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FOREST MANAGEMENT IMPLICATIONS OF PRODUCTIVITY, NUTRIENT CYCLING AND

WATER RELATIONS RESEARCH IN WESTERN CONIFERS

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ABSTRACT

The Western Coniferous Forest Biome was conceived as a multidisciplinary, integrated ecological research program with the forest ecosystem as a whole being the object of study. All research was focused on a set of common research objectives. Primary objectives centered around determining how productivity of coniferous forests was related to their structure and internal biological processes.

Planning and integration of the research project was directed by use of systems analysis methods. Conceptual models of forest ecosystems were developed and used to structure and coordinate the research.

Results of the program are discussed with emphasis on those results having potential use in forest management.

A

INTRODUCTION

About one-third of the land area of the western United States supports coniferous forests of one kind or another. These forests provide an important economic resource for the western states,-not only in terms of timber production but also in terms of grazing, watershed protection, and numerous recreational uses.

A rapidly increasing population in the western states has caused increasing demand for all forest products. Since land area actually under forest is declining, a variety of conflicts have arisen about use and management of these lands. Arguments have revolved around single versus multiple use, balance between various uses, and management schemes best suited to maintaining and/or

^{1/}University of Washington, College of Forest Resources, Seattle, Washington 98195.

^{2/}Oregon State University, Forest Research Lab, Corvallis, Oregon 97331. increasing forest productivity. More recently, fundamental questions have been raised about impacts of widely accepted practices such as clearcutting on environmental quality and long-term forest productivity.

Answering many of these questions requires an understanding of plant communities as functioning ecological systems or ecosystems. For a variety of reasons, much of the earlier ecological research in the western U.S. had not focused on these problems. Thus, there was a deeply felt need, both by researchers and land managers, for a better understanding of how natural ecosystems function.

In response to needs such as this, the International Biological Program (IBP) was initiated in 1964. In this country, the American contribution to the IBP was the U.S. Ecosystem Analysis Program of the National Science Foundation. This program was officially started in 1965 and was organized into five biomes: grasslands, eastern deciduous forest, western coniferous forest, tundra, and desert.

The Coniferous Forest Biome program was the last of the U.S. Biome programs started major research efforts did not begin until 1971. Research by the Coniferous Forest Biome ended in December 1977. The major goal of the Coniferous Forest Biome was to understand the composition, structure, and functioning of western coniferous forest ecosystems and their associated aquatic ecosystems. At the same time, considerable effort was focused on studying the impact of man's manipulation on these ecosystems.

Compared with earlier ecological research efforts, the Coniferous Forest Biome was a large research program. Scientists from many disciplines contributed their talents to studying various parts of coniferous forests with research ranging from studies of tree physiology and soil microbiology to stream and lake ecology and study of organisms living in tree crowns. Researchers were working toward the same objectives and were frequently dependent on one another for critical data. It was this aspect of the Coniferous Forest Biome that made it different from most previous ecological research; the biome was conceived as a multidisciplinary, integrated research program with all research focused on a set of common goals.

In large measure, the Coniferous Forest Biome was successful in achieving its goals. Much was learned about how coniferous forests function. A great deal of the information obtained served to answer questions about the basic ecology of coniferous forests - much of this information is of potential use in forest management. This paper has two primary objectives. The first is to outline the research approach used by the Coniferous Forest Biome. The second is to show how this approach yielded information potentially useful to the forest manager.

CONCEPTUAL STRUCTURE

The Coniferous Forest Biome differed from many earlier ecological research programs in that it was an objective-oriented multidisciplinary, integrated program. Research of this nature required that some unifying structure be imposed on the program. A structured program enabled those persons responsible for coordinating the work of individual researchers to eliminate duplication and divert resources to areas needing additional work.

To accomplish its objectives, the Coniferous Forest Biome made extensive use of a systems analysis technique called modeling both to structure the research and to provide checks on research results. Since modeling played such an important part of the Coniferous Forest Biome research program it seems appropriate to describe what is meant by modeling and to show how it was used to structure the research program.

