas-fir/larch study.

Fire behavior was predicted for inventoried and predicted fuels using mathematical models described by Rothermel (1972) and Albini (1976a and 1976b). In fire behavior modeling, moisture contents were held at 5-7 percent, and slopes were averaged for the study areas. Wind speeds shown in tables and figures are for wind at mid-flame heights. Slash at 5 years of age has been reduced in depth to 0.7 of the depth for 1-year-old slash; retained foliage has been reduced to 0.2 of that in 1-year-old slash (Albini and Brown 1978).

Union Pass Results - Lodgepole Pine

The main differences between the two harvesting treatments concerned the amount of material over 3 inches in d.b.h. and the depth of fuel left after logging. After cutting on the near-complete units, loading of material over 3 inches was reduced to 9 tons per acre, one-third of the prelogging amount. On the conventional units, loading increased three times--from 16 to 44 tons per acre. Although this size would contribute little to the spreading flame front of a fire, it would contribute measurably to total fire intensity and resistance to control. It also would contribute indirectly to fire spread by helping support smaller sized fuel at a more flammable level of compactness. Further discussion of fuel changes have been described by Brown (1974a).

Rate of spread and fireline intensity for the propagating flame front of a fire (this excludes spotting of fire brands) were estimated using the inventoried fuel data. The predictions showed that rate of spread would be about 3-4.5 times greater on the conventional units. Byram's fireline intensity (rate of heat release per linear foot of the propagating flame front) would be about 6 times greater on the conventional units for any wind speed and fuel moisture (fig. 2).

Fireline intensity is probably the most useful characteristic of fire behavior for evaluating slash fuel hazard. At fireline intensities of 500-700 Btu's/ft./s, direct attack becomes ineffective and spotting begins to be a problem.[2] At 1,000 Btu's/ft./s, crowning and serious spotting can be expected. Considering 500-1000 Btu's/ft./s to represent an unacceptable hazard, figure 2 shows that for at least one year after cutting, conventional logging creates unacceptable hazards. By 5 years, hazard in conventional units reduces to an acceptable level due to loss of needles and settling of slash. Figure 2 shows that hazard in the near-complete units is always acceptable.

Coram Results - Douglas-fir/larch

SILVICULTURAL SYSTEMS

After harvesting, fuel quantities and fire behavior potentials were similar for the shelterwood, group selection, and clearcut silvicultural systems. Quantities of fuel less than 3 inches in diameter within harvesting units varied greatly, thus masking possible statistical differences among silvicultural systems. For like treatments, the rates of spread in table 1 show the similarities among silvicultural systems.

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[2] Hal E. Anderson, Lesson Plan for Advanced Fire Behavior Officer Training S-590. USDA For. Serv. 1978.

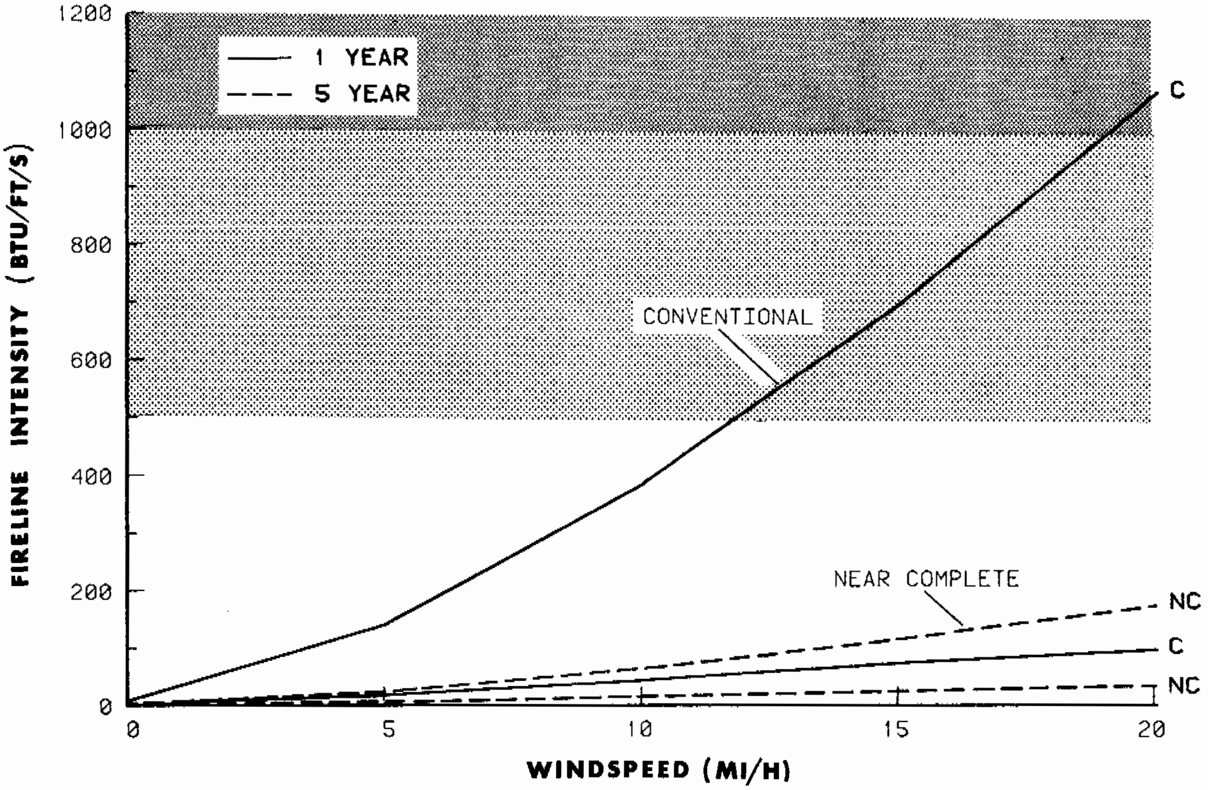

Figure 2.--Byram's fireline intensity for 1-and 5-year-old lodgepole pine fuels left after logging to conventional (C) and near-complete utilization standards (NC) at Union Pass. Shaded areas warn of unacceptable hazard.

Table 1.--Rate of spread for post-logging Douglas-fir/larch slash 1 year and 5 years after cutting at 0, 5, 10, and 15 mi/h windspeed, Coram.

Treatment	Silvicultural System	1 year				5 year			
		0	5	10	15	0	5	10	15
		Feet per minute							
Intensive	Shelterwood	26	32	42	56	10	13	16	19
	Group selection	39	49	65	87	14	18	22	26
	Clearcut	29	36	49	65	10	12	15	19
	Average	31	39	52	69	11	14	18	21
Sawlog	Shelterwood	40	51	68	90	17	21	26	31
	Group selection	27	34	46	60	13	16	20	23
	Clearcut	33	41	55	72	13	16	20	24
	Average	34	42	56	74	14	18	22	26
Intensive log	Shelterwood	17	21	28	35	9	12	14	16
	Group selection	12	15	20	26	5	6	7	8
	Clearcut	12	15	19	25	5	7	8	9
	Average	14	17	22	29	6	8	10	11
Near-complete	Shelterwood	7	9	12	15	4	4	5	6
	Group selection	9	12	15	20	4	5	6	7
	Clearcut	8	10	14	19	3	3	4	5
	Average	8	10	14	18	4	4	5	6

COMPARISON OF UTILIZATION LEVELS REFERRED TO AS TREATMENTS

Intensive tree and sawlog treatments, both having understories slashed (small trees cut and left on the ground), showed similar fire behavior predictions. Slashing created a major portion of the fine fuels. Although the utilization standards for the sawlog treatment allowed more residues, this additional fuel was not great enough to produce fire behavior predictions different than those of the intensive tree treatment. Consequently, for the remainder of this paper's discussion of treatment effects on fire behavior, intensive tree and sawlog utilization levels will both be referred to as "slashed" treatment.

As at Union Pass, near-complete utilization resulted in substantially less fire behavior potential than the other treatments. For example, predicted rate of spread for the near-complete treatment was approximately 0.25 of that for slashed and 0.6 of that for no slashing (intensive log) treatments (table 1). Fireline intensity for the near-complete treatment was approximately 0.1 of that for slashed and 0.25 of that for no slashing treatments (fig. 3).

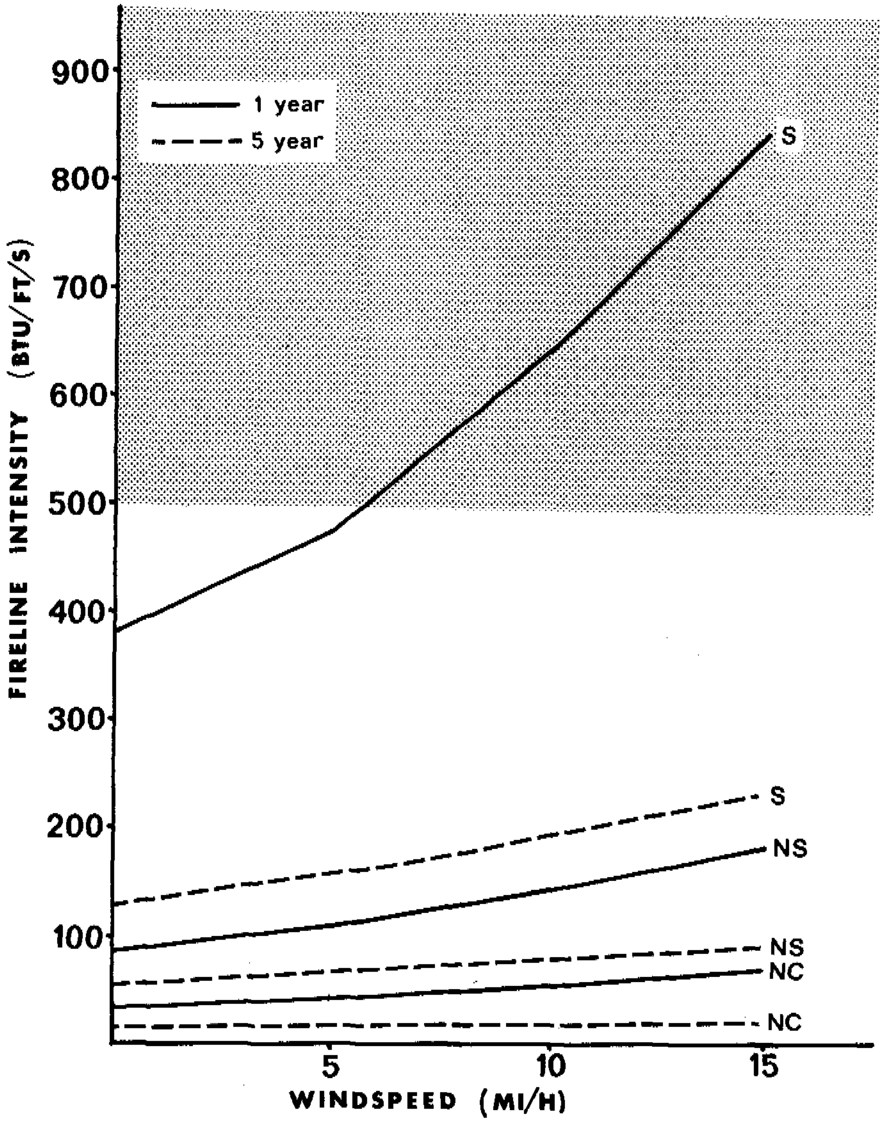

Figure 3.-- Byram's fireline intensity in 1-year and 5-year-old Douglas-fir/larch slash for slashed (S), no slashing (NS), and near complete (NC) treatments. The shaded areas signal unacceptable hazard.

Loading of fuel smaller than 3 inches in diameter was less for near-complete harvesting than for other treatments. This fuelbed was also more compact as illustrated by the relative compactness in Table 2. Both factors contributed to lower predicted burning rates. The fuelbed under the near-complete treatment became very compact--twice that of the sawlog treatment--due to extensive trampling and removal of residues. The slashing treatment's fuelbed also was very compact because of the absence of a fluffy, slashed understory. The least compact (most porous) fuelbed resulted from the sawlog treatment that had the largest merchantable diameter limits along with a slashed understory.

Unlike lodgepole pine at Union Pass, loadings of 3 inch and larger fuels were left at reasonable levels in all treatments (table 2). The reason for this is that the utilization standards specified removal of merchantable sound dead wood.

Table 2.--Loadings and relative compactness of downed woody material by treatment, averaged over silvicultural systems at Coram

Treatment	3 inches and greater			Less than 3 inches			Relative comp- actness[2]
	Pre- logging	Post- logging	Change[1]	Pre- logging	Post- logging	Change[1]	
	(T/a)	(T/a)	pct.	(T/a)	(T/a)	pct.	
Intensive tree	17.1	15.1	-12	3.90	10.77	176	1.2
Sawlog	16.5	17.0	3	4.18	10.74	157	1.0
Intensive log	16.4	13.0	-21	4.40	10.60	141	1.6
Near-complete	19.2	10.4	-46	3.87	7.66	98	2.1

[1] Percent change is $(100)\left(\frac{\text{Postlogging - Prelogging}}{\text{Prelogging}}\right)$

[2] Based on fuelbed bulk densities for 1-year-old slash. Sawlog treatment was a common divisor.

Whole tree skidding removed considerable slash from the surface fuelbed by transporting it off-site and grinding it into the forest floor and soil. Because whole tree skidding effectively reduced fuels, the no slashing treatment showed only slightly greater fire behavior potentials than near-complete harvesting (table 1 and figure 3).

For group selection and clearcutting systems, the only unacceptable hazards expected to last for about 5 years resulted from the slashing treatments (intensive tree and sawlog). After that, hazard fell to an acceptable level (fig. 3). Under shelterwood, where protection of the overstory is important, the no slashing treatment might have left unacceptable hazards depending on the fire resistance of the remaining trees. Near-complete harvesting under all silvicultural systems resulted in acceptable fuels and hazards.

OTHER TREATMENTS OF FIRE POTENTIALS

Considerably greater fire potentials could be expected from harvesting that leaves all tops and limbs on-site such as would result from ground lead skidding of only bucked and limbed merchantable pieces. For example, fuel and fire behavior were predicted for the two slashing treatments assuming all residues less than 3 inches in diameter remained on the site. A comparison of fire behavior for all fuels present with that for fuels from actual harvesting showed rates of spread that were 2-4 times greater for all fuels present. Fireline intensities with all fuels present were approximately 4 times that produced by the Coram harvesting (fig. 4).

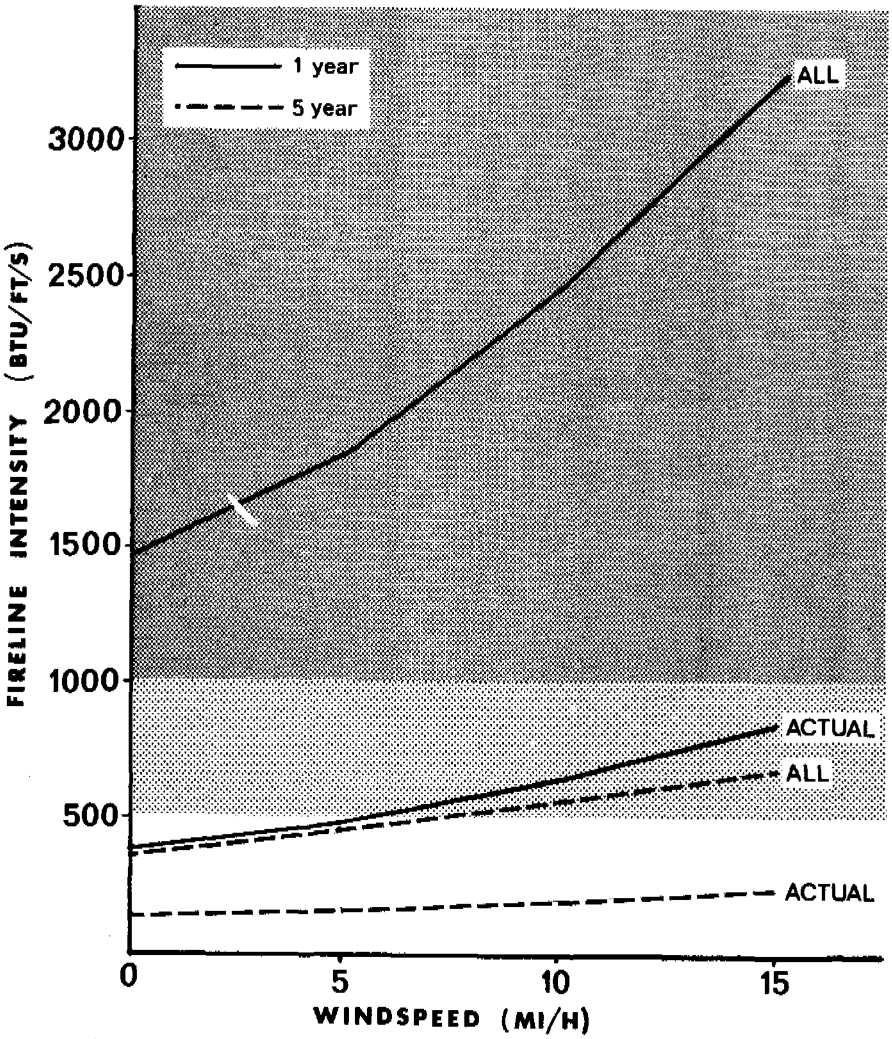

Figure 4.--Byram's fireline intensities in 2-year and 5-year-old Douglas-fir/larch slash for all potential fuels present and for actual fuel, after partially whole tree skidding. Shaded areas indicate unacceptable hazard.

Unacceptable hazard levels persisted beyond the 5-year prediction and could be expected to hold for 20 or more years.

PREDICTED VERSUS ACTUAL LOADINGS

Actual slash loadings (post logging minus prelogging inventories) of all material less than 3 inches in diameter averaged 0.7 of the predicted loadings. Interestingly, actual loadings of branchwood 0-0.25 inches in diameter averaged 0.4 of the predicted loadings. Thus, partially whole tree skidding removed considerably more fine fuel than larger branches from the slash fuel bed. Apparently, more finer, flammable branchwood than larger material is trampled into the forest floor during skidding.

Fire Management Implications

The following implications on fire management were apparent from the Union Pass and Coram studies:

1. Conventional Utilization Without Fuel Treatment. Conventional harvesting leaves unacceptable hazard levels with fireline intensity exceeding capabilities for direct fire control. Depending on species and volume cut, excessive hazards can exist for 3-5 years up to 20 years or more. There are ways to reduce hazards to an acceptable level. For example, utilization standards calling for removal of most bolewood and some dead material can mitigate hazards. If large-sized fuels are expected to be a problem, removal of some dead material is necessary to alleviate hazard. But it is important to remember that whole tree skidding coupled with slashing produces an unacceptable hazard for 3 to 5 years. Costs of skidding unmerchantable material may exceed the benefits of reduced hazard. This latter possiblility should be evaluated on a case by case basis.

2. Near Complete Utilization. Logging to near-complete utilization standards reduces fire behavior potential to a point requiring no further fuel modification for hazard reduction. In fact, insufficient fuel may exist for prescribed burning to meet silvicultural objectives. The same applies to whole tree skidding under conventional utilization standards without slashing, even though whole tree skidding results in somewhat greater fire potential than near-complete harvesting. To facilitate prescribed burning after whole tree skidding, understory slashing would be an asset and perhaps a necessity.

Although complete utilization can probably be relied upon to reduce fire hazard to an acceptable level, as it did in these studies, the desirability of complete utilization also depends on the need for residue material to carry prescribed fire, stabilize soils, shade seedlings, and recycle nutrients.

3. Conventional Utilization, with Fuel Treatment. Broadcast burning and piling and burning both reduce fire hazard to an acceptable level. Except for time limitations in scheduling, broadcast burning is a more desirable treatment because it causes less disruption of soil and leaves more large pieces of residue scattered throughout an area to provide site protection and a source for nutrients.

At Union Pass, lopping of slash solely for hazard reduction appeared unnecessary because natural deterioration alone should reduce hazard to acceptable levels. However, lopping may be desirable for bringing large pieces in contact with the soil to hasten decay and for aesthetic or other reasons.

4. Prediction of Fire Behavior. When predicting fuel and fire potential using procedures described in the next section of this paper, over-estimates are likely because material less than 0.25 inches in diameter is trampled out of the slash fuel bed. The significance of this problem varies with harvesting method and should be evaluated for individual situations.

METHODS FOR APPRAISING SLASH HAZARD

Procedures for estimating fuel quantities and fire behavior potential are available for appraising slash hazard on specific land units. Land managers who wish to appraise slash hazard should first decide on how accurately they need to know fuel quantity and fire behavior potentials. Then, one of the following methods can be used to help appraise slash hazard.

1. Nomographs of Rate of Spread, Fire Intensity, and Flame Length. Using nomographs developed by Albini (1976b), fire behavior at variable fuel moisture and wind speed can be predicted for low, medium, and heavy logging slash. These nomographs were developed for slash left after logging to an 8-inch top and skidded using a ground lead system. Resolution in the fire behavior estimates is relatively broad since the method recognizes only three levels of fuel quantity.

2. Photo Series. A series of photographs depicting a wide range of slash conditions identified by estimates of fuel loadings and fire behavior ratings were developed by Koski and Fischer (1979) for thinning slash in northern Idaho, and by Maxwell and Ward (1978a, 1978b) for forest residues in Washington and Oregon. U. S. Forest Service Region 1 and Region 6 also have developed a photo series. These photos in field manual edition can be compared with existing slash accumulations. By selecting the photo that most nearly compares with what is seen on the ground, one can estimate fuel loading and fire behavior potentials. This method affords more resolution than the preceding one, but its accuracy is unknown and probably somewhat limited. The method is appropriate where the most accurate other method available is not needed.

3. Computer Analysis Using Program HAZARD. Estimates of head fire spread rate, perimeter growth rate, flame length, crown scorch height, fireline intensity, and other fire characteristics can be obtained using a computer program, HAZARD, that can be accessed through the USDA Forest Service Computer Center at Fort Collins, Colo. Procedures for making the hazard assessment are described in a users' guide published by the U.S. Forest Service Northern Region (Puckett and others 1979).

Operation of the HAZARD program requires estimates of downed woody fuels existing before, and debris expected from a cutting. If necessary, existing fuels can be inventoried using the planar intersect method (Brown 1974b). Expected quantities of debris can be estimated using tables developed by Brown and others (1977) for some western U.S. Forest Service Regions, using a computer program called DEBMOD. This program furnishes predictions of debris from timber stand inventories.

Of all current methods, HAZARD provides maximum resolution and accuracy. It permits assessment of slash problems before they are created and is flexible enough to apply to a variety of harvesting systems through an adjustment of fuel inputs.

HOW MUCH FUEL IS ACCEPTABLE

Fire managers commonly want to know the tonnages of fuel that are acceptable. This question is difficult to answer because fire behavior depends not only on fire potential at one location but also on other factors, such as distribution of fuels and fire behavior potential over surrounding areas that may cover one or more drainages. Acceptable fuel loading depends on resource values, management objectives, pattern of land ownership, suppression capability, and multi-resource considerations. Professional judgment is certainly needed to determine acceptable fuel tonnages.

Decision Steps

Deciding how much fuel is acceptable requires one to integrate many factors (fig. 5). This can be done systematically as follows:

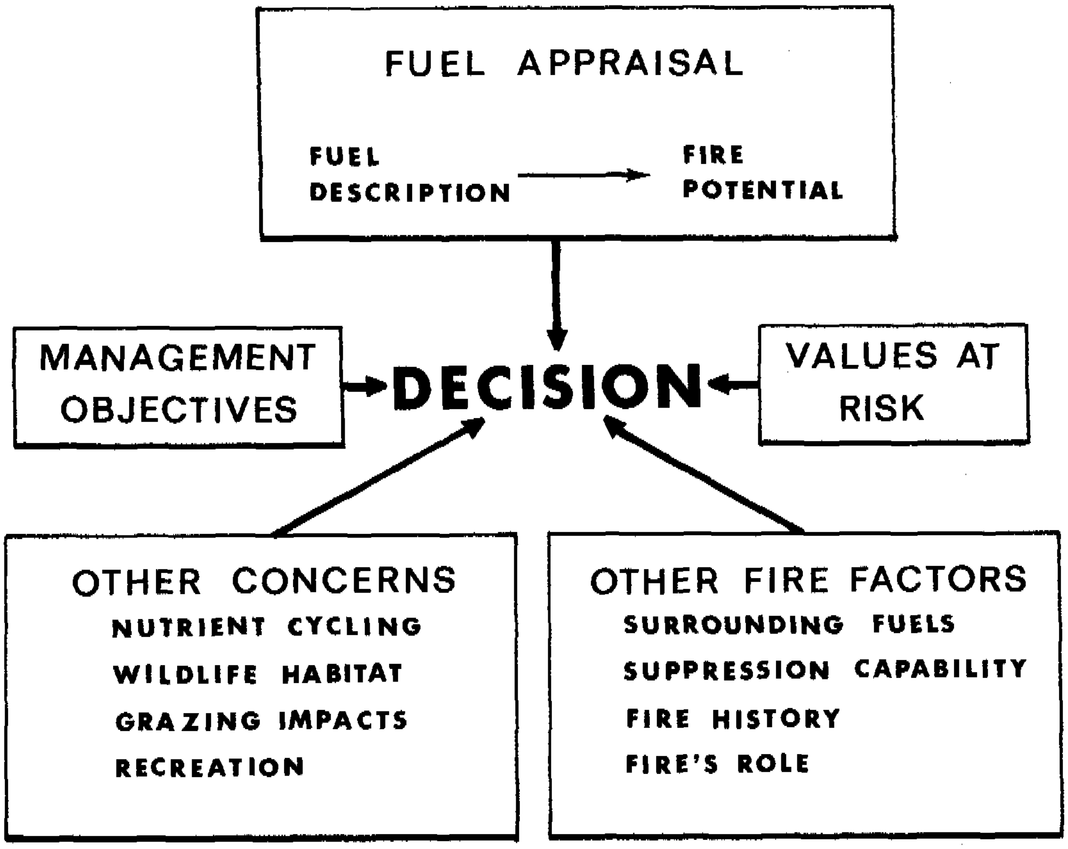

Figure 5. -- Factors to consider when deciding how much fuel is acceptable.

1. Consider management objectives and values at risk. For the latter, one considers both resource values and the risk of a fire causing damage during a high fire-danger period.

2. Appraise fuels by (a) describing fuels from inventory and prediction and (b) interpreting fire behavior potentials such as rate of spread, flame length, intensity, and scorch height.

3. Consider other fire-related factors such as fuel and fire behavior potential on adjoining areas, suppression capability, frequency and severity of historical fires, and fire's ecological role. Acceptable fuel loadings can depend to a high degree on these factors. For example, a heavier fuel loading would be acceptable on a unit surrounded by sparse fuels with little chance of ignition than on a unit surrounded by heavy fuels with a high chance of ignition.

4. Consider requirements of nonfire factors for attaining land management objectives. For example, some downed woody material is needed as a source of nutrients--particularly nitrogen. Debris fulfills habitat needs for some wildlife. Too much debris adversely affects grazing, wildlife, and recreational opportunities. An optimum quantity of downed woody material certainly exists and will vary by localities. Determining this optimum requires professional judgment integrated over several disciplines. Importantly, debris fuels represent an organic reserve that has a vital role in the functioning of ecosystems. They are more than just a fire problem.

Cost-Benefit Analysis

Cost-benefit analysis of fuel treatment alternatives can help a manager decide how much fuel is acceptable. However, the validity of cost-benefit analysis rests on several weakly quantifiable factors. Specifically, dollar values of some nonfire concerns are difficult to establish. Improvement in protection due to fuel treatment requires considerable speculation. Finally, risk of a fire occurrence is a very low probability event of considerable uncertainty.

Cost-benefit analysis of fuel treatment investments on the Lolo National Forest (Wood 1979) and Clearwater National Forest[3] have shown that:

1. Benefits due to factors other than fire protection can strongly influence the outcome.
2. Fuel treatment may be justified on high-value sites but is difficult to justify on low-value sites.
3. When benefits accrue only to treated areas, fuel modification is difficult to justify. Where possible, fuels must be treated so larger than the area benefited by reduced fire control costs and losses is larger than the area treated. For example, by treating fuels on a strategically located 100 acres, fire control costs and losses may be reduced on a surrounding 500 or more acres.

In conclusion, this study shows that fuel quantity and fire hazard can vary substantially with utilization standards. Often, conventional utilization standards result in unacceptable fuel and fire hazard. However, by implementing a high degree of utilization, acceptable fuels can result. Including an appraisal of fuels in preparation of harvesting prescriptions offers managers a way to deal with fuel problems before they are created.

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[3] Memo from the National Fuel Inventory and Appraisal Systems Project, Rocky Mountain For. and Range Exp. Sta., Fort Collins, Colo. to the Clearwater National Forest.

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ESTHETIC IMPACTS OF HARVESTING AND RESIDUE MANAGEMENT: PUBLIC PREFERENCE RATINGS

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ABSTRACT

The public concern about timber harvesting emphasizes its effect on the visual appearance of an area. The esthetic impact of different harvest and utilization alternatives were evaluated by the Scenic Beauty Estimation method that uses color slides rated by panels of viewers to provide a quantitative measure of public likes and dislikes. In general, the less an area shows logging debris and signs of soil disturbance, the better the area is liked. Esthetic quality improves as trees and other vegetation regenerate in the years after logging or road construction. These evaluations can provide guidelines for harvesting, especially in visually sensitive areas, and a means for evaluating the effectiveness of alternative harvesting methods in meeting visual objectives.

KEYWORDS: esthetics, scenic quality, forest landscapes, logging impacts

INTRODUCTION

During the past few years the public and land managers have displayed increasing concern about the impact of timber harvesting. Effects on soil, water, and wildlife are part of that concern; but perhaps the one aspect most noticeable to people is the visual impact of harvesting.

This paper summarizes studies that were undertaken to determine if different levels of visual impact exist for alternative harvest and utilization methods. Although the evaluation of public preferences might be considered as a socioeconomic undertaking, our initial studies indicate that public reaction to harvesting is tied to physical and biological impacts.

Important and rapid progress has been made in the field of visual planning and management of forest resources. For example, the visual management system used by the U. S. Forest Service and similar efforts by other land managers combine landscape design principals, public concern, and a variety of land management tools to protect and enhance the visual forest resource. Guidelines and principals for various activities are introduced at the ground level of project planning. In relation to these planning and management efforts, the studies reported here are intended to provide a detailed and quantitative appraisal of a narrow segment of visual management--harvesting and related activities. The results can be used for planning harvest activities to meet visual quality objectives, and to provide a means by which alternative harvest activities can be weighed and evaluated.

SCOPE AND METHODS

The studies deal primarily with the harvest of old-growth coniferous forests, and road construction associated with harvest. The objective is to evaluate public opinion of various harvest treatments as seen first hand--along a road or trail. The location and shape of units seen from a distance also influence public opinion and landscape planning, but our aim was to evaluate harvest and residue alternatives from an "up close" perspective.

At the outset, we sought a method of evaluating treatments, and in our first study we tried nothing more sophisticated than a 0 to 100 rating of different treatment by a landscape architect.

By coincidence, at the same time researchers in Arizona were developing and testing the Scenic Beauty Estimation Method.[1] This technique proved ideal for our measuring needs and because the SBE studies were used in so much of our work, I'd like to briefly describe the method.

A large number of slides were taken at random points in the treatments we wanted to evaluate. We then selected a sample of these slides, 5 to 10 in each treatment, and arranged them in random order in the slide tray. We presented the slides to viewers who were asked to rate each slide on a 0 (dislike) to 9 (like) scale.

From these ratings, arithmetic means of viewers ratings were developed for each scene, and an SBE score. The SBE score is a sophisticated measure of the viewers' response based on mathematical transformation that reflect the fact that viewers use the rating scale differently--some may use the whole 0 to 9 range, while others use only the 3 to 8 range for the same scenes.

For homogeneous groups of observers, arithmetic mean ratings and SBE scores are closely related. In all the panels used in our studies, the mean ratings and the SBE scores gave virtually the same results. The mean ratings are used here to present results because they are somewhat easier to understand, and the results are reported in the same units of measurement the viewers used to rate the scenes. It should be noted, however, that the means could not be used with confidence if we had not developed and compared the SBE scores.

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[1] Daniel, Terry C., and Ron S. Boster 1976. Measuring Landscape Esthetics: The Scenic Beauty Estimation Method, USDA Forest Service Research Paper RM 167. Rocky Mt. For. & Range Exp. Sta.

The various statistical data on SBE, arithmetic means, and tests of significance are on file at the Forestry Sciences Laboratory. These analyses were performed in cooperation with the Arizona researchers and the University of Montana.[2]

RESULTS

The results summarized here are based on study areas in Wyoming, Montana, and Idaho. Evaluations were made by 15 viewer panels that included timber industry representatives, public school teachers, and university psychology students. The findings that could have a direct bearing on management activities are included in the following summary.

Undisturbed Forests - The Baseline

Often when construction or a timber harvest is planned, the visual impact is compared to the undisturbed natural condition. We found that typical scenes in four mature, undisturbed forest types, (lodgepole pine, grand fir, western larch, and Douglas-fir) were rated by viewers at the like end of the scale, usually between 6 and 8 (fig. 1). However, when we looked in detail at the lodgepole pine ratings, we found that at the edge of a typical stand, such as along a meadow, the rating was highest; within a dark and enclosed mature stand, ratings were lower; and in a decadent stand with dead and fallen material, the ratings were actually on the dislike side of the scale. This suggests that a preference for the "undisturbed natural condition" actually meant a liking for green, neat conditions and a dislike for the clutter and debris that occurs even in nature.

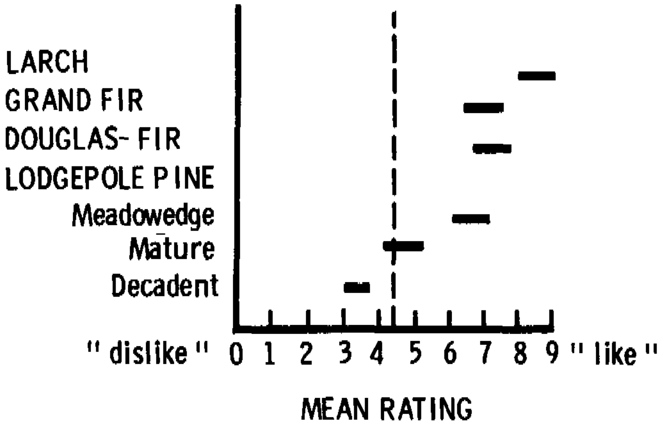

Figure 1.-- Mean rating of mature forest types from 0 (dislike) to 9 (like).

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[2] Design and analyses were results of cooperative studies with the University of Montana, with Dr. James Ullrich as principal investigator.

Harvested Areas

What happened when harvest and postharvest treatments were undertaken? A large number of combinations of treatments were undertaken in our research, but esthetic evaluations were made on harvesting methods--clearcuts or partial cuts--utilization levels, and postharvest treatments.

In an area of lodepole pine clearcuts, the ratings were based on evaluations by 6 panels (table 1 and fig. 2). Initially, all postharvest treatments were rated low, on the dislike end of the scale. By the fifth year after harvest, ratings for piled and burned residue had increased from 1.5 to 2.5; ratings for residues chipped and spread on site remained steady at 2; and ratings for near-complete removal of residues increased from 2.1 to 3.6.

Although these small differences are statistically significant, from a practical point of view we would have to conclude that all treatments on these cold, dry sites were disliked after harvest, and improve only slightly after 5 years.

Table 1.--Mean esthetic rating of lodgepole pine harvest treatments, Teton National Forest, Wyoming

Treatment	Rating[1]	
	Mean	Range
Mature, uncut	5.0	4.3-5.8
1st year postharvest		
Residues removed	2.1	1.0-3.6
Residue chipped & spread	2.7	2.1-3.9
Residue piled & burned	1.7	1.2-2.1
5th year postharvest		
Residue removed	3.6	[1]
Residue chipped	2.3	[1]
Residue piled/burned	2.8	2.0-4.2
Residue broadcast burned	2.5	[1]

[1] Based on 0 (dislike) to 9 (like) scale, treatments rated by 6 panels. In the 5th year broadcast burned, residue removed and residue chipped were rated by one panel only.

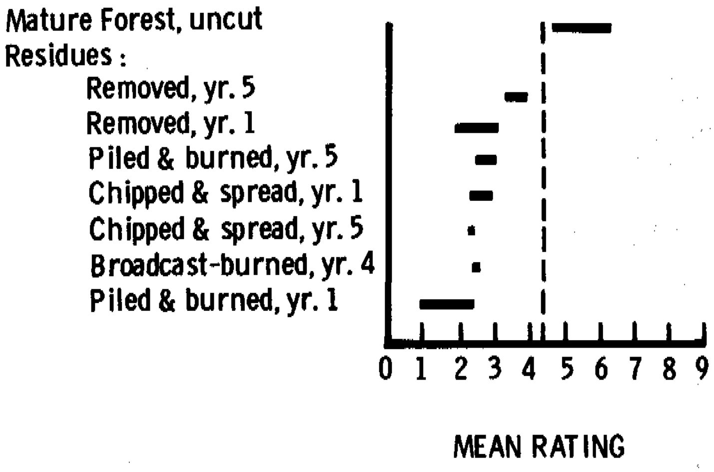

Figure 2.-- Mean rating of harvesting alternatives in lodgepole pine.

A Doulgas-fir/larch stand in a moist Montana location harvested by skyline showed more rapid response in ratings (table 2 and fig. 3). All treatments improved significantly from year to year; by the third year unburned clearcut treatments were rated exactly between like and dislike, and shelterwood treatments were on the like side of the rating scale.

Table 2.--Mean esthetic rating of Douglas-fir/larch harvest treatments, Coram Experimental Forest, Montana.

Treatment	Mean Rating		
	1st year	2nd year	3rd year
Uncut stand	6.9	6.9	6.9
Clearcut			
Residue burned	1.9	2.7	*
Residue removed	*	3.2	4.7
Understory protected	*	*	4.7
Shelterwood			
Residue burned	2.9	4.0	*
Residue removed	3.9	6.1	5.8
Understory protected	*	*	5.3

*Not rated

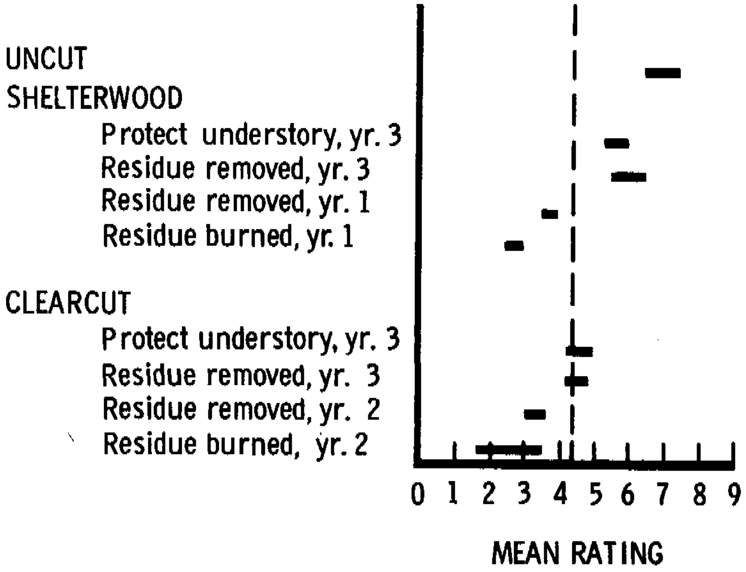

Figure 3.-- Mean rating of harvest alternatives in Douglas-fir.

First year evaluations of a 2-year old study illustrate some differences of type of harvest cut utilization level in public preference ratings. Because this study area (Lubrecht Experimental Forest, Montana) is used heavily for cross-country skiing, treatments were evaluated in winter, when the residue treatments were covered with snow. Cutting methods were rated as follows:

Uncut	5.2
Understory cut	5.0
Overstory cut	4.5
Clearcut	4.1

We subsequently evaluated these areas in the summer, when residue treatments were visible. These were the first year results :

	Mean Rating	
	Residues removed	Residues left
Uncut	--	5.4
Understory cut	6.1	4.4
Overstory cut	3.5	2.9
Clearcut	2.4	2.2

Again, partial cutting was preferred to clearcutting, and residue removal was rated higher than slash on site. Interestingly, the areas where only the understory was cut and residues were removed rated higher than the uncut stand.

Other studies

In addition to harvest studies, evaluations of roads also have been attempted. Because our first efforts were not well designed and other studies are only recently underway, results are limited.[3] Indications are that leave strips along roads must be dense enough to actively screen a logged area: the often-seen scraggly, narrow strips are of no esthetic value. Also, roads with vegetal regrowth on modest cut and fill slopes, may actually be more attractive than plain, undisturbed mature forests seen from the roadside. Fresh cuts and fills along new road construction are disliked.

Although evaluating the viewing point and distance were not part of our study, it appears that esthetic appeal of a common and monotonous forest areas can be enhanced if the sky, ridges, and drainage patterns can be seen.

CONCLUSIONS AND POTENTIAL APPLICATIONS

Although the studies cited are limited in time and scope, the findings are consistent with research based on other methods and well-established landscape-design principles. Basically, people prefer naturalness and orderliness in their forest. Debris and disturbances are generally rated low, and the more rapid the vegetal regrowth, the quicker the area approaches acceptable levels of public esthetic ratings.

Although measuring anything as elusive as public preferences for esthetic qualities is, at best, inexact, esthetic impacts are different among alternative harvest systems. To this extent our initial study objectives have been validated.

Fig. 4 illustrates one example of how these findings might be applied. Using the SBE method, we have developed a time profile for two forest types, Douglas-fir and lodgepole pine, that begins after harvest and continues through the life of the stand. These areas were clearcut and the logging slash burned.

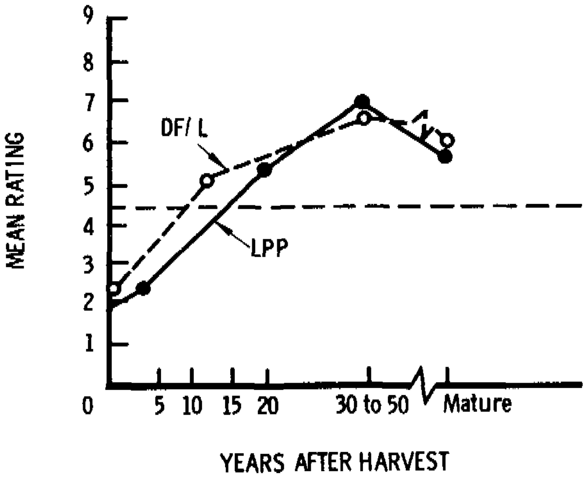

Figure 4.-- Time response of mean rating following harvest.

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[3] Benson, Robert E. and James Ullrich. Visual impacts of forest management activities: Interim findings on public preferences. INT Research Paper (in process).

Initially the areas are rated low. By the fifth year--roughly when tree regeneration and other vegetation begins to "green up"--the site received higher ratings. Between 10 to 15 years after harvest, ratings on the moist Douglas-fir site reach the mean point between dislike and like; for lodgepole pine, this takes about 15 years longer. At age 30 to 50, both types peak at a 7+ rating. Then, when the stand becomes over mature with dead and down trees, public preference ratings decline.

If harvesting alternatives are available, such as partial cutting or removal of residues, the ratings at year 0 may be shifted from curve A to curve B in fig. 5. The manager has a quantitative measure of esthetic response against which he can weigh the time lost or gained in reaching an acceptable esthetic level against the costs of the alternative.

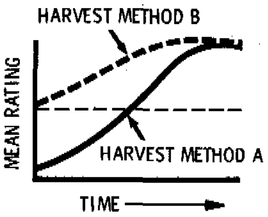
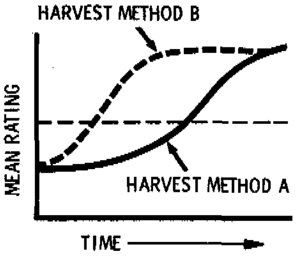


Figure 5.-- Comparing increase in esthetic rating of alternative harvest systems A and B.

If an alternative either enhances or diminishes the capacity of the site to produce vegetative regrowth, then the esthetic response curve may shift as in fig. 6. In this case, the manager can weigh the time lost or gained in reaching an acceptable esthetic level against the costs or benefits of the alternatives used.

Figure 6.-- Comparing time gained in reaching a given esthetic rating with alternative harvest systems A and B.



One study (not yet complete) will evaluate esthetic impacts of different harvesting methods on the same area, using SBE ratings of artists' sketches of the alternatives. Prior to this study, the SBE method was used to measure how well such sketches can portray actual scenes. This study was also tied to visual management objectives and in general, the SBE scenes correlated closely with "naturalistic," "retention," or "deterioration" of the area.

There is a great deal of research underway in the field of scenic visual quality. Evaluating esthetic impacts has come of age in land management planning. The findings of these initial studies and the development of quantitative measurements show promise of being valuable tools to aid in visual management planning and evaluate the effectiveness of different harvest and residue treatment alternatives.

INFLUENCES OF TIMBER HARVESTING AND RESIDUE MANAGEMENT ON BIG GAME

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ABSTRACT

Road construction and timber harvesting displace elk and grizzly bears at least temporarily. Elk sometimes accept logging disturbances, but usually do not return until harvesting ends. Increased contact between grizzly bears and humans is undesirable.

Logging slash may increase cover, but normally only obstructs animal movement. Broadcast burning produces more food plants for both elk and grizzly bears than other slash treatments. Although increased vehicle traffic adversely affects elk and grizzly bears, road closures should be carefully planned to achieve specific results.

Development of post logging big game habitat is a long-term process involving complex and dynamic relationships, not merely forage production. Elk, grizzly bears, and other big game require year-around habitat that satisfies daily and seasonal needs.

KEYWORDS: timber harvest, roads, slash, elk, grizzly bear

Road construction, timber harvesting, and slash disposal are of continuing concern to big game managers in the northern Rocky Mountains. Historically, the most productive big game habitat in this region has been seral forest vegetation developing after forest fires. Plant communities that develop following logging normally provide comparable productive vegetation. Yet, positive benefits to big game following logging have been difficult to verify, while the negative influences have generated a substantial volume of literature.

The primary reason for this discrepancy is that timber harvest consists of a series of events, each of which can produce positive or negative responses by animals and may have radically different effects in different seasons. Road construction and logging activity, slash treatment, road management, and postlogging habitat development must be considered individually and in concert. It is especially necessary to recognize that big game animals do not rely solely on habitat within treated sites. Any treatment evaluation requires simultaneous evaluation of treated and untreated habitat in relation to species requirements. And, herein lies a further problem in that habitat requirements are not well defined for most species. In this paper, we summarize some of the more recent research in timber management/big game relationships and specify areas where additional research seems most urgently needed. We confine the discussion almost entirely to the Rocky Mountain elk (*Cervus elaphus nelsoni*) and the grizzly bear (*Ursus arctos horribilis*). This is a narrow perspective, but the alternative would require discussion of at least 11 species for which adequate information is not readily available. This limitation is not intended to suggest that the elk is a representative ungulate and the grizzly a representative carnivore. We prefer to stress that other big game species and their responses to timber management must be evaluated specifically rather than by implication.

GENERAL CONSIDERATIONS

In a broad sense, Rocky Mountain elk and grizzly bears do provide justification for a generalized logic of habitat management based on maintenance of diversity in the forest environment. In addition to food, cover, and water -- needs common to all big game --elk and grizzly bears utilize some fairly specialized habitat (breeding areas for elk, denning areas for bears). A mosaic of vegetation types and edges is considered indicative of productive big game range (Biswell and others 1952; Leopold 1948; Stelfox and Taber 1969; Mackie 1978). Although elk can adapt to a variety of habitat conditions, a heterogenous mosaic is most likely to contain all the required components. In many areas of Montana, Idaho, Oregon, and Washington, specific proportions and juxtapositions of elk forage and cover areas have been defined.

Less is known of the specific habitat required by grizzly bears, but current research suggests that diversity of vegetation types is as important for bears as for elk (Martinka 1976; Varney and others 1976). In the Yellowstone Park area, some radio-monitored bears have annual home ranges in excess of 777 km^2 (300 square miles) (Knight and others 1978). Studies in this area (Mealey 1975; Graham 1978; Knight and others 1978) corroborate findings elsewhere (Mundy and Flook 1973) that the grizzly is an opportunistic omnivore. Food selection is often seasonally specific and concentrated within preferred habitat niches constituting a small proportion of the annual range. The remaining, larger portions apparently serve as travel routes and buffer zones. Presumably, the size of an individual range is dictated by the variety, quality, abundance, and juxtaposition of these habitats, routes, and zones and their combined capability to meet the bear's needs. Again, a diverse mosaic appears most likely to contain the required components.

As a basic guideline for timber harvest on any big game range, managers should avoid the creation of large areas of any single type or successional stage. The wildlife habitat objective should be to maintain a continuing diversity of habitats while simultaneously preserving the integrity of niches important to particular species. In grizzly bear management, an equally important objective is to reduce the probability of encounters with man.

ROAD CONSTRUCTION AND TIMBER HARVEST

Road construction and timber cutting constitute a major disturbance of the forest environment. Elk, particularly on summer range, have responded by moving form 0.8 to 6.4 km (0.5 to 4 miles) from the source of the disturbance (Beall 1974; Marcum 1975; Lyon 1975; Ward 1976; Lonner 1978). Specific movement patterns have not been described, but research results suggest that the location of the disturbance is more important than intensity in determining the distances moved. Elk appear to move only as far as necessary to escape line-of-sight contact with men and equipment (Marcum 1975; Lyon 1975; Ward 1976).

Under most circumstances, displacement is temporary, but the time elk require to return has proved extremely variable. Some elk will remain quite close to a logging area and return during the night and on weekends (Beall 1974; Marcum 1975; Ward 1976). Others may leave for a short period and gradually return while logging is in progress (Beall 1974). In a study of winter logging in British Columbia, McLellan (1978) recorded increases in overnight use of active logging areas as compared with elk use of the same areas before logging began. Some elk may even become habituated to logging activity during daylight hours (Beall 1974; McLellan 1978).

Most commonly, at least some of the displaced elk return within a few days to weeks after the disturbance has ended. Marcum (1975) has noted that animals forced to move great distances to find security are less likely to return immediately, and Lyon (1979b) has speculated that repeated disturbance in the same area over several consecutive years can result in avoidance behavior for one or more years after logging is completed. To date, all studies indicate that elk will eventually reoccupy logged areas.

In summary, it appears that temporary displacement is a significant but not fatal inconvenience for elk. If movement patterns are well known, it may be possible to protect key areas and time logging operations to avoid disturbances while elk are in those areas (Roberts 1974). Providing an adjacent security area (Lyon 1975; Marcum 1975), concentrating management activity into the shortest possible period of time (Black and others 1976), and confining the area of activity to a single drainage (Ward 1976; Black and others 1976) should mitigate most of the apparent displacement problems.

We are unaware of any study explaining how logging and road building affects grizzly bears; however, we can speculate that in many instances the bear's characteristic shyness will keep it from the logging area for the duration of the activity. Displacement may be for much longer periods in specialized areas. For instance, bears seek den sites far isolated from man's activities, presumably because the bear's lethargic state immediately before and during hibernation renders it particularly vulnerable to man (Craighead and Craighead 1972b). Students of the European brown bear -- a conspecific of our grizzly -- suggest that logged areas may be abandoned as denning sites for many years (Zunino and Herrero 1972).

In contrast to displaced bears, some individual bears are easily conditioned to man's presence, and logging activities may not deter bear use for very long near preferred foraging sites. Conditioning to man is also enhanced by logging camps where carelessness with food supplies, refuse disposal, pets, and pet food can attract bears and easily create a "nuisance bear" situation. The unfortunate result of repeated bear/ man encounters is that the bear loses its shyness and becomes dangerous (Jonkel and Servheen 1977). The inevitable consequence is killing of the bear to protect human life or property. Thus, prevention of bear/man encounters is important.

Studies of several grizzly populations show a strong seasonal use of certain habitat components: an early spring attraction to avalanche chutes for the vegetation green-up, and to ungulate wintering areas to feed on dead or dying animals; a mid- to late-spring attraction to elk calving grounds for carrion or easy prey; a late spring and early summer use of meadows for succulent herbs; movement to streams at spawning times; a summer and early fall preference for patches of ripe berries; a fall attraction to hunter camps. Recognition of these seasonally specific feeding sites provides a means of protecting bears and reducing bear/man encounters by deferring logging during periods of bear use.

SLASH TREATMENT

Following completion of a timber sale, variable amounts of limbs, branches, and other waste materials remain on the ground. The influence of this slash on big game use of logged areas has been reported from several areas. Generally, untreated slash impedes elk movement (Pengelly 1972; Beall 1974), especially when windrowed along roads. Slash within logging units has also been reported as a barrier to elk use of clearcut openings (Reynolds 1969; Day 1973; Lyon 1976) and of selectively logged areas (Beall 1976).

The recommended solution, of course, is some kind of slash treatment (Black and others 1976; Lyon 1976). This treatment can take a number of forms: broadcast burning or piling and burning, on-site crushing, piling, chipping, or removal from the site. Regardless of the method, the treatment will have both an immediate physical effect and an additional long-term influence on vegetal development. Black and others (1976) have suggested that windrowed or piled slash might provide some cover and help break up long sighting distances in openings; and Reynolds (1966a) found that undisturbed light slash made openings more attractive for deer. Few other authors suggest a specific method of slash treatment, and if reducing barriers to elk movement is the only consideration, most methods are probably acceptable.

A different viewpoint is suggested by the number of publications on postfire forage development on elk ranges (Leege 1968, 1969; Leege and Hickey 1971; Lyon 1971a; Basile and Jensen 1971; Asherin 1976; Irwin 1976; Wittinger and others 1977). By implication, slash should be reduced by fire because burning produces the most satisfactory response in forage plants.

Foraging opportunities for grizzlies are also enhanced by slash burning because fire often produces a greater abundance and variety of food items than other treatments. Broadcast burning is preferable to piling and burning, particularly where rhizomatous berry producers (mainly the *Vacciniums*) are conspicuous contributors to the seral community. If piling is necessary, a brush blade is recommended to minimize disturbance of rhizomes. Slash is probably only a minor deterrent to bear travel and may be of some value as cover.

ROAD MANAGEMENT

More than any other single facet of forest management, road construction and the post-logging management of those roads has been reported as a problem in elk management and in grizzly bear management. During the 1960's, greatly accelerated timber harvest on National Forests, and an expanding network of new roads, made elk more vulnerable to hunters and harassment (Wyoming Forest Study Team 1971). Unwanted side effects included reduction in the length and quality of hunting seasons, loss of habitat, overharvest and declines in elk populations (Janson 1973; Stankey and others 1973; Thiessen 1976; Hershey and Leege 1976; Coggins 1976; Perry and Overly 1976).