An ecosystem model can be compared with the schematic diagram of a radio or television set. A schematic diagram shows where the various components are, what they do, their size and flow of electrical current between the various parts. A schematic diagram can also be used to determine effect of outside factors, such as changing station or volume, on the various components and electron flows. An ecosystem model serves the same purpose. It shows where the various ecosystem components are, how large or small they are, describes their function and describes flow of energy, water and mineral nutrients between the various components as a function of time. The ecosystem model also describes how outside factors, in this case the physical environment, influences the flow of energy, water and nutrients between components. Ecosystem models differ from schematic diagrams in one important respect, trees and shrubs grow, resistors and transistors do not. Thus an ecosystem model must also be able to deal with changes in flows of energy, water, and nutrients as a forest ecosystem grows.

The long-term objective of ecosystem modeling is to develop a computer simulation that behaves the same way as a real ecosystem. While real progress has been made in this direction (CFB Modeling group, 1975), computer simulation models capable of dealing with the incredible complexity of forest ecosystems, do not presently exist, nor are they likely to in the foreseeable future.

Models used in integrated ecological research generally represent a compromise between methods available to the researcher and the level of research support. Some flows of energy, water or nutrients cannot be measured with present technology; others can be measured but only at great expense. Ecosystem models must reflect these realities.

The simplest ecosystem model represents an ecosystem as a black box or single compartment (Figure 1). Energy (usually expressed as organic matter), water and nutrients enter the compartment via precipitation, sunlight and soil weathering, and leave at rates influenced by the physical environment and the organisms present. If more energy or water, or nutrients enter the compartment than leave, then it increases in size. In this context,

Figure 1. A simple one-compartment model of a forest ecosystem.



a growing forest represents a net accumulation of energy and nutrients by the ecosystem. Single compartment models such as this are often used in studying the behavior of watersheds, especially in response to various forest management regimes. For example, a number of researchers have described changes in water or nutrient outflow from watersheds following clearcutting and other management practices Fredriksen <u>et al.</u> 1975, Bormann <u>et</u> <u>al</u>. 1969).

While single compartment models are useful in describing the response of an ecosystem to disturbances or changes in the physical environment they are of limited use in explaining why such responses occur. For this it is necessary to examine components and processes occurring within the ecosystem. This requires a more complex model that more realistically describes the structure of the ecosystem.

A first look at the internal structure of a watershed ecosystem would be one that groups the various components into functional groups. Figure 2 is a simple model of an ecosystem in which the various elements are grouped together in compartments according to how they obtain their metabolic energy. In this diagram (derived from study of an old-growth Douglasfir. [Pseudotsuga menziesii] stand) circle size

Figure 2. A three-compartment model of a forest ecosystem.



DECOMPOSERS

CONSUMERS

is scaled to the amount of energy stored in a compartment, the numbers of the arrows are estimates of annual energy flow. Thus an ecosystem can be viewed as being composed of green plants (photosynthetic, primary producers), decomposer organisms (fungi and bacteria) and consumers (grazing animals and their predators).

This model serves as a simple description of processes actually taking place in an

ecosystem. Green plants fix solar energy via photosynthesis and thus are the source of energy for the entire ecosystem. Consumers feed either directly on green plants or on each other while decomposers obtain their energy from dead plant parts reaching the forest floor in litterfall. Other energy pathways in this diagram result from consumers feeding on fungi and bacteria and vice versa. Again, as in the single compartment model, if flows into a compartment are greater than those out, then the compartment must increase in size. Similar models can be used to describe distribution and flow of water and nutrients within ecosystems. A model such as this is a substantial help in outlining research tasks since the required information is represented by the circles and arrows, and the required measurements are clearly defined.

Simple three-compartment models are only a first step in describing the dynamic behavior of an ecosystem. In Figure 2, all of the green plants were lumped together in a single compartment. But for a researcher interested in evaluating the influence of understory vegetation on growth rates of trees, a model that is not structured to distinguish between the two would not be useful.

Figure 3 shows a model structured to deal with energy partitioning among the various vegetative strata of a forest. Note that energy flow pathways between green plants and the decomposer and consumer compartments are the same as in Figure 2. The only difference between Figures 2 and 3 is that the green plant compartment has been expanded to show its internal structure. This sort of expansion can be continued well beyond the

Figure 3. A multi-compartment model of a forest ecosystem.



level shown in Figure 3. For example, the tree new foliage compartment could be expanded to show its internal structure while at the same time remaining linked with other compartments in the figure. Modeling of this sort is termed hierarchical.