In recent years it has been repeatedly confirmed that elk avoid habitat adjacent to travelled roads. The width of the area avoided depends on the kind and amount of traffic and the available cover. Apparently, elk will become accustomed to the consistent movement of highway traffic and are most disturbed near secondary roads with slow-moving or erratic and noisy traffic and people outside vehicles (Burbridge and Neff 1976; Ward 1976). Habitat adjacent to primitive and dirt roads is not as persistently avoided, possibly because it is disturbed less often (Perry and Overly 1976, Rost and Bailey 1979). Elk avoidance of any road is greatest in meadows and openings and least in heavy or dense cover (Perry and Overly 1976, Lyon 1975).

Unlike the temporary displacement of elk by logging activity, avoidance of habitat adjacent to roads is significant and continuous while the roads are open to vehicles. Perry and Overly (1976) pointed out that more than 2.6 km^2 (640 acres) of habitat can be affected by 1.6 km (one mile) of road, and Lyon (1979a) calculated that as little as 1.86 km/km^2 (3 miles per section) of open road can terminate elk use. In many circumstances, elk can retreat to undisturbed habitat, but this avoidance response may entail some nutritional risk if an expanding road system restricts animals to substandard habitat (Rost and Bailey 1979).

In addition to obvious mitigation through road closures, it has been recommended that roads be located in timber rather than openings (Ward 1976; Black and others 1976), designed to have minimum cuts and fills, no long straight stretches, the smallest possible widths, and construction features facilitating effective closure (Black and others 1976; Lyon 1975).

Despite the volume of information showing negative elk response to open roads, the expected positive response following road closure has not been fully investigated. Marcum (1975) reported increased elk use following closure of logging roads in the Sapphire Mountains in Montana; Burbridge and Neff (1976) detected increased use in the closed unit of paired areas; and Lyon (1979b) reported that elk use of a logged drainage returned to prelogging levels after road closure. In both of the latter studies, weather was considered an important factor influencing elk movement.

Several investigators have displayed an interest in elk and hunter response to road closures during the hunting season. Such travel restrictions have generally been successful in improving the perceived quality of the hunt (Coggins 1976; Basile and Lonner 1979; Stankey and others 1973). Closures, however, have not resulted in the creation of refuge areas (Burbridge and Neff 1976; Coggins 1976) with the possible exception that elk emigration from areas of sparse cover is reduced when hunters are limited to foot travel (Basile and Lonner 1979).

Quantitative data on grizzly behavior with respect to road management are lacking. Circumstantial evidence, however, is quite convincing that most bears avoid habitat adjacent to roads in direct correspondence to the intensity of traffic, roadside activity, and lack of protective cover. Unrestricted use of roads and roadsides may disrupt the bear's normal foraging, travel, and distribution patterns and result in habitat loss.

Authorities agree that isolation is a major ingredient for grizzly bear survival, that today's remaining populations owe their existence to the paucity of resource exploitation in the bears' current range, and that significantly increased roading will lead inevitably to the disappearance of the grizzly (Varney and others 1976; Mundy and Flook 1973; Jonkel 1975). Support for this strong condemnation of an expanded road network is found in the striking parallel between the shrinkage of grizzly range and numbers in North America and similar losses of the brown bear in Europe. Bear declines in Italy (Zunino and Herrero 1972), Norway (Elgmork 1976), Sweden (Burmann 1974 as cited by Elgmork 1976), Finland (Pulliainen 1972) and Estonia (Kaal 1976) have each been attributed to a combination of agriculture, mechanized forestry, forest roads, and accompanying human activities.

POSTLOGGING HABITAT DEVELOPMENT

Following timber harvesting, substantial increases in forage production have been reported (Reynolds 1969; Patton 1974; Basile and Jensen 1971; Leege 1968, 1969; Leege and Hickey 1971; Asherin 1976; Irwin 1976; Wittinger and others 1977). However, the benefits produced for big game depend on forage and cover relationships, slash treatment, road management, and other factors that determine whether the increased forage can actually be used or whether it was even needed in the first place. Elk response to habitat manipulation is more complex than the uncritical assumption that food is a limiting factor (Lyon 1971b; Allen 1971; Pengelly 1972). Modifications in wildlife habitat cannot be evaluated on the basis of a single environmental condition. Thus evaluation of postlogging habitat is virtually always an equivocal comparison of prelogging, immediate postlogging, and expected habitat changes over a period of years.

One area of concern is exemplified by the number of reports describing the size of opening preferred by elk. Tolerance for large natural parks and open sidehills is widely recognized (Murie 1951; Anderson 1958; Boyd 1970; Ward 1973), but the majority of investigators have reported elk preference for smaller openings (Reynolds 1962, 1966b; Miller 1974; Lyon 1976). In specific situations, elk have demonstrated a preference for large clearcuts (Hershey and Leege 1976), for unroaded brushfields over clearcuts with more abundant forage (Leege and Hickey 1977), and consistent refusal to use clearcuts of any size (Marcum 1975).

These apparent discrepancies in elk behavior show a considerable degree of adaptability to habitat modification and demonstrate that elk use of clearcut openings does not depend solely on opening size. Several studies have shown that open roads and untreated slash reduce elk use of any habitat; other studies illustrate the importance of vegetation age and seral development (Pengelly 1963; Lyon 1966; Mueggler 1967). Peak use by elk might occur within 5 (Pengelly 1972) or 10 years (Hershey and Leege 1976), terminate within 12 years (Pengelly 1972), or continue for several hundred years (Lyon 1966).

During the years of high forage production in clearcuts, snow in the opening may prevent utilization by elk. Elk begin to experience difficulty at snow depths of 46-61 cm (18-24 inches) (Gaffney 1941; Telfer and Kelsall 1971; Beall 1974; Leege and Hickey 1977). Movement to areas with less snow, to lower altitudes or uncut timber, appears to occur without regard for forage availability (Beall 1974; Leege and Hickey 1977). Beall (1974) reported that elk in the winter have a strong association with cover types and less association with forage. Stelfox and others (1976) found no winter use of 17-year-old clearcuts in Alberta and estimated that summer use was less than 10 percent of capacity because cover was so poor. And in Montana, Lyon and Jensen (1980) reported that cover at the edge of clearcuts as well as cover height inside the opening was an important determinant of elk use.

The grizzly bear evolved from its forest-dwelling Pleistocene ancestors (Kurten 1968) into a species adapted to treeless habitat (Herrero 1972; Martinka 1976) at a time when primitive man posed no threat. In response to modern man's capacity to annihilate it, the grizzly today shows an apparent dependence on timber cover in proximity to foraging areas (Graham 1978; Knight and others 1978) and den sites (Craighead and Craighead 1972a). The amount of cover necessary for security remains to be defined.

Much of the unused portion of the bear's range is in broad expanses of coniferous forest. Of apparently minor value for feeding, and presumably in excess of minimum cover needs, these forests appear to offer the potential for creating new foraging sites through logging and subsequent successional development. Although the floristics of seral stages in the various habitat types are not well documented, it is reasonable to assume that prudence in the timing and spacing of logging operations will maintain a heterogeneity of conditions beneficial to the bear. The challenge is whether this can be done without adversely affecting the bear. We need additional knowledge of habitat components, of alternate food sources, of travel corridors, of minimum buffer zones, and of how to maintain the integrity of these collective habitat components. Meanwhile, we can only recommend a cautious and conservative approach to logging in grizzly range.

The influence of postlogging habitat development on big game can be described as the most important and complicated influence of harvesting and residue management. Road construction, timber harvest, slash treatment, and road management are short-term problems for which partial solutions are already available. Repeated or prolonged timber sale activity will compound the negative effects on elk and grizzly bears, but when the disturbance is over, the slash treated, and the roads closed, the habitat will represent some combination of cover, forage, and diversity with an ability to support both species. This capability may be higher or lower than that before timber harvest, and it will change constantly as forest vegetation grows and changes.

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INFLUENCES OF HARVESTING AND RESIDUE TREATMENTS ON SMALL MAMMALS AND IMPLICATIONS FOR FOREST MANAGEMENT

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ABSTRACT

Following logging and residue treatments, there is a successional sequence of small mammal species in response to the availability of cover and food. Small mammals increase dramatically during the first few years after logging. Species composition is related to habitats resulting from harvesting methods. Small mammal impacts on forest regeneration may be reduced by not creating optimum habitat for problem species during harvesting. Small mammals may also play beneficial roles. A vegetative mosaic in species and structure is recommended for areas where wildlife management is of high-priority.

KEYWORDS: small mammals, logging, residue treatments, fire, northern Rocky Mountains

INTRODUCTION

Small mammals were of little interest to foresters until their potential affects on forest regeneration after logging became evident. Results of studies in cut-over plots and in the adjacent forest showed that small mammals were more numerous in logged areas than in the uncut forest, and they were consuming significant amounts of conifer seeds and seedlings. Methods of direct control were found effective only for the duration of the sustained effort. Small mammal populations rebounded as soon as the trapping or poisoning ended.

Presently, many silviculturalists consider the habitat requirements of small mammals that retard forest regeneration and, where feasible, select harvesting methods that do not provide optimum habitats for problem species.

The importance of small mammals in the forest ecosystem is gradually becoming understood. The symbiotic relationship of small mammals with the forest community may be important for forest regeneration. In addition, the public has become increasingly interested in nongame species for strictly aesthetic reasons. People enjoy seeing porcupines and photographing chipmunks. This interest is underscored by new nongame programs, which emphasize the aesthetic values of small mammals.

SMALL MAMMAL HABITAT REQUIREMENTS

The response of small mammal populations to logging and slash disposal depend on the extent of habitat alteration. Structure of the vegetation and food seem to be the most important aspects of small mammal habitat.

Removal of vegetation has profound effects on small mammals. Physical barriers are created or removed. More sunlight reaches the ground and the range of temperatures at the ground surface increases. Moisture regimes are altered by changes in the amount of precipitation reaching the ground, evaporation, dew, and transpiration rates. Over the long-term, increased light and moisture result in abundant growth of forbs, grasses, and shrubs, which favors increased numbers of small mammals.

Most species of small mammals are adversely affected by the short-term effects of logging and fire: injury or death from logging and burning, loss of food and cover, displacement, and increased predation (Lawrence 1966). Hawks (Baker 1940) and small carnivores are attracted to recent burns. The blackened ground improves thermals for soaring raptors, and the removal of ground vegetation makes surviving small mammals more visible. Carnivores may be attracted by the smell of decomposing carcasses of animals killed during burning (Motobu 1978). Over the long-term, populations of most small mammals increase following logging and fire. Small mammals multiply rapidly in favorable habitats because they reach sexual maturity early, and they have short gestation periods, large litters, and potential for several litters each year.

The small mammals found in the successional stages following clearcut logging and burning are shown in figure 1. Each species has specific habitat requirements. Some are more adaptable than others, but each has limiting requirements. For example, tree squirrels depend on mature forests. Flying squirrels (*Glaucomys* spp.) must have trees with cavities for nesting. Red squirrels (*Tamiasciurus hudsonicus*) use cone-producing trees for food and shelter. Clearcutting eliminates essential habitat, and displaces both of these arboreal mammals. The microtines, red-backed voles (*Clethrionomys gapperi*), and voles of the genus *Microtus*, are creatures of the organic layer on the ground surface. Important elements of their environment are a mat of ground cover, palatable herbaceous plants, and moisture. Logging improves the growth of forbs by increasing light and ground moisture. After logging, increased numbers of *Microtus* can be expected, however, *Clethrionomys* populations may be suppressed by the removal of the forest canopy and the loss of adequate surface moisture (Odum 1944). Occasionally, red-backed vole populations remain high until logging slash is burned. After burning, populations decline (Gashwiler 1959).

The shrews (*Sorex* spp.) generally require a mat of ground vegetation for cover, although, as insectivores, they are less dependent on vegetation types than the microtines (Rickard 1960). Shrews and microtines are temporarily eliminated by a hot fire that removes duff and ground vegetation and will not reinvade until herbaceous vegetation is reestablished.

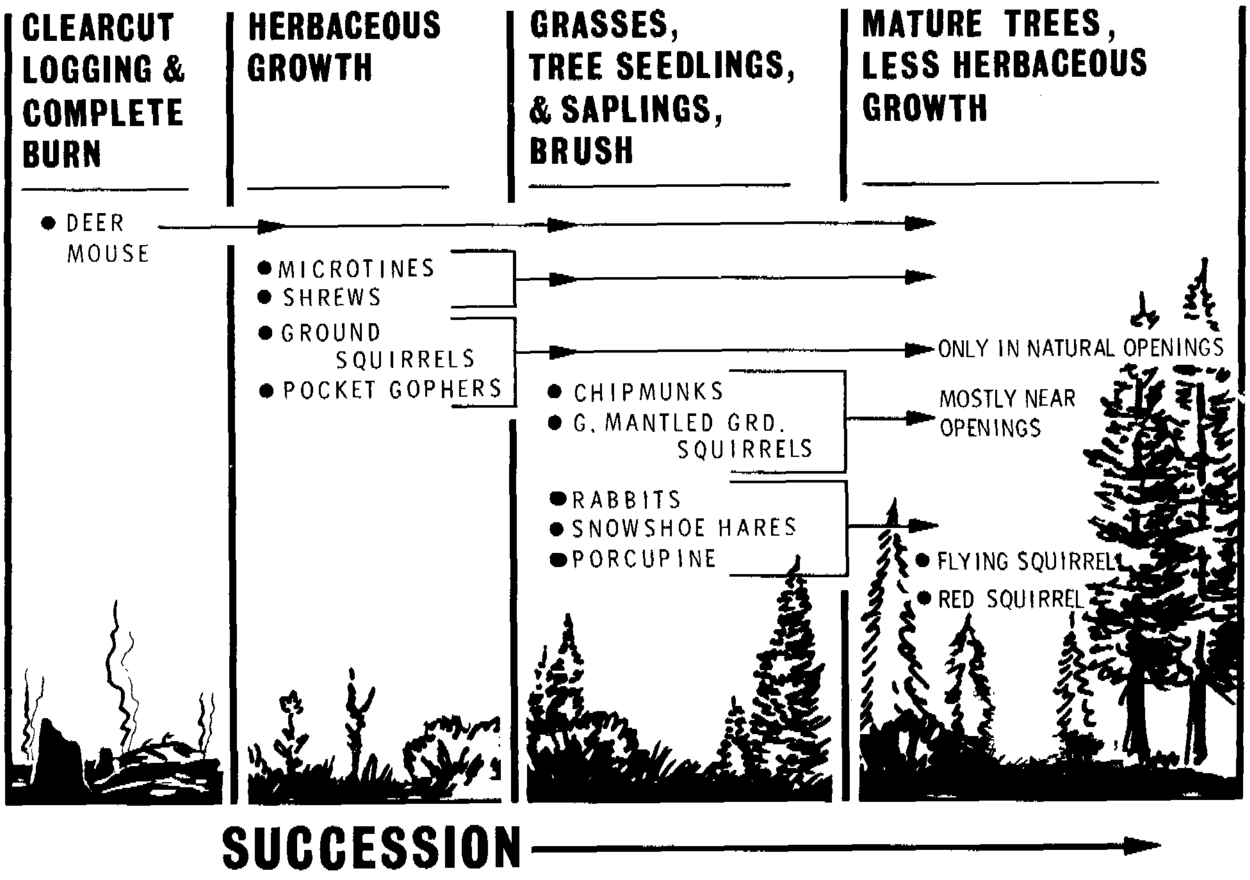

Figure 1.--Small mammals found in the successional stages after clearcut logging and burning.

Deer mice (*Peromyscus maniculatus*) are present in most stages of plant succession, but not always in great numbers. They are a pioneering species that proliferate on newly burned clearcuts soon after the ash has settled. Their diet at this time is insects, conifer seeds, and other seeds that remain in the soil after burning. As the vegetation develops, the seeds of herbaceous plants are eaten. Apparently the nocturnal habits (LoBue and Darnell 1959) and erratic movements of these mice provide some protection from predators. Deer mice are most abundant in clearcuts about five years after logging, but decrease with time and vegetal development. Sometimes this decrease is rapid. Numbers in closed-canopy forests are usually quite low.

Open areas are preferred by pocket gophers (*Thomomys talpoides*) and Columbian ground squirrels (*Spermophilus columbianus*). The protective burrow systems of these animals enable them to invade and use large open areas that lack shrub or tree cover. Opening of the forest canopy and coincident development of herbs results in optimum habitat conditions.

Golden-mantled ground squirrels (*Spermophilus lateralis*) and chipmunks (*Eutamias* spp.) prefer open areas, but they are reluctant to venture where cover from boulders, fallen trees, limbs, or shrubs is lacking. The numbers of these animals increases in partial cuts and clearcuts where some residue remains on the ground (Davis 1976).

Cottontail (*Sylvilagus* spp.) populations may increase in clearcuts where there is dense tree regeneration or shrubby and herbaceous undergrowth. Windrowing slash benefits this species (Costa and others 1976).

Snowshoe hare (*Lepus americanus*) and porcupine (*Erethizon dorsatum*) reoccupy logged areas after the establishment of shrubs and saplings needed for food and cover.

EFFECTS OF HARVESTING METHODS: CLEARCUT VS. PARTIAL CUT

Clearcuts and partial cuts both result in an increase of light and available moisture, with the resultant release of understory vegetation. The major difference is that habitat modification in a clearcut is more extreme than in a partial cut. Extreme habitat modification results in the displacement of some species and unusual increases in numbers of other species. For example, although tree squirrels are displaced from clearcuts, ground squirrels and pocket gophers, which prefer open areas and scarified soil, increase in clearcuts (Barnes 1974).

The impacts of microtines and deer mice on forest regeneration are not as significant on partial cuts as on clearcuts. Generally, habitat changes are less dramatic on partial cuts than on clearcuts. The results are less pronounced changes in small mammal populations. Figure 2 shows the small mammal species that may be found after different harvesting and residue treatments.

EFFECTS OF RESIDUE TREATMENTS

Broadcast Burns

Broadcast burns may result in the nearly complete removal of living vegetation and a scattering of unburned slash. Under the ashes are roots, corms, bulbs, rhizomes, dormant seeds, and spores. Many of these sprout immediately, stimulated by fire, increased light, moisture, nutrients, and the lack of competition.

Most burrowing small mammals survive a fire due to the insulation of the soil, if their burrows are sufficiently ventilated. In a Montana study, subsurface temperatures at 2 inches were 118°F (48°C) in spite of 500°F (260°C) soil surface temperatures (Halvorson in press). Howard and others (1959) found subsurface temperatures of 140°F (60°C) to be lethal to caged rodents buried beneath a chapparal fire. In unventilated burrows or where the relative humidity was above 50 percent, death occurred around 120°F (49°C) (Lawrence 1966).

Species living above ground may escape by fleeing (Komarek 1969). However, large and small mammals and birds, are sometimes killed by a hot, fast-moving fire (Kipp 1941). A burn is reoccupied soon after the ash settles if species habitat requirements are met (Tevis 1956d). Other animals may remain in adjacent unburned areas, where as newcomers they are more vulnerable to predation than the resident small mammals (Metzgar 1967). Where fire has removed all ground cover, deer mice are usually the only species that will become immediately established in significant numbers. Other species will return as vegetation becomes established. (Dimock 1974, Tevis 1956d).

Incompletely burned residue in broadcast burns usually provides a better distribution of cover than concentrated incomplete burning of piled slash. Chipmunks and golden-mantled ground squirrels benefit from this distribution of slash.

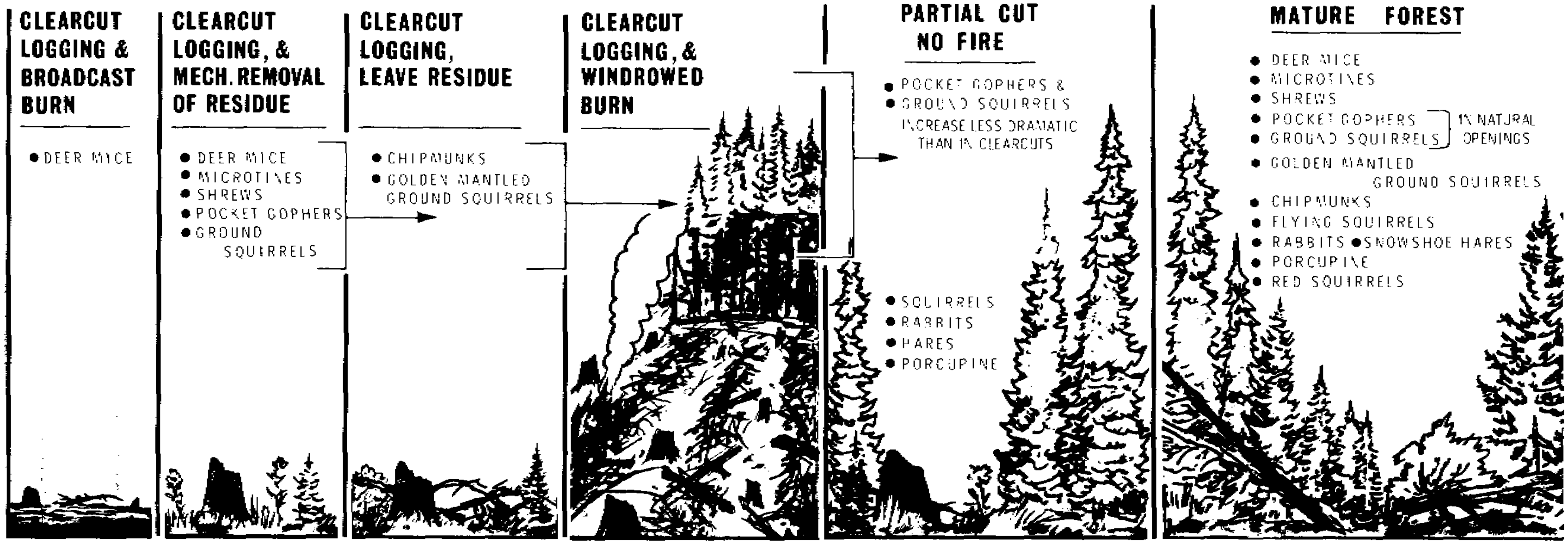

Figure 2.--Small mammal species found in different harvesting and residue treatments

Windrow, Slash Pile, and Jackpot Burns

Burning windrows and slash piles often results in large areas between piles where the vegetation is unaffected by fire. Because of this, small mammal populations in these unburned areas remain essentially unchanged. Jackpot burning (the burning of slash concentrations), is similar to burning piled slash in that large areas are left unburned. However, jackpot burning has the additional benefit to chipmunks, golden-mantled ground squirrels and shrews of leaving residue in the unburned areas. Since there is less soil disturbance with jackpot burning, this treatment may be used to discourage pocket gopher populations which tend to increase with scarification (Barnes 1974, Volland 1974). Columbian ground squirrels and pocket gophers are attracted to forest openings and do not seem to be significantly affected by the presence or absence of slash. Voles, shrews, and deer mice increase in response to increasing herbaceous and seed-producing ground cover.

When slash is piled several months before being burned, it provides a home for small mammals (Tevis 1956d). When these slash piles are burned, more animals may be killed than in a broadcast or jackpot burn.

Slash burning has been used in attempts to control some small mammal populations (Tevis 1957d, Motobu 1978, Fala 1975). However, the potential reproductive rate of small mammals is so great that fire-induced mortality only has a short-term effect on population levels (Tevis 1956a).

MECHANICAL REMOVAL OF RESIDUES

Little has been published on the effects mechanical slash removal has on small mammal populations. The literature suggests that many species of small mammals will continue to inhabit areas where residues of 3 inches diameter and larger are removed mechanically if the mat of ground vegetation is not altered appreciably. The exceptions to this prediction are shrews, chipmunks, and golden-mantled ground squirrels, which may become less numerous with removal of large woody materials. Red-backed vole populations may be suppressed by the removal of the forest canopy, and the removal of large woody residues further reduces their habitat (Gashwiler 1959, 1970, Tevis 1956c, Gunderson 1959). Voles of the genus *Microtus* will flourish because of the retention of ground cover. Deer mice will increase, as will pocket gophers and Columbian ground squirrels. The presence of rabbits, hares, and porcupines will depend on the availability of brush or young trees for cover and food.

LEAVING RESIDUES

Leaving residues can be disadvantageous in view of fire and insect hazard, and hampered big game movements. Yet leaving residues can provide ideal habitat for small mammals. Removal of the overstory releases the growth of herbs, grasses, and shrubs, but protection from predators is still provided by the slash. Where residues are not removed, the numbers of most small mammal species already present could be expected to increase with the exception of the red-backed voles, which are generally associated with forest communities. Porcupines probably would be restricted unless, or until, there are saplings or brush for food.

EFFECTS OF SMALL MAMMALS ON FOREST REGENERATION

Beneficial Effects

Animals that have evolved with specific plant communities frequently impart benefits to, as well as receive benefits from, the plant communities. These benefits include soil disturbances that improve opportunities for germination and growth of some species of trees (Tevis 1956b, Larrison 1942). Burrowing animals such as pocket gophers and ground squirrels bring mineral soil to the surface and introduce organic matter below the surface. They also improve soil aeration and reduce erosion by improving water infiltration. Because of a preference for perennial forbs with deep or bulbous roots, numbers of pocket gophers usually increase where heavy grazing by ungulates has destroyed the turf and allowed an increase of these forbs. This relationship has sometimes implicated pocket gophers as the cause of erosion and range deterioration that was actually a result of over-grazing by livestock (Ellison 1946).

Forest mycologists have suggested that dispersal of mycorrhizal fungi by small mammals may be critical to the survival and growth of trees on some unfavorable sites (Maser and others 1978a, b, Trappe and Maser 1977). These fungi assist plants in absorbing water and nutrients from the soil and often protect roots from disease. In return, the fungi obtain their nutrition from the trees. Most green plants are dependent on these fungi. There appears to be a successional sequence of fungi correlated with forest succession. Truffles are the reproductive bodies of the mycorrhizal fungi commonly found in clearcuts. Because truffles are entirely underground, they are dependent on animals for spore dispersal. The consumption of truffles by small mammals and subsequent excretion of viable spores has been documented. Since the viability of spores of many forest fungi is limited to about a year, small mammals are important as dispersal agents for these spores. (Trappe and Maser 1977).

In some areas, unrecovered seed caches of golden-mantled ground squirrels and chipmunks (*Eutamias* spp.) are the primary source of germinating ponderosa pine (*Pinus ponderosa*) (Saigo 1968), and bitterbrush (*Purshia tridentata*) (West 1968). Despite rodent consumption of cached seeds, some caches germinate and develop into clumps of seedlings. An Oregon study reported at least 50 percent of pine regeneration was from rodent seed caches. This source of regeneration was considered especially important in areas where logging, road building, or fire had occurred (Saigo 1968).

Small mammals eat a significant number of insects, including insects that damage trees. Some of these small mammals are usually thought of as seed eaters and are not recognized as being insectivores as well. A study in the tamarack swamps of the Lake States documented a greater consumption of larch sawfly prepupae by voles which are primarily herbivores than by shrews, which are known for their insectivorous food habits (Graham 1928). Balch (1937) states that small mammals, by consuming up to 36 percent of the cocoons in eastern Canada, are the only significant natural factor in the control of the cocoon stage of spruce sawflies.

In contrast, Morris and others (1958) in a 10-year study on the response of avian and mammalian predators to spruce budworm density, found that small mammal populations fluctuated independently of budworm density. They felt that predators were of little control during the budworm outbreak. Hamilton and Cook (1940) estimated that a moderate population of small mammals (100 per acre) could consume as much as 266 pounds of insects per year. In a Montana study, chipmunks, red squirrels, and golden-mantled ground squirrels were observed eating spruce budworm larvae; one golden-mantled ground squirrel had 179 budworm larvae in its stomach (Pillmore and others 1970).

Detrimental Effects

Harmful effects of small mammals on forest regeneration include the harvest and caching of cones by red squirrels (Schmidt and Shearer 1971). Unlike the seed caches of golden-mantled ground squirrels and chipmunks, the probability of conifer seed germination from undisturbed red squirrel cone caches is very low. However, these cone caches are frequently a seed source for restocking programs.

Small mammals and birds consume a large percentage of conifer seed before it germinates. Schmidt and Shearer (1971) found that small forest animals consumed 24 out of 25 mature ponderosa pine seeds. Red squirrels harvested 66 percent of the mature cones. After seeds were dispersed, deer mice, chipmunks, and birds consumed the equivalent of an additional 30 percent. Gashwiler (1967) found that only 12 percent of Douglas-fir seed survived until the end of the germination period in Oregon.

Small mammals continue to affect conifer regeneration after germination. Tree seedlings are eaten by small mammals, birds, and ungulates (Saigo 1968). Although pocket gophers expose the mineral soil necessary for the germination of some conifer seed, they may eat root systems of young trees. They also girdle and eat seedlings below the snow surface during the winter. Tevis (1956b) found that the greatest loss of red fir (*Abies magnifica*) seedlings resulted from root exposure to the air inside pocket gopher tunnels. Hooven (1971) reported similar effects on ponderosa pine in Oregon.

Young trees are subject to girdling by mice and rabbits. Red squirrels in northwestern Montana girdle the tops of western larch (*Larix occidentalis*).[1] Porcupines can be very destructive to trees of all ages.

SMALL MAMMAL MANAGEMENT

Trapping, Poisons, Insecticides, and Herbicides

Trapping and poisoning are temporary measures for reducing small mammal populations that retard conifer regeneration. These measures are not generally considered practical, long-term solutions (Tevis 1956b, Hooven 1971, Smith and Aldous 1947). The effects of these treatments persist only as long as the effort is sustained (Tevis 1956c).

Insecticides, in sufficient concentrations, will cause mortality in small mammals (Morris 1970). Unfortunately, small mammals which eat insects receive disproportionately high concentrations of these poisons.

The effects of herbicides on small mammal populations are generally indirect. The killing of vegetation may eliminate essential food or cover required by certain species. In a Colorado study, range treatment with 2,4-D improved the growth of grasses and killed the forbs. This resulted in a sharp reduction in pocket gophers that fed on forbs, and an increase in montane voles (*Microtus montanus*), which prefer close-canopied grass cover (Johnson and Hansen 1969).

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[1] Personal Communication: Curtis Halvorson, USDI, Fish and Wildlife Service, Ft. Collins, Colo.; George Wilson, Glacier View Ranger Station, Columbia Falls, Mont.

Habitat Manipulation

Small mammals have evolved with the communities that they inhabit (Bendell 1974). Mutual compatibility is a result of this evolution. Disruptions such as fire or logging may cause serious imbalances (Tevis 1956b): some animal populations may be eliminated, new species may invade, some species will greatly increase in numbers.

Fires or logging may initiate an early successional stage as a disclimax. This may be perpetuated by recurrent fire, unusually high rodent populations, heavy grazing by large mammals, or edaphic factors. Special consideration, including alternative harvesting methods, should be given to situations with this potential.

To reduce impacts on forest regeneration, small mammal control is best implemented by not creating suitable habitat for potentially destructive species.[2] Consideration should be given to the kind of habitat created by different treatments and the proximity of logging to potentially colonizing populations. For example, pocket gophers invade and multiply in clearcuts where they damage and destroy tree seedlings. Retention of 500-foot wide buffer strips in lodgepole pine forests has been suggested to alleviate this situation. Another alternative for discouraging pocket gopher populations, is partial cutting to maintain partial shade and minimal soil disturbance (Barnes 1974).

Golden-mantled ground squirrels are considered a threat to reforestation because of their seed-eating habits. Historically, in northwestern California, these squirrels occurred only in open granite outcroppings and avoided the virgin Douglas-fir (*Pseudotsuga taxifolia*) and white fir (*Abies concolor*) forests. After the initiation of harvest programs, golden-mantled ground squirrels spread from these isolated areas through virgin forest into clearcuts 2-1/2 miles distant (Tevis 1956a).

In areas where all vegetation has been removed by clearcutting and burning, as much as 100 percent of on-site conifer seeds have been consumed by wildlife (Tevis 1956c). Halvorson (In Press), Tevis (1956c), and Sullivan (1979) have suggested that leaving some patches of unburned vegetation would provide alternate food sources and might reduce seed depredation. Unburned patches allow more species of small mammals to survive the fire, but there is also a wider variety of food remaining to buffer the effect of seed consumption.

The effectiveness of aerial seeding in northern Montana was improved by delaying seeding until snow was on the ground. This made the seed unavailable to rodents until spring when small mammal populations are at a seasonal low. Seed was also unavailable to birds because it penetrated into the snow. Germination occurred in the spring after snow melt, thereby reducing the time the seed was exposed to depredation.[3]

If wildlife habitat is a major consideration in forest management, priority should be given to the creation of a vegetative mosaic of species composition and vegetative structure. Benefits of a vegetative mosaic include:

a) Variety of food and cover.
b) Edge effects.

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[2] Personal Communication: William Beaufait, USDA Forest Service, Regional Office, Missoula, Mont.

[3] Personal Communication: G. Wilson.

c) Protection from catastrophic fire.
d) Protection from disease and insect damage that can occur in monotypes.
e) Increase of dew and a higher water content of herbs in new openings.
f) Wildlife species diversity.
g) Long-term stability of predator populations.

CONCLUSION

Small mammals have evolved as a component of the forest community in which they live. Following logging or fire, there is a successional sequence of small mammal species in response to the availability of cover and food. Unusual densities of small mammals may result from severe habitat alteration. In these instances small mammals may retard regeneration. Potential problems should be considered in planning cutting units and, where feasible, modifications made to discourage the increase of species of small mammals that may retard regeneration. If wildlife management is a high-priority consideration, a vegetative mosaic of species composition and structure is recommended.

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INFLUENCES OF HARVESTING AND RESIDUE MANAGEMENT ON CAVITY-NESTING BIRDS

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ABSTRACT

Coram Experimental Forest (CEF) plots on which different harvesting prescriptions and residue utilization intensities were applied in 1974 were studied during 1974-1979 to determine impacts on nesting and feeding activities of cavity nesters, especially woodpeckers. Uncut controls on the CEF and on other sites in the Flathead National Forest and Glacier National Park also were studied. Cavity nesters preferred western larch, ponderosa pine, black cottonwood, paper birch, or aspen nest trees with heartwood decay. Forests with a component of old-growth western larch supported the highest density and diversity of cavity nesters. Uncut controls received the highest % of feeding use. Shelterwood cuts and uncut islands within group selection plots received relatively high feeding use. Clearcuts received little use, regardless of the intensity of residue utilization.

KEYWORDS: bird management, cavity nesters, old growth, residue management, timber harvesting, western larch

INTRODUCTION

Foresters are placing increased emphasis on the utilization of trees that are dead (snags), dying, defective, diseased, or down; such trees are termed 5D wood by McMichael (1975). These forest components often are referred to as wasted resources if they are unused by man.

Old-growth forests which produce a lower annual increment of wood than do younger stands frequently are viewed as obstacles preventing efficient forest management. On commercial Rocky Mountain forests, management objectives usually call for conversion of nearly all old growth to short-rotation stands as rapidly as possible. Yet large old trees, which constitute the old-growth component in forests, and 5D wood are essential elements of suitable habitat for cavity-nesting birds and a number of small mammals. About 25% of the bird species nesting in northern Rocky Mountain forests are cavity nesters. They are especially sensitive to timber harvesting practices because of their need for nesting and roosting cavities within snags or live trees with heartrot. This group of birds is largely insectivorous. Thus harvesting and residue utilization practices that affect insect populations also influence cavity-nesting bird populations. The birds affect insect numbers through predation and may maintain endemic population levels of some forest insects, or at least lengthen intervals between epidemics (Beebe 1974). But consideration of cavity nesters, or any other life form, should not be confined to possible economic benefits of the species or group (Ehrenfeld 1974). Ecological, scientific, and esthetic values also are essential factors, though not easily quantified. The fact that cavity nesters are a natural part of forest ecosystems is by itself sufficient reason for forest managers to give them careful consideration. Perpetuation of cavity nesters within a forest subjected to harvesting is possible only with careful planning based on knowledge of the environmental consequences of the proposed manipulation.

Conner and Crawford (1974) studied woodpecker foraging in Appalachian clearcuts. Conner et al. (1975) evaluated the influence of cutting on woodpecker nesting habitat in Virginia. Other studies have dealt with the impact of cutting on both open and cavity-nesting birds: Hagar (1960) in California; Franzreb (1978) in Arizona; Titterington et al. (1979) in Maine; Kessler (1979) in Alaska.

The study described in this report was designed to provide some of the basic information needed by managers concerned with the welfare of cavity nesters in western larch/Douglas-fir[1] forests. Study objectives were: 1) to evaluate the influence of alternate timber harvesting and residue utilization practices on the nesting and feeding activities of cavity-nesting birds; 2) to quantify variables descriptive of the timber, character of dead material, the area, and of harvesting prescription and residue utilization that significantly influence continued use by cavity nesters; 3) to provide recommendations for modifying harvesting and utilization practices to minimize adverse impacts on these species.

In this study students and I have concentrated on "primary" cavity nesters, the woodpeckers (fig. 1), all of which are capable of excavating their own nesting cavities within trees. Most secondary cavity-nesters (e.g., bluebirds, small owls (fig. 2), some swallows and ducks) must rely on the woodpeckers or on natural decay processes for production of nest and roost cavities.

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[1] Scientific names are listed in the Appendix.

STUDY AREA

General

The study focused on the Coram Experimental Forest (CEF), located approximately 9 miles (14.5 km) east of Columbia Falls, in northwestern Montana. Latitude is approximately N 48° 25' and longitude W 114° 00'. The CEF (part of the Flathead National Forest) encompasses 7,460 acres (3,019 ha), 811 acres (328 ha) of which are set aside as a natural area. Elevations range from 3,500 to 6,300 feet (1,067 to 1,920 m). Mean annual precipitation in the central (Abbot Creek) basin is 35 in (89 cm). The mean annual temperature is 42°F (5.6°C). The western larch/Douglas-fir forest cover type predominates. Average number of trees per acre, mean d.b.h., and mean height for tree species (based on sampling units totalling 80 acres (32.4 ha)) on typical sites in the CEF are shown in table 1. Timber, terrain, soils and wildlife are representative of many areas in western Montana and northern Idaho. More detailed descriptions of various environmental parameters on the CEF study site are given later in this paper or have been presented in earlier papers in this symposium.

TABLE 1.-- Number of trees ($\geq$ 9 in (23 cm) d.b.h.) per acre based on total sample of 80 acres (32.4 ha), CEF.

Tree species	Trees per acre (ha)	Relative density (%)	Mean dbh in (cm)	Mean height ft (m)
Douglas-fir	21.6 (8.7)	52	15.0 (38)	76.6 (23.3)
Subalpine fir	9.5 (3.8)	23	11.0 (28)	71.5 (21.8)
Engelmann spruce	4.9 (2.0)	12	12.9 (33)	76.4 (23.3)
Western larch	4.6 (1.9)	11	19.2 (49)	114.0 (34.8)
Western hemlock	0.4 (0.2)	<1	12.8 (32)	69.5 (21.2)
Lodgepole pine	0.4 (0.2)	<1	11.8 (30)	71.5 (21.8)
Western white pine	0.4 (0.2)	<1	12.9 (33)	81.1 (24.7)
Western redcedar	0.1 (<.1)	<1	14.7 (37)	77.7 (23.7)

All woodpecker feeding observations and general bird censuses were done on the CEF, primarily in and near units harvested in 1974. We searched for active nest trees on the CEF and other areas of the Flathead National Forest, and in Glacier National Park.

1974 Harvesting Treatments

Two sets of timber harvesting units were logged in 1974 by the skyline method. In each set, in this report termed the lower units (average elevation approximately 4300 ft (1311 m) and higher units (average elevation approximately 5030 ft (1534 m)) there were control, shelterwood, group selection, and clearcut units. Unit treatments were as follows:

CONTROL: No manipulation. Uncut forest adjacent to cutting units was sampled. No precise boundaries were designated in the controls.

SHELTERWOOD: About 50% of the merchantable timber was removed in 1974. The remainder is to be removed after a new stand becomes established. Lower unit: 34.1 acres (13.8 ha). Higher unit: 21.5 acres (8.7 ha).

GROUP SELECTION: All merchantable trees were harvested in 8, 1 to 2 acre (0.4 to 0.8 ha) irregular plots.

CLEARCUT: All merchantable trees were harvested. Lower unit: 11.5 acres (4.7 ha). Higher unit: 12.6 acres (5.1 ha).

Residue Subtreatments

Within all harvesting treatments, 4 levels of residue utilization were applied (table 2). In tables 2 and 3, subtreatments are listed in order of increasing % of original wood volume removed. For example, in the higher shelterwood unit, 86% of the original volume remained in the sawlog subtreatment after logging and only 42% in the near complete subtreatment. However, in terms of absolute volume remaining, increased utilization or original volume did not always result in less volume remaining on the site because of differences in the pre-logging volume. The amount of woody material available (as substrate for insect prey), not the % of original material removed, is the parameter relevant to woodpecker feeding opportunities. Therefore, the sequence of subtreatment units in most of the remaining figures and tables shows decreasing amounts of woody material remaining after logging and subtreatment. The wood-fiber utilization specification for any unit can be traced back to table 2, regardless of its place in the sequence.

TABLE 2. Specifications for the 4 residue utilization subtreatments.

Utilization Subtreatment	Specification
"Sawlog" (SL)--current sawlog utilization standards	Trees $\geq$ 7 in (17.8 cm) dbh were cut; logs $\geq$ 6 in (15.2 cm) small end diameter were removed and the area was burned* after harvest.
"Intensive log" (IL)	Trees > 7 in (17.8 cm) dbh were cut; logs $\geq$ 8 ft (2.4 m) long and $\geq$ 3 in (7.6 cm) small end diameter utilized and remaining trees and understory were protected as far as possible and left as advanced regeneration.
"Intensive tree" (IT)	All material $\geq$ 8 ft (2.4 m) long with > 3 in (7.6 cm) small end diameter was removed (this included trees $\geq$ 5 in (12.7 cm) dbh) and the area was burned* after harvest.
"Near complete" (NC)	All trees $\geq$ 1 in (2.5 cm) dbh were cut and removed and the area was left "as is" after harvest.

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*Subtreatments in lower shelterwood were not burned.

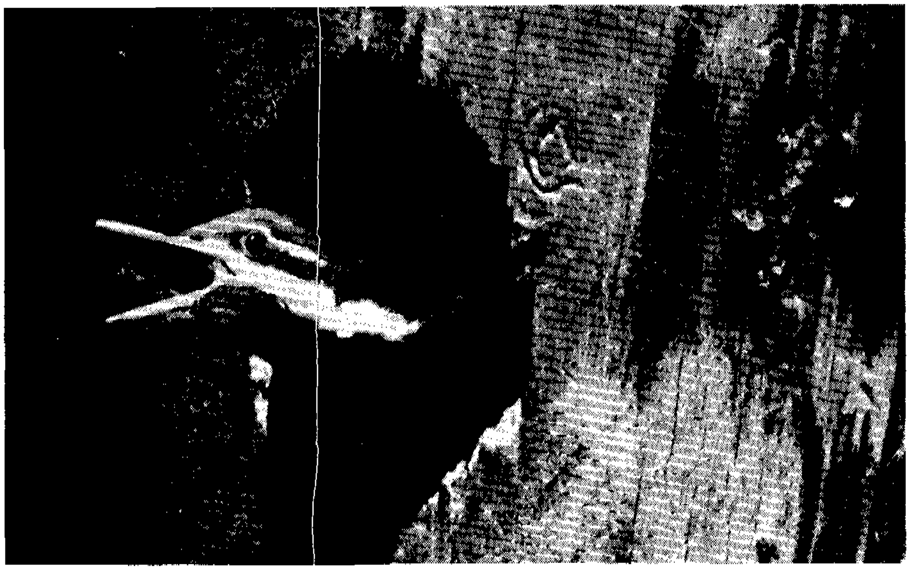

Figure 1.--A nestling Pileated Woodpecker calls from a nest cavity in a ponderosa pine snag.

Figure 2.--A Saw-whet Owl peers from a nest hole in a live western larch. The cavity was excavated by a Pileated Woodpecker.

TABLE 3. Pre- and post-logging volume of wood $\geq$ 3 in (7.6 cm) diameter in shelterwood units.

Utilization Subtreatment	Pre-logging ft^3/acre	m^3/ha	Post-logging ft^3/acre	m^3/ha	% of original volume remaining after treatment
	LOWER SHELTERWOOD				
Sawlog (SL)	4,972	(348)	3,669	(257)	74%
Intensive Log (IL)	5,280	(369)	3,645	(254)	69%
Intensive Tree (IT)	6,841	(478)	3,849	(269)	56%
Near Complete (NC)	5,862	(410)	2,763	(194)	47%
TOTALS	22,955	(1605)	13,926	(974)	Mean 61%
	HIGHER SHELTERWOOD				
Sawlog (SL)	4,410	(309)	3,778	(265)	86%
Intensive Log (IL)	4,961	(347)	3,794	(266)	77%
Intensive Tree (IT)	6,719	(470)	3,863	(270)	57%
Near Complete (NC)	4,558	(319)	1,911	(133)	42%
TOTALS	20,648	(1445)	13,346	((934)	Mean 65%

The pre-logging measurements were made by Forest Service personnel during 1973-1974. Harvest was in the summer of 1974, and post-logging measurements were taken in 1975-1977.

METHODS

Locating and Describing Nest Sites

Active nest sites were located by using visual and auditory cues (flight paths to to and from nests, sounds of excavating or drumming, vocalizations of adults near the nest tree, and nestlings' calls from the nest cavity). Only those trees in which the nesting sequence reached at least incubation stage were considered active sites. After confirmation as a active nest site (and usually after fledging so that the risk of nest abandonment was avoided) a series of measurements was taken at the nest tree and surrounding habitat. These included: 1) tree: condition (fig. 3), species, dbh, height, % bark, lean, evidence of decay, and fire evidence; 2) nest hole: orientation, height from ground, surrounded by bark?, nest hole/canopy relationship, and number of other nest holes in tree; 3) site: slope, aspect, altitude, location on slope, distance to water, canopy height, % canopy cover, understory description, and basal area of surrounding forest.

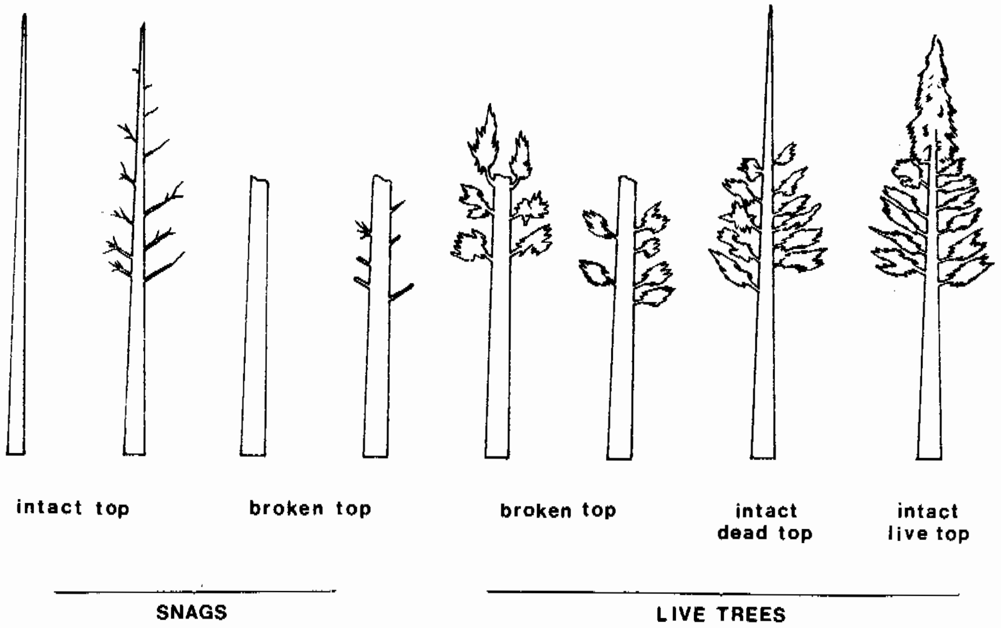

Figure 3.-- Five nest tree conditions based on whether tree is live or dead and condition of the top.

Woodpecker Feeding Activity

Each of the control (uncut) units and the cutting units in both the lower and higher units were observed for at least 60 hours (total for summer 1977 and spring and summer 1978). Feeding woodpeckers were detected by visual and auditory cues. Once located, a bird was observed until it left the feeding site. Bird species, feeding methods, total time the bird fed, feeding substrate, substrate species, and substrate dbh were recorded. Observation time spent in each unit and its 4 subtreatments was divided between walking and stationary observation. As nearly as possible, equal time was devoted to each unit and subtreatment, during similar weather conditions and hours of the day. The shelterwood units and the group selection units were observed from trails and routes through and around areas. Suitable vantage points were chosen from which to view the clearcut units. In all units, if it was possible to hear or see feeding birds in more than one subtreatment, the same observation time was recorded for both. The total time each woodpecker species was observed feeding in each unit and subtreatment within a unit was calculated. Total feeding times were then derived for species, unit, and subtreatment.

Censuses

Censuses for all species (cavity and open nesters) were conducted on 2 variable width strip line transects. One transect passed through the lower units and one through the higher set. Both transects roughly followed a contour line. The observer walked a slow, even speed for 25 paces, stopped for 15 seconds, then continued. Birds were detected by visual and auditory cues. Census strip width varied with the subtreatment and unit, from 90 to 700 ft (27 to 213 m), due to the density of trees and shrubs and resulting variability in limits of detectability of feeding woodpeckers. Censuses were conducted in the early morning, during fair weather. Direction of travel was changed on alternate days. A total of 16 censuses were run between 27 June 1979 and 24 July 1979. Bird species diversity was calculated using the formula: Diversity = $1/\Sigma p_i^2$, where p = the proportion of the total number of birds represented by the ith species (Munger 1974).

RESULTS AND DISCUSSION

Nesting

Western larch was selected as a nest tree to a much greater degree than would be expected from its relative abundance (fig. 4). Douglas-fir is about 5 times more abundant than western larch (based on total counts of trees $\geq$ 9 in (23 cm) dbh on 80 acres (32 ha) of sample plots on the CEF). But larch nest trees outnumbered Douglas-fir approximately 17 to 1.

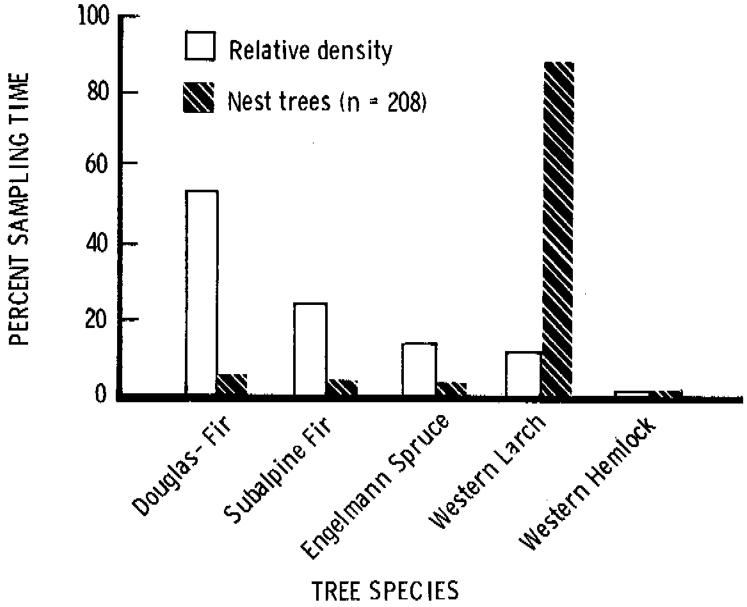

Figure 4.-- Nest tree species preferences and relative density of tree species, all hole-nesting bird species combined.

The primary reason for larch selection and apparent avoidance of Douglas-fir is related to decay characteristics of the two species. After tree death, Douglas-fir sapwood decays rapidly along with the heartwood (Wright and Harvey 1967). A protective "shell" of sapwood is missing in snags of that species. In western larch, the sapwood decays very slowly, perpetuating a shell around decaying heartwood for many years. Cavities in Douglas-fir deteriorate more rapidly and are more susceptible to predation (a predator is able to gain access to the nest chamber by enlarging the entrance, which is in decaying wood). No live Douglas-fir were used as nest sites, but live larch were used more often than were larch snags. Nest cavities in live larch were usually excavated through living wood tissue into decaying heartwood rather than in a dead top or a dead branch. With one exception (a Black-backed Three-toed Woodpecker nest), Douglas-fir snags were used only by the "weak" excavators (flickers, chickadees, and nuthatches). They seem to require very soft wood for successful completion of cavities. In instances where the weak excavators nested in trees species such as western larch, they typically used cavities abandoned by stronger excavators. Mountain Chickadees and Red-breasted Nuthatches usually nested in old nest holes of Yellow-bellied Sapsuckers (woodpeckers nearly always excavate a new nest cavity each spring).

In western larch, selection related to tree condition was directed toward broken tops (fig. 5). Although there were nearly equal numbers of intact-top and broken-top larch snags (and mean dbh of both groups exceeded 15 in (38 cm)), there were about 5 times more nests in broken-top snags. This selection process probably involves decay presence. A broken top provides an avenue of entry for decay organisms (Hepting 1971). Top breakage in western larch commonly results from lightning (fig. 6), snow or ice accumulation, or windstorm. Broken tops also may result from breakage at a point weakened by pre-existing decay or the presence of a nest cavity (Conner et al. 1975).

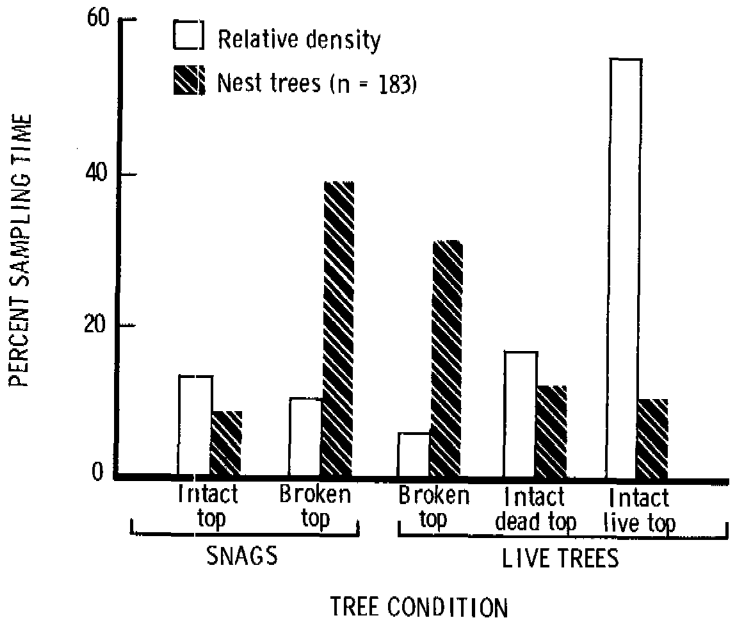

Figure 5.-- Tree condition preferences, western larch nest trees, all hole-nesting bird species combined.

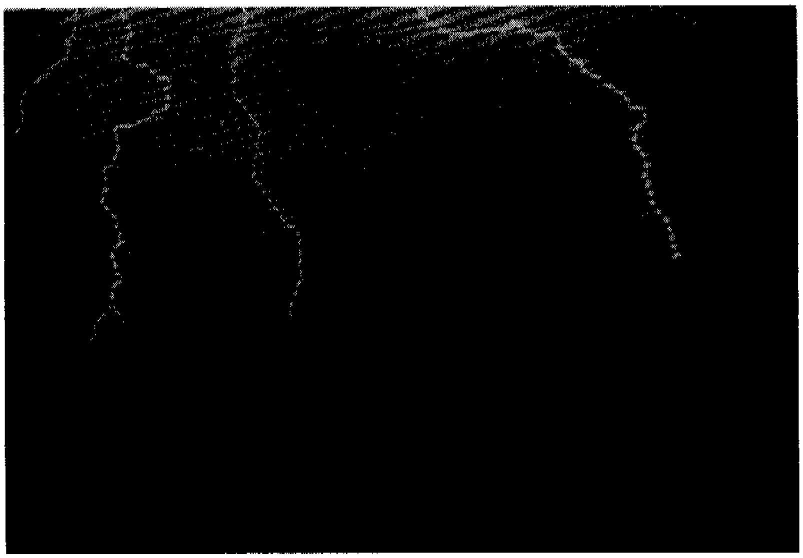

Figure 6.-- Lightning and other storm events often produce broken tops resulting in exposure of heartwood. Spores of decay fungi then may enter and initiate the decay process that creates suitable substrate for nest cavity excavation.

Characteristics of active nest trees located on the CEF and adjacent areas of the Flathead National Forest and Glacier National Park are shown below in table 4.

TABLE 4. Nest trees by tree species and condition (all cavity-nesting species combined.

	Tree Condition						
Tree Species	Snag-intact top	Snag-broken top	Live-broken top	Live-intact dead top	Live-intact live top	Total	%
Western larch	15	69	57	22	20	183	56
Paper birch	0	17	23	1	0	41	13
Aspen	4	13	8	1	14	40	12
Ponderosa pine	1	15	1	0	0	17	5
Black cottonwood	0	12	0	1	0	13	4
Douglas-fir	3	7	5	0	0	10	3
Subalpine fir	0	5	0	1	1	7	2
Engelmann spruce	1	3	1	0	0	5	2
Western hemlock	0	1	1	1	0	3	1
Western redcedar	1	0	0	1	0	2	<1
Whitebark pine	0	2	0	0	0	2	<1
Limber pine	0	2	0	0	0	2	<1
Lodgepole pine	0	1	0	0	0	1	<1
Grand fir	1	0	0	0	0	1	<1
Telephone pole	0	1	0	0	0	1	<1
TOTALS	26	148	91	28	35	328	100
%	8	45	28	8.5	10.5	100	

Nest tree species selected by each bird species are shown in table 5. Optimum habitat occurred in forests with an old-growth component (mean basal area for all nest sites was 105 ft^2/acre (24 m^2/ha). Most cavity nesters used large dbh nest trees. The mean dbh for 54 Pileated Woodpecker nest trees was 29.5 in (75 cm). The Yellow-bellied Sapsucker and Common Flicker selected nest trees with a mean dbh greater than 20 in (51 cm). Hairy, Downy, Black-backed Three-toed, and Northern Three-toed Woodpeckers used trees less than 15 in (38 cm) dbh.

TABLE 5. Nest trees used by each bird species, listed by tree species.

Tree Species	Western larch	Aspen	Paper birch	Ponderosa pine	Black cottonwood	Douglas-fir	Subalpine fir	Engelmann spruce	Western hemlock	Western redcedar	Whitebark pine	Limber pine	Grand fir	Lodgepole pine	Telephone pole	Totals	%
Goldeneye sp.	1				1											2	<1
American Kestrel	5															5	1
Saw-whet Owl (roost)	1															1	<1
Common Flicker	15	3	2	3	2	1	1					2				29	8
Pileated Woodpecker (nests)	29	4		12	8								1			54	15
Pileated Woodpecker (roosts)	8				2											10	3
Lewis' Woodpecker			1		1											2	<1
Yellow-bellied Sapsucker	79	10	29	1	1		2	2	1	1						126	35
Williamson's Sapsucker	5															5	1
Hairy Woodpecker (nests)	8	1	1				1	1								12	3
Hairy Woodpecker (roosts)										1						1	<1
Downy Woodpecker		3														3	1
Black-backed Three-toed Woodpecker	1					1										2	<1
Northern Three-toed Woodpecker									2					1	1	4	1
Tree Swallow	1	14	2	1	1					1						20	5
Black-capped Chickadee	1	3	7													11	3
Mountain Chickadee	33	1			1	1										36	10
Chestnut-backed Chickadee	1															1	<1
Red-breasted Nuthatch	19	3	1			5	2	1					1			32	9
Brown Creeper						2	1	1								4	1
House Wren		1														1	<1
Mountain Bluebird	2										2					4	1
TOTALS	209	43	43	17	17	10	7	5	3	3	2	2	2	1	1	365	100
%	57	12	12	5	5	3	2	1	1	1	<1	<1	<1	<1	<1		100

Black-capped Chickadees selected the smallest nest trees (8 in (21 cm)dbh) and commonly excavated cavities by entering the top of a broken-top paper birch, making a vertical entrance to the nest chamber.

Pileated Woodpeckers on the CEF nested only in western larch and only in stands with an old-growth component of larch and Douglas-fir. One nest was on the edge of the lower shelterwood unit. Common Flicker, Mountain and Black-capped Chickadee and Red-breasted Nuthatch nests were found in stubs left in cutting units. Yellow-bellied Sapsuckers occasionally nested in paper birch left in shelterwood units or even in clearcuts.

The cutting units involved in this study were relatively small; the effects on overall nesting populations appeared to be minor because of an abundance of old-growth forest left between and adjacent to the cutting units. Shelterwood units initially continued to provide both nesting and feeding sites for many birds, but when the remaining large trees are removed (10-20 years after the first cutting) such units will lose their usefulness to species that need a denser canopy or large trees.

In cutting units where few snags and stubs were left, the availability of hole-nest sites probably was a limiting factor for some hole nesters. In uncut western larch/Douglas-fir forests, food rather than nest sites is probably the limiting factor for woodpeckers. On any unit where timber harvesting tends to eliminate western larch larger than 20 in (51 cm) dbh, and other snags and culls, the impact on cavity nesters will be strongly negative.

Feeding Activities

During 1977 and 1978, control units and logged units (3 and 4 years after harvesting) on the CEF were observed for a total of 569 hours, a minimum of 60 hours in each unit. The following woodpecker species were observed feeding: Pileated, Hairy, Downy, and Northern Three-toed Woodpeckers, Common Flicker, and Yellow-bellied and Williamson's Sapsuckers. In general, feeding activity was greater in the lower units than in the higher units and greater in the control (uncut) units than in the harvested units (table 6). The absence of paper birch in the higher units may account in part for the reduced feeding on those sites. Yellow-bellied Sapsuckers feed heavily on birch sap during the summer months. Overall feeding activity was slightly less in the summer of 1978 (1.9%) than in the summer of 1977 (1.6%). Conner and Crawford (1974) found a much higher percentage of activity in Appalachian clearcuts. They recorded woodpecker feeding time of 55%, 43%, and 9% of sampling time in clearcuts 1-year old, 5-years old, and 12-years old respectively. However, they also included activities such as preening and courtship.

TABLE 6. Percent of sampling time that woodpeckers were observed feeding in lower and higher treatment units.

	Harvesting Treatment					
		Group Selection				
Treatment elevation	Control	Uncut Islands	Cut	Shelterwood	Clearcut	All units Combined
Lower 4300 ft (1311 m)	6.9	2.7	0.1	5.9	0.1	3.5
Higher 5030 ft (1534 m)	4.4	2.6	-0-	1.3	-0-	1.4
Both	5.9[1]	2.7	0.1	3.7	0.1	2.5

[1] Not the mean between lower and higher units because of unequal total observation times.

Total volume of woody material remaining in harvested units is compared with woodpecker feeding time in figure 7. Although a substantial amount of woody material, particularly logs ≥ 6 in (15 cm) diameter, remained in both lower and higher clearcuts, very little feeding activity was observed. Wood-fiber utilization intensity had no apparent influence on woodpecker feeding time in the clearcut portions of the group selection units or in the clearcut units (table 7). There were however, major differences in the shelterwood subtreatments.

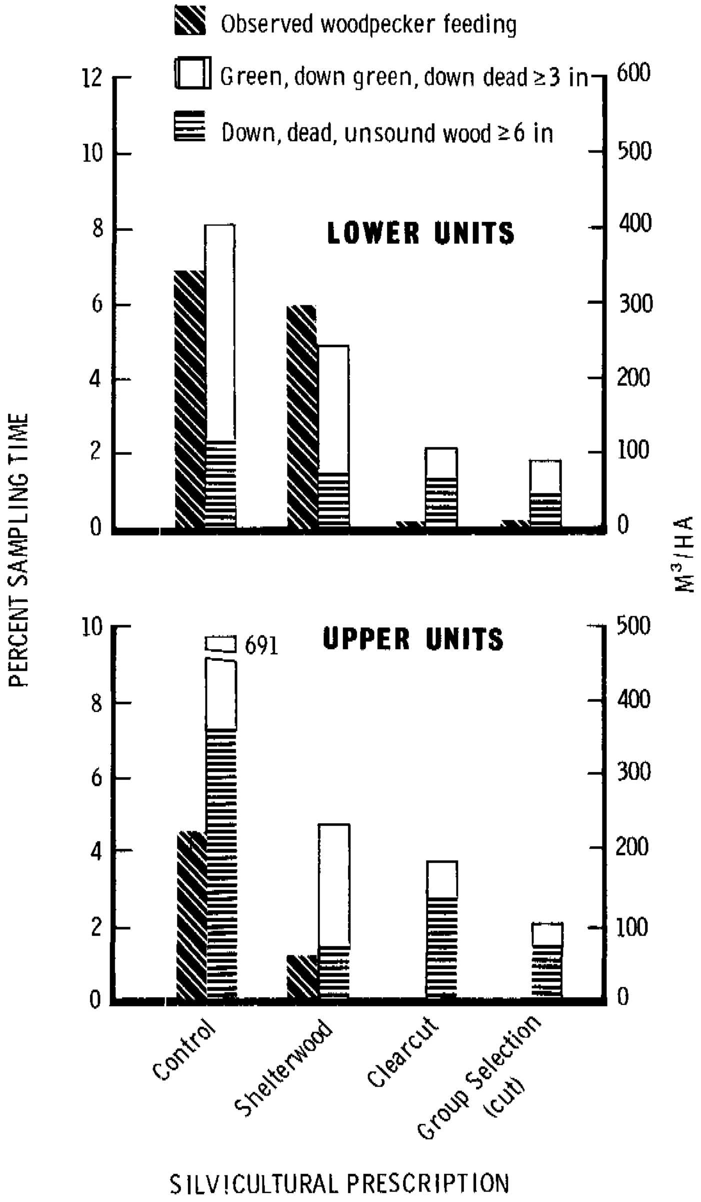

Figure 7.-- Woodpecker feeding time and volume of woody material in control and cut units after logging.

TABLE 7. Percent of sampling time that woodpeckers were observed feeding in subtreatments units of different intensities.

Subtreatments	Control	Group Selection Uncut Islands	Group Selection Cut	Shelterwood	Clearcut
	Lower Treatment Units				
None	6.9	2.7	--	--	--
Sawlog	--	--	0	6.6	0.3
Intensive Log	--	--	0.4	11.3	0
Intensive Tree	--	--	0	5.0	0
Near Complete	--	--	0	0.2	0
	Higher Treatment Units				
None	4.4	2.6	--	--	--
Sawlog	--	--	0	0.8	0
Intensive Log	--	--	0	0.1	0
Intensive Tree	--	--	0	3.5	0
Near Complete	--	--	0	0.8	0

Comparisons were made between woodpecker feeding time and various components of total wood fiber remaining on shelterwood unit subtreatments after logging. There was no apparent relationship between feeding time and number of trees per acre (fig. 8). Comparison of feeding time with volume of woody material ≥ 3 in (7.6 cm) diameter indicates "near complete" removal intensity in the lower unit may be associated with a major reduction in woodpecker feeding opportunities (fig. 9). That association is not as clear in the higher unit. Several components make up the overall wood volume measurements and these were compared with woodpecker feeding time in an attempt to determine which component most directly influences feeding opportunities. Amount of woody material ≤ 3 in (7.6 cm) diameter is plotted with feeding time in figure 10. The results are similar to the comparison in figure 9 (material ≥ 3 in (7.6 cm) diameter), with a definite drop in woody material and feeding activity in the "near complete" lower unit treatment. Because more woodpecker feeding (all woodpecker species combined) occurred on logs larger than 6 in (15 cm) diameter, a comparison of that component of remaining wood fiber and woodpecker feeding time would be expected to show show a strong relationship (fig. 11). In both units the highest level of feeding took place where the greatest volume of material was available. When feeding time and woody material volume for both shelterwood units were averaged, the negative influence of the "near complete" utilization treatment was indicated (fig. 12).

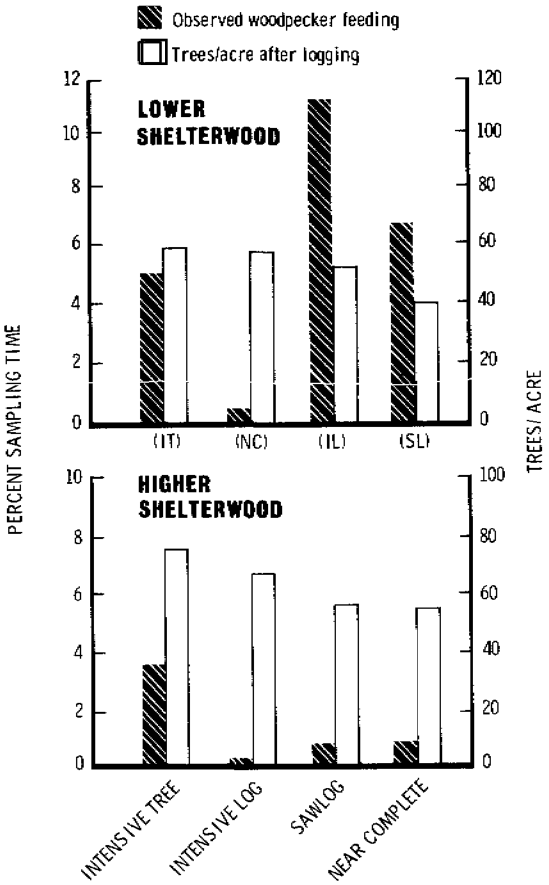

Figure 8.-- Woodpecker feeding time and number of trees per acre in shelterwood residue utilization subunits after logging.

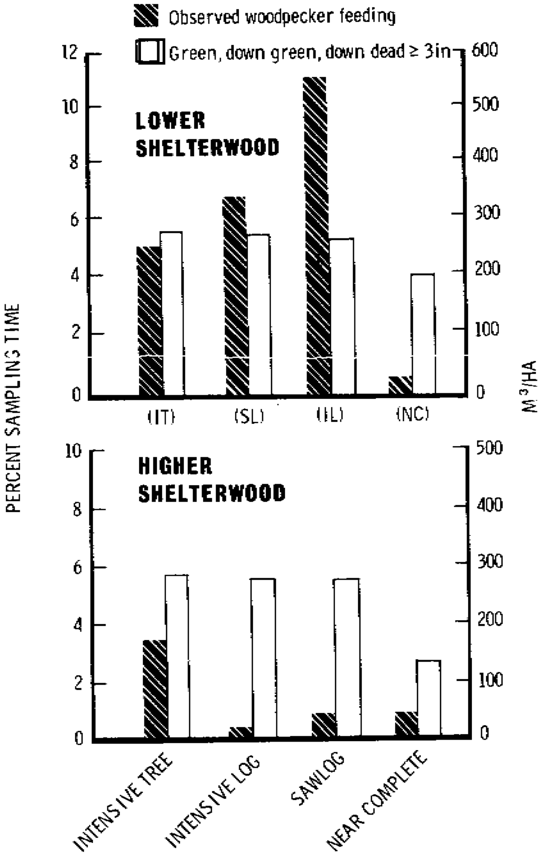

Figure 9.-- Woodpecker feeding time and volume of wood remaining in shelterwood residue utilization subunits after logging.

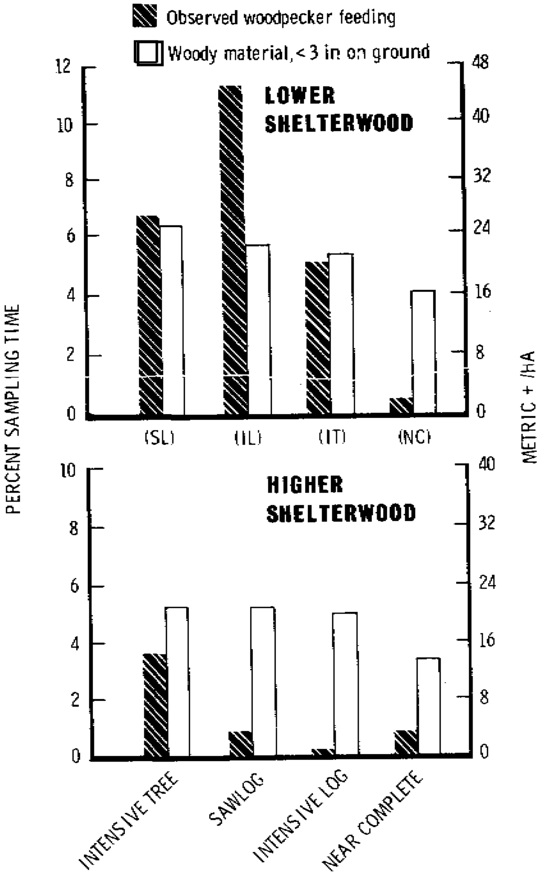

Figure 10.-- Woodpecker feeding time and amount of woody material remaining in shelterwood residue utilization subunits after logging.

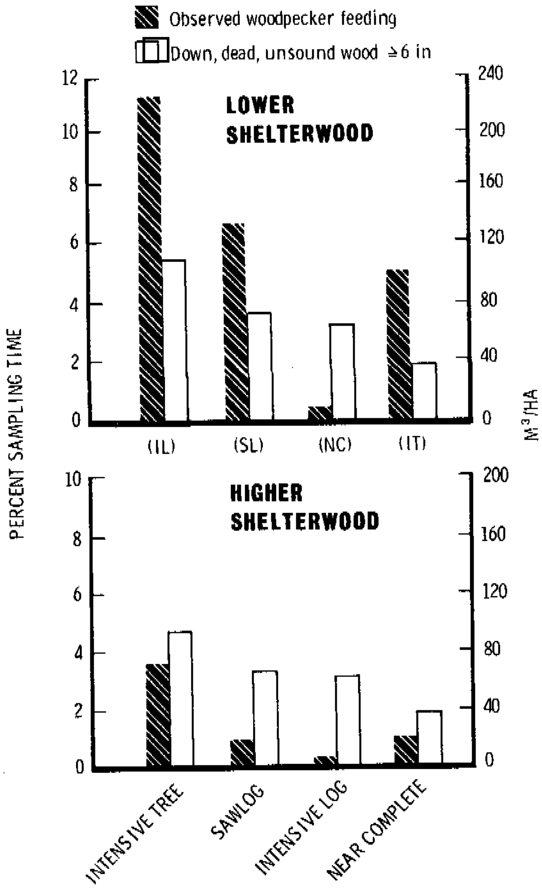

Figure 11.-- Woodpecker feeding time and amount of down, dead, unsound wood remaining in shelterwood residue utilization subunits after logging.

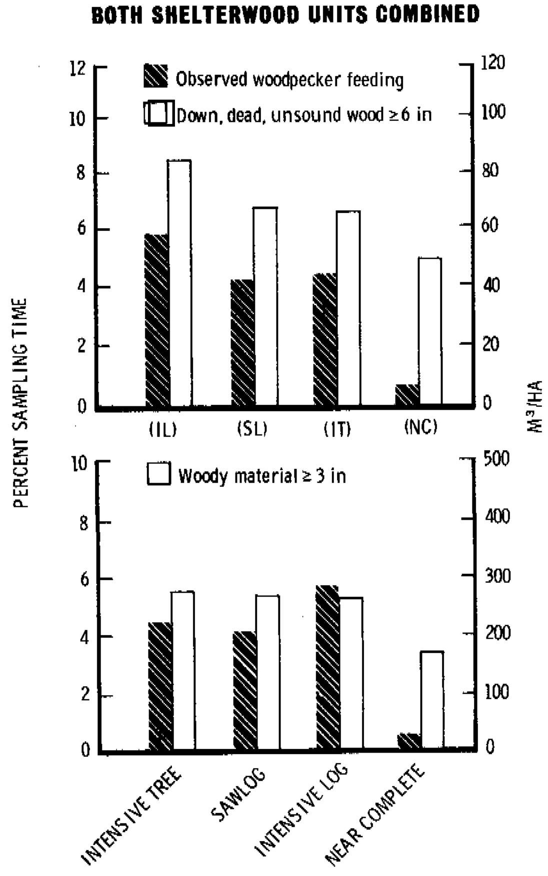

Figure 12.-- Woodpecker feeding time and volume of woody material in shelterwood residue utilization subunits.

The only clear relationships evident in these comparisons are: 1) when considering all woodpecker species together, feeding in shelterwood units and uncut portions of group selection units was substantial although less than in control (uncut) units. There was little feeding activity in the clearcut units. 2) Wood fiber utilization levels influenced woodpecker feeding time only in shelterwood units. "Near complete" utilization seemed to reduce woodpecker feeding opportunities to a much greater degree than the other 3 less intense levels. 3) A much longer term study will be needed if the relationships between bird feeding opportunities and residue utilization levels are to be quantified in a manner useful in predicting different consequences of the various levels.

Each woodpecker species has different feeding habits. The analysis of total woodpecker feeding time may obscure feeding site differences between species. The only species recorded feeding in the clearcut area was the Yellow-bellied Sapsucker (table 8), which fed upon paper birch left within the unit. Common Flickers often were seen feeding in clearcuts outside the study area; they were not seen in the 1974 clearcuts. They fed within uncut stands, although always within several hundred feet of a cutting edge. Conner and Crawford (1974) recorded flicker feeding during 30% of 60 hours sampling time in a 5-year old clearcut in Virginia.

TABLE 8. Percent of sampling time that woodpecker species were observed feeding in different treatment units, lower and higher units combined.

Species	Treatment Unit					All units
	Control	Uncut Islands	Cut	Shelterwood	Clearcut	Combined
Yellow-bellied Sapsucker	4.0	0.7	0.1	1.9	0.1	1.3
Pileated Woodpecker	<0.1	<0.1	-0-	1.2	-0-	0.4
Hairy Woodpecker	0.3	0.5	-0-	0.2	-0-	0.2
Downy Woodpecker	0.5	0.6	-0-	-0-	-0-	0.2
Common Flicker	0.3	0.2	-0-	0.3	-0-	0.2
Northern Three-toed Woodpecker	0.8	0.1	-0-	0.1	-0-	0.1
Williamson's Sapsucker	-0-	0.6	-0-	-0-	-0-	0.1
TOTAL	5.9	2.7	0.1	3.7	0.1	2.5

Recorded feeding time of Pileated Woodpeckers was low in control units, probably because Pileateds have very large feeding territories in north-western Montana (500 to 1000 acres (200 to 400 ha)). Pileateds spend most of their feeding time in forests with an old-growth component and high basal area. The concentration of Pileated feeding time in the shelterwood unit was at least partially due to a nest location on the edge of that unit. Overall, table 8 shows all species avoided clearcuts for feeding sites, and that the shelterwood units were used substantially, although generally less than the controls.

Table 9 shows feeding time in the lower shelterwood unit subtreatments. Only Hairy Woodpeckers fed in the most intensely utilized unit ("near complete"). Yellow-bellied Sapsuckers fed most heavily in "intensive log" and "intensive tree" subtreatments because of paper birch left within those units. The birch were used as both nest and feeding sites.

TABLE 9. Number of minutes woodpecker species were observed feeding in subunits of different intensities of wood fiber utilization in low elevation shelterwood cutting unit.

	Lower Shelterwood				
Species	Sawlog	Intensive Log	Intensive Tree	Near Complete	Totals
Yellow-bellied Sapsucker	39	105	70	0	214
Pileated Woodpecker	85	32	3	0	120
Common Flicker	6	25	0	0	31
Hairy Woodpecker	0	0	0	3	3
Totals	130	165	73	3	368

1979 CENSUS

Although this study focused on cavity nesters, a series of all-species censuses was conducted using line transects. This was done in 1979, 5 years after logging, to provide a general picture of species, density, and diversity differences in the cut and uncut units.

Numbers of birds per 100 acres (40 ha) represent averages for 16 censuses (table 10). Bird species diversity was consistently higher in the uncut or shelterwood units than in the clearcuts (fig. 13). A comparison of bird species diversity and volume of woody material remaining after logging exhibited an anomaly in the group selection - small clearcut/regular clearcut relationship (table 11). The higher diversity in the group selection cuts, in spite of a lower volume of woody material, probably was related to the very small size of the group selection cuts and edge effects. In the CEF study site in general, MacGillivray's Warbler, Swainson's Thrush and Dark-eyed Junco were the most common species. Red-breasted Nuthatch and Mountain Chickadee were the most common cavity nesters.

TABLE 10. Densities of birds on different cutting units, 1979, in No./100 acres (40 ha).

Bird Species	Lower Units					Higher Units				
	Control	Group Selection (Uncut)	Shelterwood	Group Selection (Cut)	Clearcut	Control	Group Selection (Uncut)	Shelterwood	Group Selection (Cut)	Clearcut
Cooper's Hawk	0.5	8*								
Blue Grouse						1				
Spruce Grouse						1		1		
Rufous Hummingbird										1
Common Flicker						3	15		4	0.5
Pileated Woodpecker						3		1		
Yellow-bellied Sapsucker	4	16	1			2	10	5		
Hairy Woodpecker						3		1		
Olive-sided Flycatcher						1				
Gray Jay	0.5					11	24	3	24	
Common Raven		39*	2			1				
Black-capped Chickadee	4		3			2		3		
Mountain Chickadee	6	8	13			22	19	15		
Red-breasted Nuthatch	7	23	14			32	48	11		
Brown Creeper	2		1			1		1		
Winter Wren							5			
American Robin								1		
Varied Thrush							5			
Swainson's Thrush	26	124	14			51	82	20	4	
Golden-crowned Kinglet	3		3			6	10	4		
Ruby-crowned Kinglet	1					9	10			
Solitary Vireo	3	8								
Warbling Vireo	2	8								
Orange-crowned Warbler	0.5					1				
Yellow-rumped Warbler		8	1			5				
Townsend's Warbler	5	23	5			17	15	8		
MacGillivray's Warbler	2	54	18	36	50	11	44	25	124	33
Wilson's Warbler			0.5							
Western Tanager	10	23	5			6	34	3		
Black-headed Grosbeak		16	1			2			7	
Pine Grosbeak						1	10			
Pine Siskin	3	8			3	6	24	4		1
Dark-eyed Junco	1	23	7	15	8	12	24	13	48	7
Chipping Sparrow	0.5	16	6	15		2	10	11	7	2
TOTAL	81	405	94.5	66	61	212	394	130	218	45.5
DIVERSITY $\left(\frac{1}{\Sigma p_i^2}\right)$	6.8	7.1	8.7	2.5	1.4	8.9	10.2	9.3	2.6	1.8

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*artifact of nest location

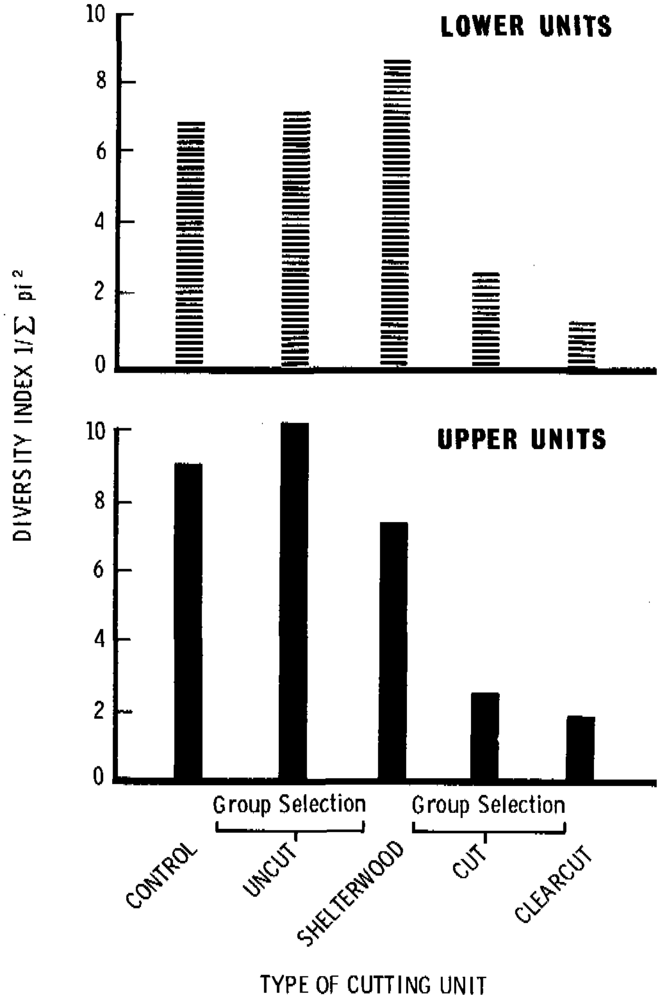


Figure 13.--Bird species diversities in control and cut units.

TABLE 11. Comparison of amount of woody material remaining after logging and bird species diversity in different types of cuts.

	m³/ha post-logging (≥3 in (7.6 cm) diam.)	Bird species diversity index[1]
	LOWER UNITS	
Control (uncut)	3710	6.8
Shelterwood	974	8.7
Group Selection (cut)	345	2.5
Clearcut	425	1.4
	HIGHER UNITS	
Control (uncut)	4360	8.9
Shelterwood	934	9.3
Group Selection (cut)	508	2.6
Clearcut	727	1.8

[1] Bird species diversity index formula: $\frac{1}{\Sigma p_i^2}$

The Dark-eyed Junco and MacGillivray's Warbler were found in uncut units and in all treatment unit types (shelterwood, group selection and clearcut). The Orange-crowned Warbler, Winter Wren, Varied Thrush and Blue Grouse were found only in uncut units; Wilson's Warbler was found only in shelterwood units.

SUMMARY OF RESULTS OF SPECIAL IMPORTANCE TO MANAGERS

1) In the study area, western larch is the most important nest tree species for cavity nesters (fig. 14). Paper birch, aspen and black cottonwood are locally important. Ponderosa pine is heavily used as a nest tree, but it is uncommon in the study area. Grand fir may be an important nest tree where larch and ponderosa pine are absent.

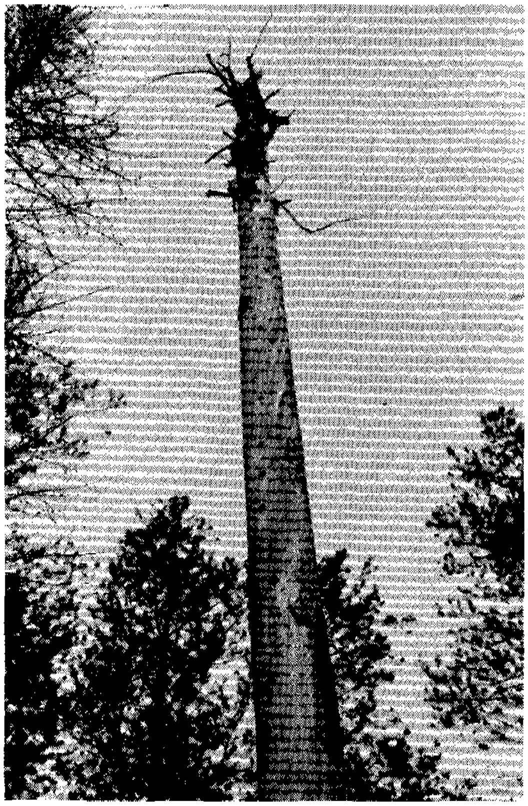


Figure 14.--A western larch nest tree with numerous Pileated Woodpecker nest holes. Common Flickers and red squirrels used abandoned cavities and osprey nested on the broken top.

2) Douglas-fir, which is more common than western larch on most sections of the study area, is seldom used as a nest tree, but Douglas-fir snags are important as feeding sites.

3) In nearly all nest trees, heartwood decay precedes nest cavity excavation. Heartwood decay was the most consistent characteristic present in nest trees. Decay softens the heartwood and makes possible the excavation process. Sapwood remains relatively undecayed as a shell around the nest cavity in western larch (fig. 15).

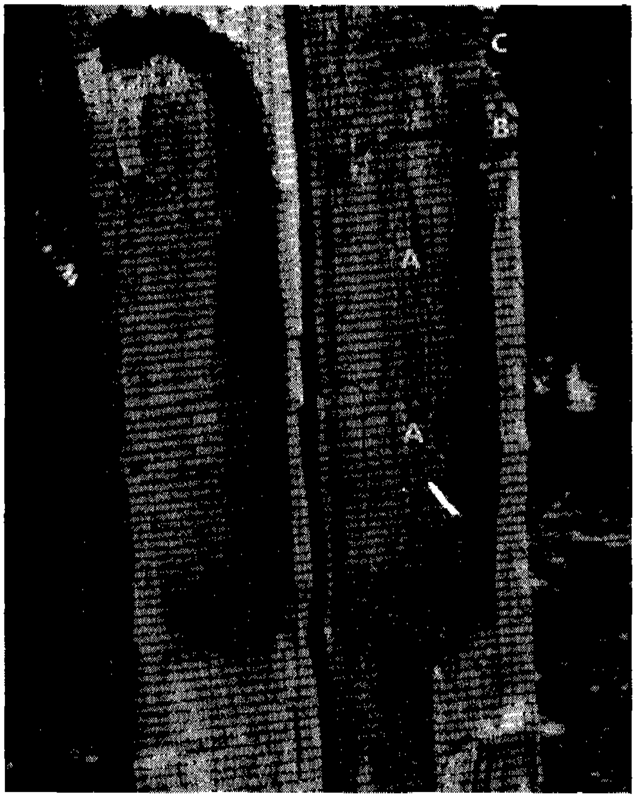


Figure 15.-- A Hairy Woodpecker nest cavity in a western larch snag. The cavity (A) was excavated in well-decayed heartwood. The nest entrance (C) passes through relatively undecayed sapwood (B).

4) Broken-top larch nest trees had a high incidence of heartwood decay. *Laricifomes laracis* or *Phellinus pini* were evident in most larch nest trees. Broken tops or fire scars provide access for the spores initially and broken tops allow water entrance which hastens decay. Douglas-fir is less suitable than larch because decay proceeds more rapidly and involves the sapwood.

5) The broken top characteristic is a useful key to the nest-site potential of both snags and live trees. Seventy-three percent of 328 nest trees had broken tops. Intact-top snags are important as drumming and perching sites.

6) Western larch nest trees are typically old and large. The mean dbh of all western larch nest trees was 26.4 in (67 cm).

7) *Fomes fomentarius* or *Fomes igniarius* decay are usually present in paper birch and aspen nest trees.

8) The Yellow-bellied Sapsucker is the most common woodpecker in western larch/Douglas-fir forests. The Pileated Woodpecker is the most sensitive to timber harvesting (McClelland 1979).

9) Fifty-four active Pileated Woodpecker nest trees were located. The nest tree "search image" for the Pileated (the largest woodpecker in the Rocky Mountains) is a western larch, ponderosa pine, or black cottonwood snag (with a broken top), greater than 24 in (61 cm) dbh, taller than 60 feet (18.3 m) (usually much taller), with bark missing on at least the upper half of the snag, heartwood substantially affected by decay, and within an old-growth stand with a basal area of at least 125 ft^2/acre (28.6 m^2/ha).

10) Pileated Woodpeckers used feeding areas ranging from 500 to 1000 acres (200 to 400 ha) in the study area. They fed in small group selection or shelterwood cutting areas where logs and snags were left, but rarely nested in open sites. The species foraged about 50% of its feeding time on logs ≥ 6 inches in diameter. The remaining 50% was spent obtaining insects (usually carpenter ants, wood borers, or pine beetles) from snags or live trees.

11) Yellow-bellied Sapsuckers fed on insects found on the bark of a variety of tree species. Sapsuckers constructed sapwell feeding stations in western hemlock and Douglas-fir in the spring and in paper birch in the summer. Paper birch is an important species for both nesting and feeding. Sapwell feeding sites in birch are important to a host of insects, small mammals, and birds (especially hummingbirds) (fig. 16).

12) Utilization intensity had no apparent influence on woodpecker feeding activity in any clearcut subunit.

13) Utilization intensity characterized as "near complete" resulted in a reduction of woodpecker feeding activity in the lower shelterwood unit.

14) Substantial feeding occurred in control (uncut) units and shelterwood units.

15) Feeding activity recorded in this study covered a very short period of time (only spring and summer, and only 3 and 4 years after logging). The observations can only indicate impacts on feeding opportunities for woodpeckers during a brief period on the temporal scale and at particular locations in a spatial framework. General extrapolations from the observations on feeding reported here is not possible. The difficulty in interpreting the results of feeding activity observations emphasize the need for studies of much longer term and the problems of quantifying in a meaningful way woodpecker feeding opportunities within complex environments, where subtle changes may have major impacts. In addition to amount and size of woody material, its distribution is also important.

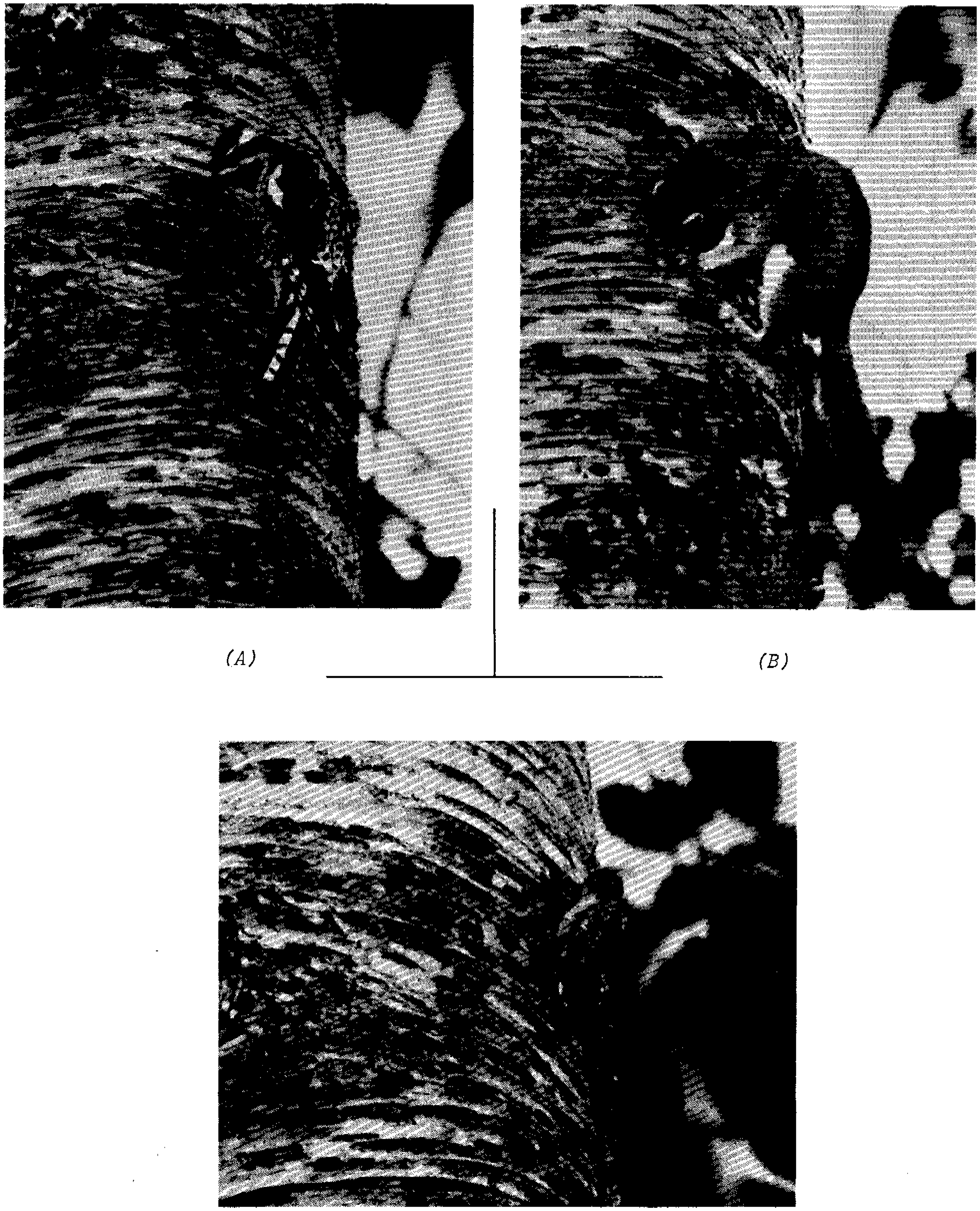
16) Old-growth western larch/Douglas-fir supports the greatest number of hole-nesting bird species in the study area. Sites near water are more heavily used than are dry sites. Optimum habitat is in the productive valley bottoms where timber potential is also highest.

MANAGEMENT SUGGESTIONS

1) Large western larch, ponderosa pine and black cottonwood snags are intensely sought by firewood cutters and need special protection. Post-logging road closures may be necessary at many sites, if snags are to be saved.

2) Simply saving existing snags is not sufficient if habitat management for cavity-nesting birds is to be taken seriously. This approach concentrates on habitat components that result from ecological processes rather than the processes themselves. The logical management objective is the perpetuation of a diversity of forest habitats, a mosaic pattern which (on the Flathead National Forest) includes old-growth larch and ponderosa pine stands, black cottonwood stands on riparian sites, and aspen groves.

3) Where Pileated Woodpeckers are to be maintained, a manager should plan for stands with an old-growth component of larch, ponderosa pine, or black cottonwood constituting a minimum of 10% of the total forest area in which those species typically occur (McClelland et al. 1979). A similar approach has been described by Bull (1978) for Wallowa-Whitman, Malheur, Umatilla, and Ochoco National Forests in Oregon. Guidelines for those forests call for 5% of the total of each timber type to be managed as old-growth and stands are to be no less than 20 acres (8.1 ha) in size.



(A)

(B)

(C)

Figure 16.--Sapsucker sapwell use in a paper birch. (A) Yellow-bellied Sapsucker, (B) Red squirrel, (C) Rufous Hummingbird.

4) Old-growth units should not be isolated with vast stretches of clearcuts or short rotation stands separating them. Ideally, old-growth units of 50-100 acres (20 to 40 ha) should be connected with forest corridors at least 300 ft (91 m) wide. In many cases corridors could follow creeks, also achieving protection of aquatic ecosystems and providing travel lanes and escape cover for other wildlife.

5) High stumps support carpenter ant colonies and provide feeding sites for woodpeckers. Wherever carpenter ant activity is identified in a cutting unit, a 0.1 acre (0.04 ha) circular area of high stumps could be left around that point if provision of woodpecker food is an objective.

6) Thinning can be detrimental to hole-nesting birds when feeding sites on and near the ground are covered by cut trees and branches. Thinned material and residues should not be piled so as to cover log feeding sites.

7) The relevance of the concept of bird species diversity has been appropriately questioned in relation to resource management objectives (Wiens 1978). Diversity per se is a measure insensitive to which species are present. The species that require large territories (e.g., raptors or Pileated Woodpeckers) may receive little attention if emphasis is on high bird species diversity, particularly over small units of landscape. However, basic habitat diversity over large forest areas, is an essential element of consideration for resource managers. Certain components of the original diverse forests which existed in northwestern Montana are being greatly reduced as a result of current timber harvesting practices. Original stands of old-growth western larch, for example, have been reduced by nearly one half since timber cutting began. Where old growth is eliminated over vast areas, many birds dependent on it may be extirpated. The importance of perpetuating habitat diversity is therefore a relevant and necessary concern of forest resource managers. Old-growth stands in national parks, wilderness, and natural areas are not sufficient in themselves because they could increasingly take on the character of islands surrounded by great seas of short-rotation stands. These "islands," particularly the smaller ones, will probably be incapable of sustaining the same richness of bird species diversity that is present in larger stands. Therefore, on commercial forests the perpetuation of an old-growth component needs to be incorporated as a legitimate goal of the management process. Based on studies at the CEF and nearby areas, we suggest that about 10% of forest planning units in the western larch/Douglas-fir forests be managed as old growth. This can be accomplished by long rotations, partial cutting to encourage larch (but retaining a high basal area in large-diameter classes), not re-entering shelterwood or seed tree cuts, or other methods that can be devised by skillful interdisciplinary teams.

8) The ecological relationships between birds and the forest may never be completely understood, but recognition of the ecosystem concept requires that hole-nesting birds and their habitats be perpetuated. If for no other reason they should be perpetuated simply because (to paraphrase Aldo Leopold) the first precaution in intelligent management is to keep every cog and wheel. Sufficient data are now available to enable foresters to prepare timber harvesting and residue management plans that are more responsive to the needs of cavity-nesting birds and other members of the wildlife community.

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APPENDIX

TABLE 13. Common and Scientific Names

Trees	
Western larch	*Larix occidentalis*
Ponderosa pine	*Pinus ponderosa*
Lodgepole pine	*Pinus contorta*
Whitebark pine	*Pinus albicaulis*
Limber pine	*Pinus flexilis*
Douglas-fir	*Pseudotsuga menziesii*
Subalpine fir	*Abies lasiocarpa*
Grand fir	*Abies grandis*
Engelmann spruce	*Picea engelmannii*
Western hemlock	*Tsuga heterophylla*
Western redcedar	*Thuja plicata*
Aspen	*Populus tremuloides*
Paper birch	*Betula papyrifera*
Black cottonwood	*Populus trichocarpa*
Birds	
Goldeneye sp.	*Bucephala* sp.
Osprey	*Pandion haliaetus*
Cooper's Hawk	*Accipiter cooperii*
American Kestrel	*Falco sparverius*
Blue Grouse	*Dendragapus obscurus*
Spruce Grouse	*Canachites canadensis*
Saw-whet Owl	*Aegolius acadicus*
Rufous Hummingbird	*Selasphorus rufus*
Common Flicker	*Colaptes auratus*
Pileated Woodpecker	*Dryocopus pileatus*
Lewis' Woodpecker	*Melanerpes lewis*
Yellow-bellied Sapsucker	*Sphyrapicus varius*
Williamson's Sapsucker	*Sphyrapicus thyroideus*

Hairy Woodpecker	*Picoides villosus*
Downy Woodpecker	*Picoides pubescens*
Black-backed Three-toed Woodpecker	*Picoides arcticus*
Northern Three-toed Woodpecker	*Picoides tridactylus*
Olive-sided Flycatcher	*Nuttallornis borealis*
Tree Swallow	*Iridoprocne bicolor*
Gray Jay	*Perisoreus canadensis*
Common Raven	*Corvus corax*
Black-capped Chickadee	*Parus atricapillus*
Mountain Chickadee	*Parus gambeli*
Chestnut-backed Chickadee	*Parus rufescens*
Red-breasted Nuthatch	*Sitta canadensis*
Brown Creeper	*Certhia familiaris*
House Wren	*Troglodytes aedon*
Winter Wren	*Troglodytes troglodytes*
Robin	*Turdus migratorius*
Varied Thrush	*Ixoreus naevius*
Swainson's Thrush	*Hylocichla ustulata*
Mountain Bluebird	*Sialia currucoides*
Golden-crowned Kinglet	*Regulus satrapa*
Ruby-crowned Kinglet	*Regulus calendula*
Solitary Vireo	*Vireo solitarius*
Warbling Vireo	*Vireo gilvus*
Orange-crowned Warbler	*Vermivora celata*
Yellow-rumped Warbler	*Dendroica auduboni*
Townsend's Warbler	*Dendroica townsendi*
MacGillivray's Warbler	*Oporornis tolmiei*
Wilson's Warbler	*Wilsonia pusilla*
Western Tanager	*Piranga ludoviciana*
Black-headed Grosbeak	*Pheucticus melanocephalus*
Pine Grosbeak	*Pinicola enucleator*
Pine Siskin	*Spinus pinus*
Dark-eyed Junco	*Junco oreganus*
Chipping Sparrow	*Spizella passerina*

PROBLEMS AND OPPORTUNITIES IN INTEGRATING AND EXTRAPOLATING RESEARCH RESULTS

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ABSTRACT

Forest managers face increasingly complicated problems in selecting among harvest treatment alternatives. Managers must be able to predict the environmental consequences of alternatives, so as to make intelligent and defensible choices.

Research results are usually limited to a narrow spectrum of site conditions, treatment alternatives, and subject matter; and they are often reported in a manner that renders them difficult to acquire and interpret. Needed are methods whereby research results can be readily integrated and extrapolated, so that managers can simulate treatment alternatives in their particular situations and predict the outcomes. Some possible ways of meeting this need are presented and discussed.

KEYWORDS: Forest decisionmaking, environmental consequence prediction, integration of research results, interaction of environmental components, models, modelling

THE SITUATION

Forest land managers must choose among alternatives in an atmosphere of increasing conflict and exposure. Once management objectives for a particular tract of land are established, it ought to be relatively easy to choose the best strategy for satisfying those objectives. Unfortunately, and especially with respect to public forest lands, the objectives of forest management are seldom sufficiently clear or specific to enable a manager to define his available alternatives.

In most situations a tract of forested land has merchantable timber growing on it, or is otherwise deemed ready for or in need of some harvesting treatment. Deciding which trees should be cut, which trees and residues should be removed, the method for extracting the fiber, and what subsequent treatment of the residues and site should be undertaken, becomes a matter of weighing the environmental and economic consequences of various alternatives.

When one views a treatment as a specific combination of silvicultural prescription, removal specification, harvesting method and post-harvest site prescription, the number of treatment alternatives becomes very large. For example, even when a manager considers only two silvicultural prescriptions, two removal specifications, two harvesting methods and two immediate post-harvest site treatments, that manager is faced with choosing from among $2^4 = 16$ treatment alternatives. And if he or she further considers the size, shape, and placement of harvesting units and the subsequent silvicultural treatment alternatives his or her successors will face at various times in the future, the array of choices becomes astronomical in size.

Assume that for each alternative specified, the manager could predict with a high degree of accuracy the costs, the revenues, the environmental consequences, and some measure of associated public reactions at various points in time following treatment. How could the manager synthesize this massive quantity of information, and by what process would he or she seek a defensible decision? We will not attempt to answer this question here, but note that good decisions can be made neither in a vacuum nor in a morass of information. A manager must be provided with, or must select, that and only that information relevant to a given decision. The ability to cull information is far more important than the ability to gather information. The recent Nobel Prize winner Herbert Simon (1957) has suggested that most managerial decisions are made in the spirit of <u>satisfying</u> the constraints rather than <u>optimizing</u> some predetermined value. It appears that humans are incapable of using all available information. Information must be greatly simplified (organized) in order to be effectively utilized.

We suggest that a considerable effort should be made to address the problem of how managers utilize information. It is not sufficient to provide information; it must be provided in the right quality and kind. Note that we mean not to prescribe how decisions <u>should be</u> made but merely to study how decisions <u>are</u> made.

HOW INFORMATION IS USED IN THE DECISIONMAKING PROCESS

We feel strongly that when trying to specify how information is to be used, it is imperative that the decisionmaking process be considered. Green, of the Wharton School of Business, and Wind, of Bell Laboratories, have, we think, eloquently characterized the decisionmaking process facing executives in marketing in a way which is particularly appropos to the forest manager. We quote and paraphrase from their book, Multiattribute Decisions in Marketing (Green and Wind 1973):

> The traditional view of modeling executive decision-making behavior in terms of the objectives and actions of economic man is also being challenged as too narrow a conceptualization. . . . (The) more recent models recognize that organizational decision making, ..., is a complex, multivariable process that cannot be captured by any single function such as corporate profit maximization, enhancement of social responsibility, or the like. Rather, executive-choice behavior involves multiple influences and goals and potentially conflicting objectives. Not surprisingly, more recent (decisionmaking) models highlight the multiattribute nature of alternatives involved in managerial decisions.

The framework in which a forest manager's decisions are viewed seems to parallel closely that described by Green and Wind. Similarly, we will examine the decisionmaking of forest managers as a "descriptive approach to individual riskless choice involving multiattribute alternatives in a more or less static ...choice situation." (Green and Wind 1973). A number of alternative characterizations of the decisionmaking process are illustrated in figure 1.

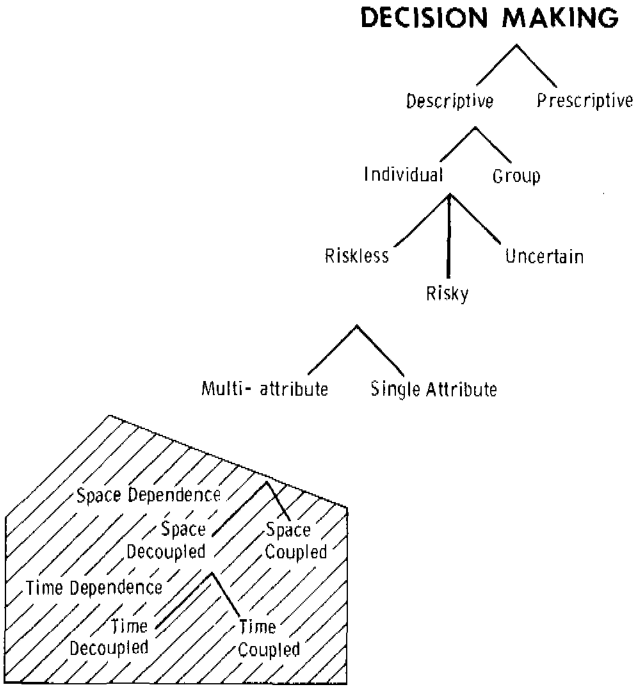

Figure 1.--Characterization of the decisionmaking process.

Decisionmaking may be studied using either a prescriptive or a descriptive approach. The fields of operations research and economics are prescriptive in that they are concerned with making decisions consistent with some set of criteria--frequently utility maximization. Whatever the criteria, a specific recommendation is made on the course of action which should be taken. This course of action is consistent with some explicitly defined set of assumptions thought to be rational.

In the descriptive approach, however, interest is focused on how decisions are made rather than on how decisions should be made. Research attention is on how decisionmakers behave, and no judgments are made about how they should behave. The descriptive approach is characteristic of many models, such as Simon's "satisficing model" mentioned earlier.

No hard and fast distinctions can be made between the descriptive and prescriptive models; indeed, the prescriptive approach may provide only a description of an ideal decisionmaker. It is important to realize that this distinction between descriptive and prescriptive models is frequently quite blurred.

We believe that examining how forest managers make decisions--what information they use and what information they ignore--will suggest strategies for emphasizing and de-emphasizing particular research results. In examining the decisionmaking process, it will be convenient to represent the outcome of each treatment alternative as a vector

$$X = (X_1, X_2, \ldots, X_n) \tag{1}$$

where X_i refers to the level or state of the i^{th} attribute. We assume the decisionmaker judges some alternatives as more valuable than others; the results of this judgment process can be represented as a utility function

$$U(X) = F(X_1, X_2, \ldots, X_n). \tag{2}$$

The mere act of making choices among a set of multiattribute alternatives is sufficient to guarantee the existence of such a function.

It should be emphasized that the number of attributes that potentially can be utilized by the decisionmaker or forest manager is astronomical in size. In such a case, n would be extremely large.

A great deal of psychological research on decisionmaking has indicated that the number of attributes utilized by people making decisions is quite small. Perhaps the decisionmaker's utility function could be described as

$$U(X) = F\ (X_1, X_2, \ldots, X_m) \tag{3}$$

where m is some small number. There may be only a small difference between decisions made by a utility function with a large number of attributes and one made with a few salient attributes.

The problem, of course, is to reduce the number of attributes to a manageable size; hence, the need to study the process of decisionmaking by forest managers. Many decisionmakers would deny that they look only at a few 'crucial' attributes when making a decision--they argue, correctly, that things are more complex. The decisionmaker may only utilize a small number of attributes, but that decisionmaker must understand each of those attributes thoroughly if the decisions are going to be intelligent ones.

An Example

Consider the purchase of an automobile as an example of the decisionmaking process and as a weak analogy to the sorts of decisions faced by forest managers. To the person choosing a car the most relevant attributes might be mileage, size, style and price. Not everyone makes identical choices and not everyone uses the same attributes, but most choices among automobiles are made on the basis of comparing a few highly salient features of those cars.

If a decision is to be made on the basis of a few attributes (and research indicates that decisions are), then the information contained in the summaries of those attributes should be well understood if the decisions are going to be good.[1] The so-called simple attributes of mileage, size, etc. are really more complex. What is meant by mileage--is it EPA figures for city driving, for highway driving, for city and highway driving combined, at 55 mph, 70 mph, with car in tune, out of tune--what? What is "size"--cubic feet, weight, headroom?

Each of these attributes has an infrastructure behind it. Mileage can be considered in a uniform manner at the top level, but for complex decisions it is important to have available more detailed knowledge about the summary figures. The decisionmaker may only examine one final mileage figure--say EPA overall--but that decisionmaker must be confident in that single figure; and the best way of creating confidence in that final figure is to provide the more detailed information. The information about the choice of automobiles could be organized as in figure 2.

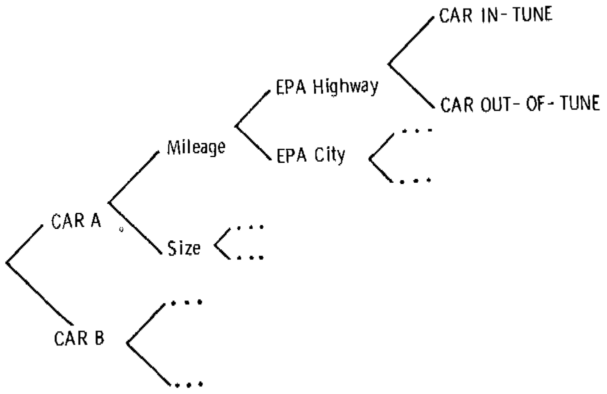

Figure 2.--Selecting information for an automobile purchase decision.

The decisionmaker should have summary figures about mileage, size, etc. available when making the decision, but must be confident--i.e., must be able to examine the more detailed information in a convenient form.

For automobiles it is not so important to be able to dig deeply into depths of the various attributes; but for forest managers who are expected to make defensible decisions it is very important to have detailed information in a usable form. We suggest that the information that forest managers need should be organized in a hierarchial fashion as depicted in the example with automobiles (fig. 2).

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[1] Where "good" means that the decisions satisfy some criteria.

ORGANIZING INFORMATION

One difference between the forest manager's situation and our automobile analogy concerns the quantity of available information. Much more information is available to the forest manager, and it can only be managed through organization. Disorganized or poorly organized information is useless--what good would a dictionary be if words were presented not alphabetically, but in the order of the number of letters?

We suggest that a forest manager's information could be organized efficiently in a hierarchial fashion. At the very top one could display the most summaried, most general, and least detailed information; at the very bottom would be the most technical, most detailed, and most specific information. This hierarchial arrangement would enable a decisionmaker to utilize the general information as it is, or to examine it more deeply as he or she requires. If a decisionmaker wishes to have more information about a specific topic there are pointers or references to more detailed information at every level; the decisionmaker may gather more detail about a specific topic or choose to accept the information as presented. Figure 3 is a general example and figure 4 is a more specific example of the selection process and information hierarchy we envision.

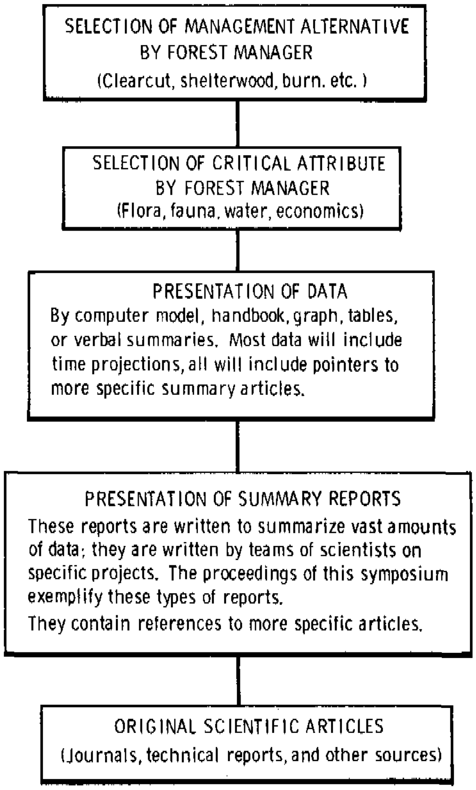


Figure 3.--Selection process and information hierarchy.

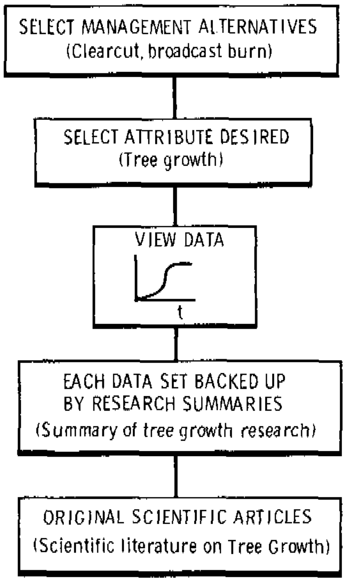


Figure 4.--Example of selection process and information hierarchy.

Of course, figure 4 represents an idealized situation and is based on the assumption that the quantity and quality of basic information will enable outcome predictions (e.g. tree growth) that are defensible. This assumption may be unwarranted. Indeed, apart from the problem of acquiring and synthesizing basic research information to predict enviromental outcomes is the more fundamental problem of information quality. Much forest research literature describes observations in the absence of generalized theories regarding cause and effect, and the reader is often admonished to "use caution in extrapolating the results to other circumstances." It may be that the failure of decisionmakers to utilize existing research information is not so much because of its limited accessibility as because of its limited applicability.

In the following we examine some alternatives for organizing and integrating research information to meet decisionmakers' prediction requirements, and we suggest methods whereby scientists might plan and conduct their research to be compatible with these prediction requirements.

INTEGRATING AND EXTRAPOLATING INFORMATION

Forest managers need organized information that predicts the environmental consequences of alternative decisions through integration and extrapolation of research results and reasoned speculation. The fundamental concern is vegetative succession and development following treatment. This is because the vegetative complex most directly influences use opportunities, and vegetation integrates and reflects the interactions of all environmental components.

As has already been stated, the forest land manager must be able to predict the outcomes of those alternative harvest treatments he wishes to consider. This means that he needs to know what the status of particular environmental characteristics will be over time after treatment. Figure 5 might represent such a characteristic vs. time relationship.

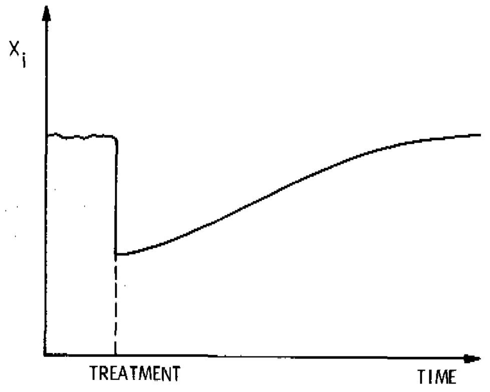


Figure 5.-- Environmental characteristic versus time.

It would be ideal if we could factorially apply a broad array of treatments to a variety of forest types and habitats and monitor forest development through rotation to obtain a direct measure of vegetative response. This obviously is impossible. Therefore, it seems necessary that we monitor more fundamental environmental characteristics over short time periods and attempt to correlate these characteristics with vegetative change to obtain a basis for prediction. The major problem we see for researchers and staff specialists doing this concerns integrating primary environmental characteristics into a holistic model to predict not only vegetative succession, but also other environmental consequences following treatment.

Most readers are familiar with models for predicting vegetative succession and stand development. Modelling efforts have been ongoing for several years now, and have resulted in such products as Stage's (1973) Stand Development Prognosis Model and the Grassland Simulation Model (Innis 1978). One purpose of such models is to meet the objectives we are concerned with here--that is, prediction of the state of the environment (or at least of certain parts of the environment) at various points in time. We will not attempt to make an exhaustive review or criticism of such models here. Instead, we wish to discuss the general issue of environmental response prediction, and the integration and extrapolation of basic environmental interactions toward that end.

We are not prepared to suggest how the many environmental characteristics can be combined in a deterministic model to predict their status over time on a specific site, nor are we convinced this is even practicable. Nevertheless, we can suggest some ways for coping with environmental interactions and estimating relatively short-term changes.

Billings (1970) has described the complexity of environmental interactions with the diagram reproduced in figure 6. His characterization of a plant or plant community and its environment is useful in portraying the problem we are addressing, but it is not very helpful as a format for its solution. Based on this characterization, and in light of our own conclusion that the decisionmaker's focus is ultimately on vegetative response, we might suggest a matrix format (fig. 7) in which the state of the various components of the vegetative community at a certain point in time are listed down the left (as row headings), and the state of the influencing environmental factors at the same point in time are listed across the top (as column headings).

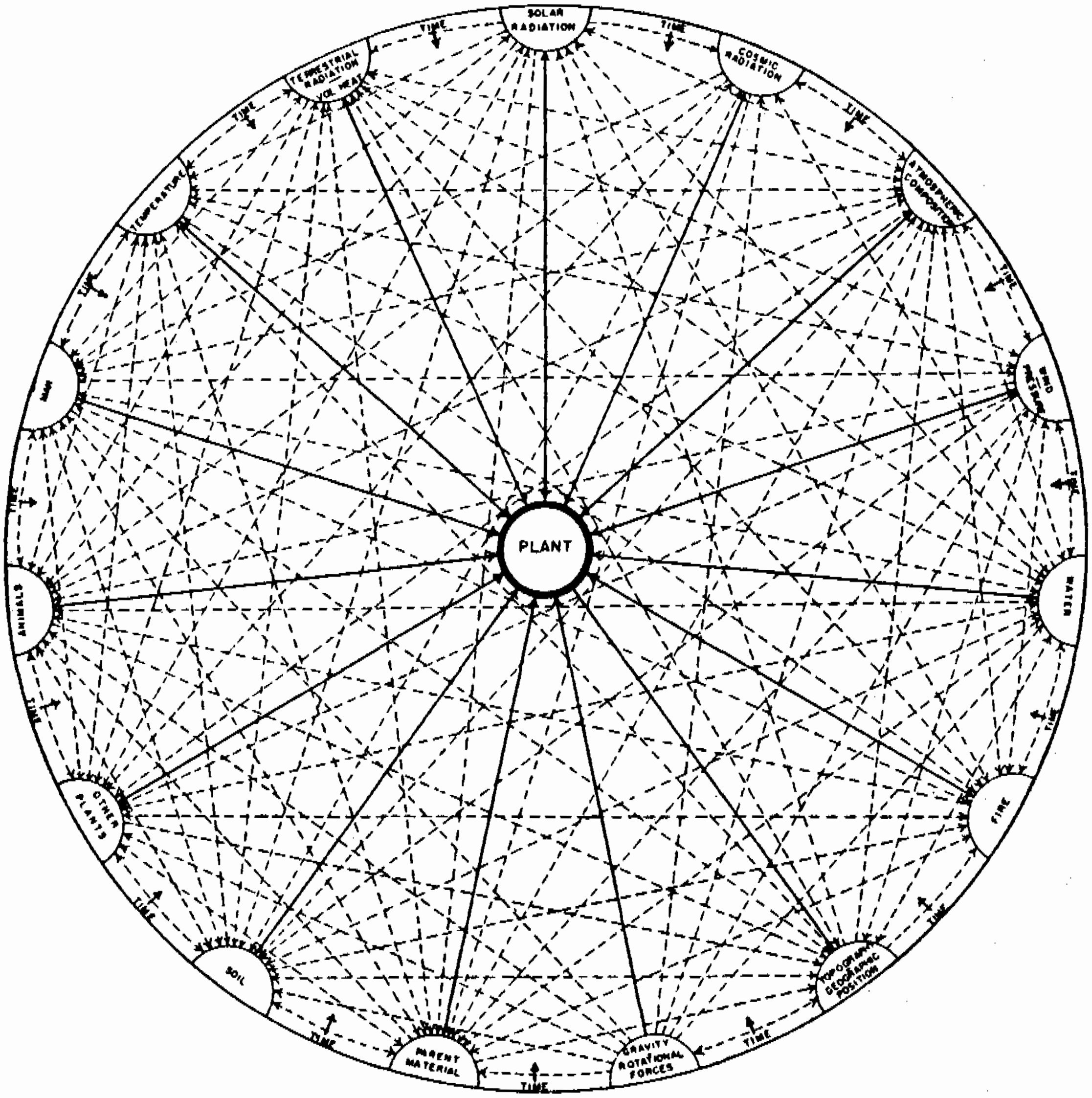


Figure 6.--Environmental interactions (from Billings 1970, p.9).

$$
\begin{array}{c||c|c|c|c|c|c||c}
\text{VEG.} \backslash \text{ENV.} & X_1 & X_2 & \cdots & X_j & \cdots & X_n & \Delta Y \\
\hline\hline
Y_1 & \Delta_{11} & \Delta_{12} & \cdots & \Delta_{1j} & \cdots & \Delta_{1n} & \Delta Y_1 \\
\hline
Y_2 & \Delta_{21} & \Delta_{22} & \cdots & \Delta_{2j} & \cdots & \Delta_{2n} & \Delta Y_2 \\
\hline
\vdots & \vdots & \vdots & & \vdots & & \vdots & \vdots \\
\hline
Y_i & \Delta_{i1} & \Delta_{i2} & \cdots & \Delta_{ij} & \cdots & \Delta_{in} & \Delta Y_i \\
\hline
\vdots & \vdots & \vdots & & \vdots & & \vdots & \vdots \\
\hline
Y_m & \Delta_{m1} & \Delta_{m2} & \cdots & \Delta_{mj} & \cdots & \Delta_{mn} & \Delta Y_m \\
\hline\hline
\Delta X & \Delta X_1 & \Delta X_2 & \cdots & \Delta X_j & \cdots & \Delta X_n &
\end{array}
$$

Figure 7.--Matrix of interactions between vegetation and environmental characteristics.

Our primary objective is to predict the status of vegetation at some later time, but because all the other environmental factors may be changing, it is necessary to predict their status as well. Thus, the integration process becomes one of assessing the influence of each environmental factor on each recognized plant species or type, and "integrating" across the respective rows to determine the new status of vegetation at some later time, t + Δt. Likewise, we must "integrate down" each column to obtain the new status of the particular environmental factor at the time t + Δt. These new values then serve as "inputs" to a new matrix representing the status at time t + Δt, and the process is repeated (fig. 8).

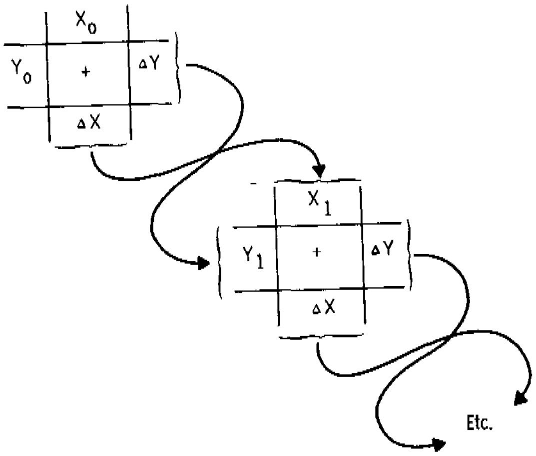


Figure 8.--Successive prediction scheme.

We are not suggesting here that the integration process would be additive, multiplicative, nor anything else--merely that this is a reasonable format for dealing with the effects of various environmental factors on vegetation and for representing the status of the vegetation and environmental factors at various points in time.

Some major weaknesses are apparent in this approach. One is that the influences of certain plants on other plants are not provided for, though this could be handled merely by adding columns representing the plant community. Another weakness is that this approach provides a method for assessing interactions only between various environmental factors and vegetation. As an alternative, we suggest a matrix format (fig. 9) in which both the row and column headings represent the status of each recognized environmental component at the same point in time, and each cell represents the influence of the respective column component on the change (or rate of change) of the respective row component. By "integrating" across each row, one could estimate the resulting change in status of the corresponding component over the ensuing time period, Δt.

$$\begin{array}{c||c|c|c|c|c|c||c}
 & X_1 & X_2 & \cdots & X_j & \cdots & X_n & \\
\hline
X_1 & \Delta X_{11} & \Delta X_{12} & \cdots & \Delta X_{1j} & \cdots & \Delta X_{1n} & \Delta X_1 \\
\hline
X_2 & \Delta X_{21} & \Delta X_{22} & \cdots & \Delta X_{2j} & \cdots & \Delta X_{2n} & \Delta X_2 \\
\hline
 & \vdots & \vdots & & \vdots & & \vdots & \vdots \\
\hline
X_i & \Delta X_{i1} & \Delta X_{i2} & \cdots & \Delta X_{ij} & \cdots & \Delta X_{in} & \Delta X_i \\
\hline
 & \vdots & \vdots & & \vdots & & \vdots & \vdots \\
\hline
X_n & \Delta X_{n1} & \Delta X_{n2} & \cdots & \Delta X_{nj} & \cdots & \Delta X_{nn} & \Delta X_n
\end{array}$$

Figure 9.--Complete environmental intention matrix.

Again, we emphasize that the nature of this integration process is yet to be defined. Nevertheless, this format would seem to provide a mechanism whereby all interactions could be accounted for.

The simplest view one can take of environmental interactions is based on Liebig's Law of Minimums. From this view, one isolates and uses as a basis for prediction that particular environmental characteristic that limits change in the characteristic in which one is primarily interested. Thus, given the current state of an environment represented by $X_1, X_2, \ldots X_n$ where X_i represents the status of the i^{th} environmental component, one must isolate that component--say the j^{th} component-- which, under the given conditions, will constrain or most directly affect the change in the i^{th} component (fig. 10). For example, suppose X_1 represents understory biomass density, X_2 represents soil nutrient concentration, X_3 represents average soil moisture content, and X_4, X_5, ...X_n represent the remainder of the forest environment being considered. Suppose further that we know the level of soil nutrients limits understory growth in this situation, and that all other environmental components that would promote growth are at or above critical levels while all that would retard growth are at or below critical levels (e.g., increasing soil moisture would not accelerate growth). In this situation, we would simply conclude that the change in X_1, say ΔX_1, over the ensuing time period, Δt, would be determined by the level of nutrients, X_2, during the same period. The amount of change, $\Delta X_1 = \Delta X_{12}$, would be based on data from the research literature or, in its absence, on professional opinion. This same thought process would be followed for each of the n environmental components, resulting in an estimate of ΔX_i for each, and a corresponding estimate of its new status, or

$$X_{i,t+\Delta t} = X_{i,t} + \Delta X_i \qquad (4)$$

where $X_{i,t}$ is the status of the i^{th} component at time t; and $X_{i,t+\Delta t}$ is the status of the i^{th} component at some later time, $t + \Delta t$ (fig. 11).

Figure 10.--Predictions based on limiting interactions.

	X_1	X_2	X_3		X_i		X_j		X_k		X_n	
X_1	–	ΔX_{12}	–		–		–		–		–	$\Delta X_1 = \Delta X_{12}$
X_2	–	–	–		–		ΔX_{2j}		–		–	$\Delta X_2 = \Delta X_{2j}$
X_3	–	–	–		ΔX_{3i}		–		–		–	$\Delta X_3 = \Delta X_{3j}$
X_n	–	–	–		–		–		ΔX_{nk}		–	$\Delta X_n = \Delta X_{nk}$

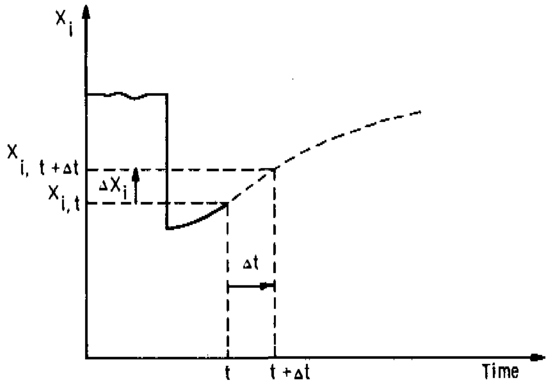


Figure 11.--Illustration of Equation 4.

Of course, it may be very difficult to isolate the limiting component for each "dependent" component, so we will treat this problem more generally. We recognize, or think we know, that the status of any particular environmental component is a function of all environmental components and time. Ideally, we would like to construct a function for the state of each component as

$$X_i = F_i(X_1, X_2, \ldots, X_n) \tag{5}$$

where

$$\begin{aligned} X_1 &= g_1(t) \\ X_2 &= g_2(t) \\ &\vdots \\ X_n &= g_n(t) \quad . \end{aligned}$$

It seems highly unlikely that we will ever define such a function, however, for both mathematical and other reasons. But given that we know the state of an environment at a particular point in time, t, and given a set of assumptions about the near future--principally with regard to macroclimate--it seems considerably more likely that we could estimate the rate of change in the state of a particular environmental component. Expressed formally,

$$\frac{dX_i}{dt} = f_i\,(X_1, X_2, \ldots, X_i, \ldots, X_j, \ldots, X_n) \quad . \tag{6}$$

Differentiating equation 6 with respect to time, t, we obtain an expression for the rate of change of the rate of change, or

$$\frac{d^2X_i}{dt^2} = \frac{df_i}{dt} = \frac{\partial f_i}{\partial X_1}\frac{dX_1}{dt} + \frac{\partial f_i}{\partial X_2}\frac{dX_2}{dt} + \ldots + \frac{\partial f_i}{\partial X_i}\frac{dX_i}{dt} + \ldots$$

$$\ldots + \frac{\partial f_i}{\partial X_j}\frac{dX_j}{dt} + \ldots + \frac{\partial f_i}{\partial X_n}\frac{dX_n}{dt} \quad . \tag{7}$$

In a finite difference format, equation 7 can be written

$$\frac{\dfrac{\Delta X_{i,t}}{\Delta t} - \dfrac{\Delta X_{i,t-\Delta t}}{\Delta t}}{\Delta t} \simeq \frac{\partial f_i}{\partial X_1}\frac{\Delta X_{1,t-\Delta t}}{\Delta t} + \frac{\partial f_i}{\partial X_2}\frac{\Delta X_{2,t-\Delta t}}{\Delta t} + \ldots + \frac{\partial f_i}{\partial X_i}\frac{\Delta X_{i,t-\Delta t}}{\Delta t} + \ldots$$

$$\ldots + \frac{\partial f_i}{\partial X_j}\frac{\Delta X_{j,t-\Delta t}}{\Delta t} + \ldots + \frac{\partial f_i}{\partial X_n}\frac{\Delta X_{n,t-\Delta t}}{\Delta t}$$

or, by rearrangement,

$$\frac{\Delta X_{i,t}}{\Delta t} = \frac{\Delta X_{i,t-\Delta t}}{\Delta t} + \Delta t \left[\frac{\partial f_i}{\partial X_1} \frac{\Delta X_{1,t-\Delta t}}{\Delta t} + \frac{\partial f_i}{\partial X_2} \frac{\Delta X_{2,t-\Delta t}}{\Delta t} + \ldots \right.$$

$$\left. \ldots + \frac{\partial f_i}{\partial X_i} \frac{\Delta X_{i,t-\Delta t}}{\Delta t} + \ldots + \frac{\partial f_i}{\partial X_j} \frac{\Delta X_{j,t-\Delta t}}{\Delta t} + \ldots + \frac{\partial f_i}{\partial X_n} \frac{\Delta X_{n,t-\Delta t}}{\Delta t} \right] . \quad (8)$$

Instead of dealing with rates of change, we can rewrite equation 8 to facilitate predictions of change per se, or

$$\Delta X_{i,t} = \Delta X_{i,t-\Delta t} + \Delta t \left[\frac{\partial f_i}{\partial X_1} \Delta X_{1,t-\Delta t} + \frac{\partial f_i}{\partial X_2} \Delta X_{2,t-\Delta t} + \ldots \right.$$

$$\left. \ldots + \frac{\partial f_i}{\partial X_i} \Delta X_{i,t-\Delta t} + \ldots + \frac{\partial f_i}{\partial X_j} \Delta X_{j,t-\Delta t} + \ldots + \frac{\partial f_i}{\partial X_n} \Delta X_{n,t-\Delta t} \right] \quad (9)$$

where $\Delta X_{j,t-\Delta t}$ represents the change in state of the jth environmental characteristic during the previous time interval from t-Δt to t; and $\Delta X_{i,t}$ represents the predicted change in state of the ith environmental characteristic during the next time interval from t to t + Δt. Of course, the time intervals (Δt) are equal in each iteration. That is

$$\Delta t = t-(t-\Delta t)$$
$$\text{and } \Delta t = (t+\Delta t) - t \quad .$$

$\partial f_i/\partial X_j$ is the partial derivative of the rate of change in X_i with respect to X_j during the interval from t to t+Δt (see fig. 12).

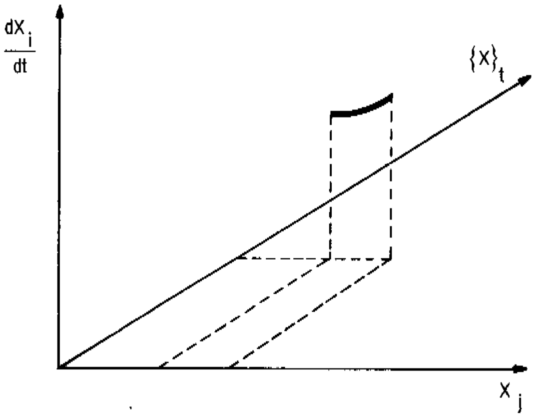


Figure 12.--Change in dX_i/dt given a change in X_j only.

If we were to plot dX_i/dt (or $\Delta X_i/\Delta t$) as a function of the value of X_j and assume no change in any other environmental component during the interval Δt, we could approximate the relationship with a linear function (fig. 13) or

$$\frac{dX_i}{dt} \simeq \frac{\Delta X_i}{\Delta t} = a_{ij} + b_{ij}(X_j) \quad . \tag{10}$$

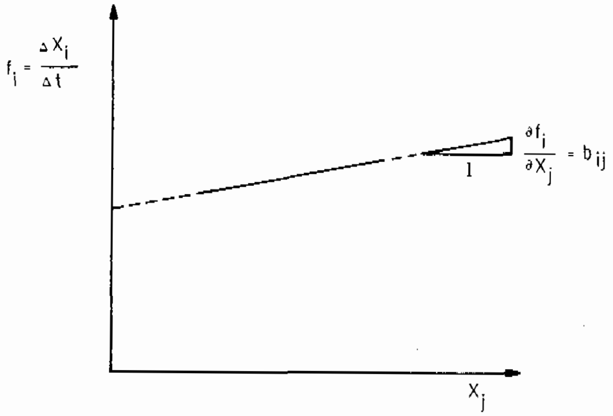


Figure 13.--Linear approximation of dX_i/dt vs. X_j.

Accordingly,

$$\frac{\partial}{\partial X_j}\left(\frac{dX_i}{dt}\right) = \frac{\partial f_i}{\partial X_j} \simeq b_{ij} \quad . \tag{11}$$

Therefore, we may write

$$\Delta X_{i,t} = \Delta X_{i,t-\Delta t} + \Delta t \left[b_{i1}\,\Delta X_{1,t-\Delta t} + b_{i2}\Delta X_{2,t-\Delta t} + \cdots \right.$$
$$\left. \cdots + b_{ii}\,\Delta X_{i,t-\Delta t} + \cdots + b_{ij}\Delta X_{j,t-\Delta t} + \cdots + b_{in}\,\Delta X_{n,t-\Delta t} \right] \tag{12}$$

where $\Delta X_{i,t} = X_{i,t+\Delta t} - X_{i,t}$

and $\Delta X_{j,t-\Delta t} = X_{j,t} - X_{j,t-\Delta t}$.

The result is that we can write a linear equation for the change in state of the i^{th} component during the ensuing period, Δt, as a function of the change in state of all components during the previous time interval.

DISCUSSION

It is important to note that for the unlikely situation wherein the change in state of a particular component, X_i, during any time interval, Δt, is unaffected by either its own state or the state of any other environmental component (i.e., that $b_{ij} = 0$; $j = 1,\dots,n$) equation 12 merely predicts that

$$\Delta X_{i,t} = \Delta X_{i,t-\Delta t} \tag{13}$$

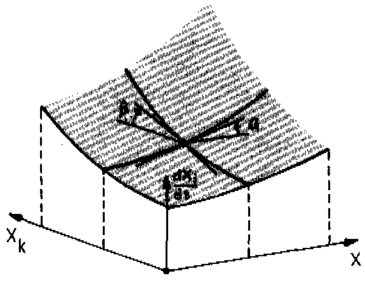
or that the change in X_i during the interval from t to $t+\Delta t$ equals the change in X_i during the previous interval from $t-\Delta t$ to t--not an unreasonable outcome.

Note also that, for the situation wherein the change in state of the i^{th} component is affected only by its current state, and not by the state of any other component, equation 12 reduces to

$$\Delta X_{i,t} = (1+b_{ii}\Delta t)\Delta X_{i,t-\Delta t} \tag{14}$$

An example of this latter situation would be one where the rate of growth in population of a particular organism is either retarded or accelerated only by the level of its current population--the exponential growth function.

Finally, we should elaborate on the meaning of the b_{ij}'s, and the corresponding challenge to researchers and staff specialists. Referring to figure 14, note that b_{ij} is the instantaneous slope of dX_i/dt under the condition that nothing in the environment is changing except X_j and dX_i/dt. Similarily b_{ik} is the instantaneous slope of dX_i/dt given that nothing is changing except X_k and dX_i/dt. When using a linear approximation as indicated in figure 13, however, we are actually defining b_{ij} as the average slope of the dX_i/dt vs. X_j relationship during the time interval Δt. The units of b_{ij} are the dimensions of dX_i/dt divided by the dimensions of X_j.



Geometrical interpretation of first partial derivatives

$$b_{ij} = \frac{\partial}{\partial X_j}\left(\frac{dX_i}{dt}\right) = \tan \alpha$$

$$b_{ik} = \frac{\partial}{\partial X_k}\left(\frac{dX_i}{dt}\right) = \tan \beta$$

Figure 14.--Geometrical interpretation of first partial derivatives.

Basically, the question being asked of the researcher is: Would a perturbation only in the state of the j^{th} component during the interval Δt have an effect on the rate of change in the i^{th} component? If the answer is no--that is, if it can be concluded that the i^{th} component would change at some average rate, $\Delta X_i/\Delta t$ = constant, regardless of the level of X_j during the time interval Δt (provided that the range of consideration of X_j is within the limits of change that it will undergo during the same time interval)--then $b_{ij} = 0$. But if the answer is yes, then the value of b_{ij} must be estimated.

Estimation of b_{ij} depends on both the state of the environment and Δt. That is, the influence of a change in state of one component (say, soil nutrients) on the rate of change in state of another component (say, biomass density) depends on the age of the biomass (time after treatment) as well as the state of many other environmental components. It also depends on the time interval, Δt, being considered, for the slope of the $\Delta X_i/\Delta t$ vs. X_j relationship will probably be different if Δt = one week than if Δt = 1 year. In this regard, one might conclude that we have not simplified the problem of environmental consequence prediction, in that the values of b_{ij} must be modelled as functions both of time and of the states of all other environmental components. We believe, however, that this approach readily lends itself to more direct understanding of the documented and assumed influences of environmental components on each other, and provides a simple and trackable mechanism for interpreting, integrating, and extrapolating research results and expert opinion.

Obviously, for most decisionmaking purposes, the predicted status of only a few key environmental components over time needs to be displayed. But, if need be, the assumptions used in constructing these relationships--that is, the estimates of the various b_{ij}'s for various time intervals--can be tracked and documented.

We see the above format as potentially useful in research as well as forest management situations. Sensitivity analyses could be made using this type of approach in order to determine which variables need to be studied. And, in multifunctional research efforts, this approach might be used as an organizational planning tool.

Of course, our principal concern is with regard to forest land management decisionmaking, and the integration of knowledge pertaining to the environmental effects of alternative treatments. Ultimately, we can envision computer-assisted procedures whereby the manager needs only to specify the treatment alternatives he wishes to consider, the situation he is planning to treat, and the environmental characteristics he wants displayed over time. Until such time as this can be accomplished, we can only suggest intermediate approaches that might be helpful in integrating and extrapolating research results and professional opinion. The approaches suggested herein are intended to be of this type.

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IMPLICATIONS FOR RESOURCE MANAGEMENT

A PANEL REVIEW

Forest land managers are faced daily with the challenge of making resource management decisions that will facilitate producing a variety of goods and services from forested lands, while avoiding unacceptable environmental impacts. Decisions regarding timber harvesting are particularly important because harvesting and associated activities almost always result in significant changes in the environment. The influences of harvesting on the site can provide the manager with a powerful tool with which to effect desired changes in the ecosystem. Broad multi-resource management objectives relating to stand regeneration, wildlife habitat, watershed management, insect control, and other such concerns are usually dependent upon carrying out closely prescribed timber harvesting activities.

The purpose of the research being reported in this symposium is to provide the land manager with an improved body of knowledge and strengthened guidelines for prescribing the most appropriate harvesting practices. Biological research must necessarily begin by investigating basic environmental responses and cause-and-effect relationships--consequences that will directly affect the production of wood, water, wildlife, and other resources on that site. The manager's ability to select harvesting treatments and to prescribe practices that best satisfy multiple objectives, while avoiding unacceptable impacts, is dependent upon being able to reliably predict consequences of alternative actions.

In the papers that follow, a panel of forest land managers addresses the implications of this kind of research for broad resource management. These individuals represent three major forest land ownership classes in the Northern Rocky Mountains--Federal lands, State lands, and lands managed by large private corporations. Resource management objectives differ somewhat among ownerships, depending upon the expressed priorities and objectives of the respective owner-user groups. For all ownerships, however, land managers are faced with the common task of assessing alternative management strategies, balancing resource use or production against environmental protection and site maintenance requirements, and ultimately choosing an alternative calculated to most nearly satisfy both short- and long-term resource management goals.

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Richard T. Wick

Burlington Northern Inc.
Timber and Land Department

Operations in the timber and land department of Burlington Northern Inc. are organized around the multiple uses of forest lands. Primary emphasis is on the sustained production of forest products under silvicultural, environmental, social, and economic guidelines. Our department, consisting of 157 permanent employees, is essentially split into separate, but complementary, areas of land management, timber management, and administrative services. About 100 of these employees have bachelors or advanced degrees. Besides foresters, specialists in the fields of engineering, wildlife biology, geology, economics, silviculture, and land use planning are represented. Further division is between the Cascades District, which is headquartered in Seattle and covers four separate management units totaling about 400,000 acres (161,880 ha) in western and central Washington and northwestern Oregon, and the Rocky Mountain District, headquartered in Missoula, Mont., and covering seven separate management units totaling about 1,100,00 acres (445,170 ha) in northeastern Washington, north Idaho, and western Montana. Of this 1.1 million acres, about 840,000 acres (339,948 ha) are located in Montana. The management units previously mentioned are the hub of BN's day-to-day operations. Each unit is operated as a separate profit center, with all activities designed to accomplish set goals within guidelines established in annually updated 5-year plans. Annual budgets provide the basis for coordinating the overall activities in the department.

Prior to the development of any forest tract, we go through an extensive in-house planning process. We utilize all available resource management tools, including computers, topographic maps, inventories, field surveys, aerial photos, and so on. Our process begins internally with our departmental land classification system. All lands are classified into one of seven major categories according to their available resources, topography, location, and soil and environmental constraints. All classifications are re-evaluated on an annual basis. Land parcels in certain classes have management limitations imposed which shape the extent to which those lands can be managed. The seven classes are as follows:

1. multiple use class
2. water resource class
3. scenic area class
4. limited use class
5. prescribed development class
6. existing development class
7. quarry mining class

This land classification system is recorded and utilized in two forms: a visual map format, and a computer printout by 10-acre (4 ha) tracts. The land classification system provides us a uniform basis from which to generate specific forest management prescriptions.

All company activities are planned to maintain or enhance resource values and preclude unacceptable environmental impacts. To further assure that a complete job of preplanning has been done and that all foreseeable impacts are considered, we conduct an environmental assessment. This procedure is prepared in a report form entitled "Environmental Assessment Report" or "EAR". This report is completed by a management unit and reviewed by the district level staff. It focuses attention to potential effects any development may have on air and water quality; fish and wildlife; soils and productivity; aesthetics; recreation; historical and cultural resources as well as any legal constraints. Input is solicited from specialists from other agencies, from the company staff, or from outside consultants when additional expertise concerning some aspect of the proposed activity is needed. As part of this process, State fish and game departments are contacted for comments and recommendations.

Following completion of the on-the-ground activities, reviews are conducted to compare actual results with those anticipated in the EAR. We believe that this is not only a useful performance measurement, but also an essential feedback mechanism which allows us to continually re-evaluate policies and requirements.

Although serious environmental impacts are normally prevented by such a check system, some environmental impacts do invariably occur as a result of resource management activities. This is a significant issue which is inherent to the land management field. The important fact is that an evaluation process is in operation to address the costs and benefits of all project proposals.

The nature of our intermingled landownership pattern (checkerboard) with other State, Federal, and private owners provides an additional challenge to how we approach timber harvesting. Such factors as land access, the not-so-complementary relationship of property lines vs. natural physical features and stand components, and external influences of adjacent landowner objectives, all have an influence on how we plan and conduct timber management operations. Being a corporate landowner also has implications in how the public resources such as fish, wildlife, air, and water are managed. We have determined that it is necessary to assume responsibility to help sustain these public values as an obligation of landownership. The company feels strongly that if private owners do not take public values into account when managing lands, then regulatory legislation will be enacted that will then limit the landowner's options and management flexibility.

A continuing responsibility of all department employees is to monitor and evaluate research and technological developments for adaptability to company programs. In addition to the monitoring, we sometimes participate directly in research efforts. Some examples of direct participation are elk-logging studies in western Montana and soils and water research in other areas. Whether our participation is direct or indirect, we believe that resource managers and researchers need to be constantly exchanging ideas to insure the quality of the job getting done on the ground as well as the research being performed.

What, then, are the "Implications For Resource Management" of the environmental consequences of timber harvesting? To answer this, private land managers will most likely have to ask themselves, "What are the consequences of not harvesting?" These two questions set base parameters by which we begin our cost/benefit analyses. We believe the "Implications For Resource Management" question can be summed up in two parts. First, evaluation of the environmental consequences of our activities makes us all much more knowledgeable of the interrelationships of the resources we are managing. We will make better decisions. Secondly, we can make resource decisions with more justification and convictions, although we simultaneously realize that these decisions become more complex every day. For every new parameter or concern that enters the land manager's consciousness, a new series of mental evaluations are performed to weigh advantages and disadvantages of a technique. Such a situation immediately connotes increased costs in performing such analyses. However, we have been and will continue to be, beneficiaries of much more valuable information that will aid us in maintaining our productive land base.

In listening to the presentations, one senses some significant challenges before us in completing the many research hypotheses and verifying their results in the field for use by management. A particular frustration one perceives in listening to the presentations is the apparent conflict that can arise between the resources themselves, the traditional industry practices, the compliance with State and Federal laws, and with public opinion. It is here that the communication channels among researchers, the disseminating agencies, and the land managing agencies are most important, as land managers must thoroughly understand these conflicts and manage them accordingly.

As a private forest land manager in most of the major forest types in the northern Rockies, we place significant importance to research efforts that attempt to characterize these types. It is refreshing to see a comprehensive approach to the research presented here.

The environmental consequence questions will continue to be put before us and it is the quality, applicability, comprehensiveness, understandability, and cost effectiveness of the alternative approaches which will be most useful to us in the forest management profession.

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Chuck Seeley

Champion Timberlands-Champion International

Biological and environmental constraints greatly affect resource management practices used on Champion Timberlands fee ownership lands. The constraints have a positive influence. They serve as guidelines within which I can make management decisions that help to produce timber with a minimum of damage to the environment.

To demonstrate the constraints in action, consider our procedures for laying out a typical logging block:

I. Planning the Timber Harvest

First, the land manager selects a harvesting method or methods that will accomplish the goals he has in mind. He devises a plan that will produce the most efficient and profitable timber harvest, while ensuring that biological and environmental needs of the area are considered and protected. In determining the proper harvest plan for an area, the land manager would consider the following:

1. Is the objective of this sale a thinning for release, a regeneration cut to establish new growth, or a salvage cut to remove dead and dying timber?

2. Is the sale visible from a major highway and if so, can the visual impact of the logging be minimized?

3. Have we minimized the disruption of streams by skid trails or logging debris?

4. Will we create a frost pocket or compact the soil? If so, what are our alternatives?

5. Does the terrain preclude use of certain types of equipment, and which type of logging will cause the least soil erosion?

6. Do the streams, fragile soils, visual impacts, or steep terrain indicate the need to use line machines? (Such machines drag only one end of the log on the ground and thereby minimize skid trail damage.)

II. Writing the Silvicultural Prescription

The second step in harvesting a timber sale is carried out by the district land manager, who writes the silvicultural prescription and then directs the tree-marking crew. The marking crew will be instructed to mark within the directives of the silvicultural plan and to make on-the-ground modifications such as leaving buffer trees around wet draws and springs, leaving trees with birds' nests, or leaving more trees on south-facing slopes where reproduction is slow. High-quality tree marking crews are ensured by requiring that crew members are foresters or forest technicians.

III. Control During Logging

Only a short time period elapses between the sale layout and logging. The district land manager writes the contract specifications for the logger for each logging block. For example, the contract will tell the logger how the area has been marked; the marking that designates trees to be left or cut; the tree cutting technique (shelterwood, seed tree, etc.); and special constraints such as wet draws, springs, skid trail locations, and dens and nests of wildlife. The land manager walks the area with the logger to ensure that the terms of the contract are understood. Most of our contractors have logged for us many years, and because of the close, long-term working relationship with the loggers, we are able to move them into a sale that will best utilize the type of equipment they own. As the blocks are logged, the district land manager periodically checks the area to ensure compliance with the terms of the sale and logging contract.

IV. Cleanup and Regeneration

Finally, when the sale is logged, the district land manager makes sure the resulting slash is disposed of in a manner which will minimize the fire hazard and prepare the site for optimum tree regeneration. For most logged areas this entails burning the piled slash in the spring or fall a year or two after the logging has been completed. While most areas regenerate naturally, some areas will require hand planting with seedlings from our nursery in Plains, Mont. Once a new crop of trees has sprouted and is flourishing, the district land manager and his successor will direct the course of the forest back to a harvestable state through three carefully planned and timed procedures: 1) the precommercial thinning, 2) the commercial thinning, and 3) finally the harvest of yet another generation of trees.

The main advantage of this system is that the land manager works so closely with the forest and the logging operations, that he becomes finely attuned to the cycles and needs of the healthy and productive forest. He quickly learns the techniques which best support a vital forest; in a very short time his silvicultural prescriptions turn into a marked cutting area, and then to a logging area, and finally into an area prepared to begin the growth of the next generation of forest. From this process, with its almost immediate feedback, come the continually refined and tested techinques by which we strive to insure healthy, productive forests.

Biological and environmental constraints also influence road construction. We try not to build more logging roads than absolutely necessary, striving for minimum spacing of a quarter of a mile apart. We also try to lay out roads to take advantage of skyline logging opportunities on steep terrain. This will avoid disturbing streams or sloughs and prevent the logging areas and roads from being visible from major highways. Of course, all roads are constructed to minimize soil erosion. Our policy is to install gates on new road systems entering drainages not readily accessible to vehicles in the past.

Champion Timberlands is involved in several programs to improve conditions for plants and animals in the forests. We are and have been an active cooperator with other agencies and private individuals. By limiting areas to walk-in hunting only, we can improve protection for game animals and provide better hunting for the public. At present, we are involved in the Hoodo, Chamberlain, and Morrison walk-in hunting areas. Also, I am now working with the Montana Fish and Game Department to obtain their help in enforcing individual road closures on old road systems. By doing this, we can provide continuous limited access to drainages rather than having the whole drainage opened or completely closed. Champion has also been extensively involved in the Blackfoot Corridor proposal with the private landowners and the fish and game department to help regulate recreation on the Blackfoot River. Other examples of environmentally supportive actions that occur daily are: leaving snags for birds that nest in tree holes, protecting and limiting logging in areas where bald eagles nest. In one case, we moved a road 200 feet (61 m) downhill to avoid ruining an Oregon junco's nest that had been found on the ground. These are not isolated examples, each forester has his particular wildlife story.

Finally, we work with the Air Quality Bureau to protect Montana's air quality during the fall slash-burning season. This year we are the local airshed coordinators. As cooperators we are required to send in a burning plan that includes section, township, range, elevation, fuel tons per acre and total acres of each burn. The coordinator will be in daily communication with the Air Quality Bureau and will notify groups on days when weather conditions would cause slash burning to create excessive air pollution.

In summary, we at Champion Timberlands are attempting to meet the environmental and biological requirements of the forest in such a way that when new restrictions are necessary, we can assure the public that Champion has already put these restrictions into effect and they are a part of our day-to-day operations.

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Earl Salmonson
Chief, Forest Management Bureau

Department of Natural Resources & Conservation
Division of Forestry

We in the Division of Forestry are responsible for the management of approximately 490,000 acres (198,303 ha) of State-owned forest land. We are also responsible for providing technical forestry assistance to owners of small private woodlands. We have several foresters taking advantage of this symposium, which is an indication of our strong interest in the various papers that were presented.

The Division of Forestry is mandated by State law to protect and manage State lands to provide a sustained income to the trust, as well as to provide for the multiple-use of these lands. We are also mandated by the Montana Environmental Policy Act to provide an environmentally sound program in the management of these lands. Although we currently are applying the results of some of the research presented here, a considerable amount of new knowledge will help us to better manage State lands and fulfill our obligation to the trust.

Several of the papers presented these past 3 days emphasized the need to leave an optimum level of residue on the ground after harvest as a source of nutrients, to maintain and promote soil mycorrhizae, and to promote the presence of beneficial insects.

The papers pointed out the superiority of prescribed broadcast burning to dozer piling and burning for slash disposal and site preparation. Land managers should be doing more broadcast burning wherever it is feasible to do so. Broadcast burning is less disruptive to the land than dozer piling and scarification, particularly in forms of soil erosion and water quality. It also promotes recycling of nutrients, regeneration of browse, maintenance of soil mycorrhizae, and the presence of beneficial insects. Broadcast burning is perhaps the only practical method for slash disposal and site preparation on steep slopes. However, modifying harvest practices to enhance wildlife or aesthetics may increase the difficulty and expense of burning for slash disposal and site preparation.

On State lands timber sales are assessed certain fees to be expended for hazard reduction, site preparation, and reforestation. When these project funds are spent, there are no other sources to finance the work. We have to balance the risk and potential costs with our ability to avoid or control escape fires over the long term with limited funds. In spite of the improvement in technology in the use of fire, occasionally unprecedented freak winds or weather results in escape fires. Weather forecasting must be improved before broadcast burning can be done economically on a broader basis.

Of special interest was Dr. Fellin's presentation on the spruce budworm. I have long felt that spruce budworm spray programs have been something less than successful. With the current high cost of suitable chemicals, spraying is uneconomical and merely buys us a little time. I feel we have to learn to live with this insect and manage our forests accordingly. I believe the answer to the spruce budworm problem is to work towards long-term management to keep the budworm in balance with nature. We will have to expect reduced growth rates and accept a certain amount of losses due to mortality and manage accordingly.

Roger Hungerford's paper, "Microenvironmental Response to Harvesting and Residue Management," also interested me. I have observed situations where clearcutting or heavy cutting practices were applied several years ago on hot dry sites or frost pocket situations. Regeneration did not occur or is extremely slow due to the severe microenvironment created by the harvest. Partial cutting to provide more shade and leaving more debris on the ground would have probably resulted in much more successful regeneration.

Research and education in the past 10 to 15 years has done much to improve our capabilities to predict the consequences of management actions on the various forest resources and values. There is still need for more research to further improve our predictive and management skills to solve the many management problems and avoid mistakes.

It would be impossible to comment on all of the papers that were presented in the time allowed. Many of these papers will require further study and analysis. I am sure that we will integrate a lot of the resource findings into our management program.

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Darrel L. Kenops
District Ranger

USDA Forest Service, Selway Ranger
District, Nezperce National Forest

When evaluating research results and predictive models relevant to my management situations, I ask these questions:

1. Is the research result or predictive model clearly defined and the environmental consequence illustrated? Does the environmental consequence threaten to endanger either long-term or short-term productivity?

2. Does the new information conflict with, or does it compliment, existing information?

3. Is the information sufficient so data and monitoring requirements are clearly understood? Do the district and forest management team members understand the predictive model and its impact?

4. At what level of program implementation is the research result applicable? How should it be included in silviculture prescriptions for stands being entered and managed? How and when do we reflect the environmental consequence in the forest timber management plan?

5. How will it affect the timber growing base, rotation length, and associated resource outputs?

6. Who in the forest and district organizations will be responsible for implementation; and how much time, training, new equipment, and cost is involved?

7. What changes would be needed in sale area improvement plans, timber sales, and silvicultural contracts?

8. How will we include research findings in environmental assessments reports and interdisciplinary team action? Should it be used as a guideline, evaluation or decision criteria, or as a monitoring requirement?

9. How do we include special interest groups, the general public, government agencies, elected officials, and communities affected by implementation of the research result or predictive model?

10. What practices or policies must be changed? For example, how do we leave snags for cavity-nesting birds, yet comply with safety provisions in timber sale contracts?

11. How do we insure that managers will use the information effectively, but drop or replace it when it becomes obsolete?

My experience is that the most valuable information and implications are those that can be applied in reaching management decisions at the project level, involving stand and/or watershed analyses.

Currently we are using the following environmental consequence information to assess timber sale activities:

1. Water yield and its impact on stream channel stability.
2. Cover/forage ratios for elk, deer, and moose.
3. Old-growth management levels, using the pileated woodpecker as an indicator specie.
4. Sediment production and its impact on anadromous fishery habitat.
5. Fuel and fire behavior potentials.
6. Timber growth and yield.
7. Habitat type information for predicting regeneration success and selection of planting stock.
8. Visual quality standards.
9. Road closures and their effect on big game populations.

In reviewing the abstracts of papers presented, I see possibilities for using new information relating to mycorrhizae, soil nutrients (nitrogen), and critical microenvironmental factors, and also possibly expanding use of information now available in fuels management programs. Considering the use of such information also implies that land managers could be collecting new data that require sophisticated equipment and analysis technique. Several papers indicate that broadcast burning is superior to dozer piling in benefits for mycorrhizae, soil and water, and wildlife.

Right now, our use of research findings is fragmentary and uneven. This is due to factors such as 1) the need to develop new environmental consequence information in light of numerous laws; 2) the need to improve interdisciplinary relationships so that comprehensive plans are devised; and 3) the need to assure sufficient time for training, and to implement environmental considerations in timber harvesting plans.

Land managers, silviculturists, and staff people are very willing to adopt and use the results of environmental studies. To assure that environmental consequences are understood and used in designing timber harvesting and other silvicultural activities, however, we need to take several actions. We should support the recommendations of the recent "Forest Service Technology Transfer Workshop" held in Tucson, Ariz., February 13-15, 1979.

We should immediately implement recommendations for refining technology transfer in the "Forest Service Program Planning and Budgeting System" (recommendations 2, 11, 18 and 29). We should then carry out recommendations to include technology transfer in program and activity reviews and to include accountability within the performance rating system for national forest managers, staff officers, and scientists (recommendations 5, 6, 8 and 15). These actions would be in addition to our current efforts to gain understanding through symposia, field trips, and personal contacts.

We also need to develop the recommendations outlined in the Intermountain Forest and Range Experiment Station and Missoula Equipment Development Center special report "Evaluating The Need For Environmental Monitoring To Predict Timber Harvest Impacts" (Hungerford and Babbitt 1976).

The concepts expressed will be useful in formulating silvicultural prescriptions for land management treatments at the stand and watershed levels of decision-making, and will help to provide a framework for gathering and displaying environmental information so it can be of use in silvicultural prescriptions and environmental assessment reports. This framework will also give us the opportunity to explain the complex ecosystems and management activities inherent in national forest programs.

In the future we will see our constituencies use environmental information more extensively in their responses to resource management activities. This will lead to more structured approaches for adopting environmental information into our daily operations. One approach is the executive decision-making as outlined in the Northern Regions's rules and operating procedures (FSM 1206.22C). Inform and Involve plans will be developed more frequently so as to strengthen the understanding and adoption of environmental information. Field tours to sites where environmental consequences are displayed for specific ranger district and forest management teams and specialists will increase dramatically and be more structured and action oriented. The public will also be more involved in visits to such sites.

If we can assure that environmental consequences are understood and displayed, and integrated into the decision-making process in a timely fashion, we will gain a clearer understanding of environmental consequences of timber harvesting and their implications for resource management.

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Reported in this Proceedings are the environmental consequences of applying alternative harvesting systems, silvicultural prescriptions, and utilization standards in coniferous forest ecosystems of the Rocky Mountain area. Although the research has necessarily been site-specific, the results have broad management implications for prescribing harvesting practices to achieve multiple resource management objectives in coniferous forests in general.

KEYWORDS: forest residues, wood utilization, timber harvesting, forest practices

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The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)