However, even a very detailed description of energy storage and flows does not suffice to completely describe an ecosystem or its behavior. Flows of energy, water and nutrients are interdependent and processes in one compartment can influence those in another. For example, photosynthesis is strongly dependent on both the nutrient and water status of a plant (Kramer and Kozlowski, 1960). Similarly, uptake of nutrients by plants is to an extent dependent on use of energy and nutrients by decomposer organisms.

Even a casual consideration of the average forest suggests that a model truly descriptive of its structure would be exceedingly complex. This is one of the reasons that models used by the Coniferous Forest Biome were seldom much more complex than that shown in Figure 3. But, as already discussed, even simple models contribute significantly to solving ecological problems.

This part of the paper is not intended as a course in ecosystem modeling. Rather, it is intended as a description of the approach used by the Coniferous Forest Biome in planning and conducting its research. The remainder of the paper will give examples of how this approach yielded results we feel are of potential use to the forest manager.

EXAMPLES OF BIOME RESULTS

Up to this point, the discussion has centered around how the Coniferous Forest Biome approached the problem of analyzing coniferous ecosystems. Research was focused on examining the structure and function of various parts of the ecosystem. Extensive use was made of conceptual models to structure and direct the research. This research approach was aimed at achieving a number of specific objectives related to understanding growth, productivity and stability of forest ecosystems and how they relate to the physical environment. Among these objectives were answering questions such as: How is forest productivity related to the physical environment? How is forest production related to soil nutrient status? How does a disturbance such as clearcutting affect site productivity? Answers to these questions can made important contributions to management of commercial forests. For example, knowning how forest productivity is related to the physical

environment could lead to a system for classifying productivity of forest lands from climatic, topographic and soils information. Knowing how nutrition influences productivity could lead to precise and predictable fertilizer applications. Knowledge of nutrient losses resulting from harvest and other forest operations could result in practices aimed at maintaining site productivity over the long term.

PRODUCTIVITY RESEARCH

Two of the fundamental components of a forest are its foliage and fine roots. Photosynthesis occurring in the leaves provides the simple sugars which are later synthesized into wood, bark, leaves and roots. On the other hand, the fine roots obtain from the soil the water and nutrients required for continued photosynthesis. In a purely biological sense, wood and bark are simply the pipes connecting roots to foliage.

Photosynthesis occurs at the surface of a leaf or needle (Kramer and Kozlowski 1960). Thus the amount of photosynthesis occurring in an ecosystem is related to the amount of leaf surface area exposed to sunlight. Other things being equal, the more leaf area an ecosystem can maintain, the more photosynthesis it can carry on. Recent studies in Arizona (Whittaker and Niering 1975) have shown that net production by coniferous forests is related to their leaf area. Studies conducted by the Biome have confirmed this and shown close correlation between stem growth of actively growing young conifer stands and total leaf area of those stands (Gholz and Grier 1978). Moreover, another Biome study showed that in stands whose leaf area was reduced by wind damage, productivity was decreased in direct proportion to the lost leaf area (Grier 1977). Clearly the leaf area of a stand is an important factor in its productivity. Sites capable of supporting a large leaf area would be more productive than those supporting smaller leaf area.

When a stand is first established and begins growing it steadily expands its leaf area. But, as the trees get larger, the rate of leaf area expansion decreases until it reaches a plateau. After reaching this plateau level, stand leaf area remains more-or-less constant throughout the life of the stand. This has been shown for both hardwoods (Marx and Bormann 1972) and conifers (Kira and Shidei 1967). Research by the Biome has confirmed this pattern in Douglas-fir stands of the Pacific Northwest (Turner and Long 1975). Figure 4 shows a typical pattern of leaf area development with age in Douglas-fir stands in western



Oregon. The maximum leaf area of a stand and the rate at which that leaf area is achieved is related to a number of factors. Among these are climate, soil, nutrition, species, and initial stocking of the stand.

The major factor influencing maximum leaf area appears to be the site water balance. Research by Biome scientists has shown stand leaf area to be primarily related to site water status (Gholz et al. 1976, Waring et al. 1978). One study showed a linear correlation between a growing season balance of evapotranspiration and soil water and stand leaf area (Grier and Running 1977). Figure 5 shows this relationship.

Figure 5. Relation between total stand leaf area and available water index for some western coniferous forests.



The climate of the Pacific Northwest includes a summer dry period commonly lasting from late spring to mid-autumn. This dry period coincides with the growing season. This means that water required by forests for growth and survival through the summer is provided mainly by water stored in the soil at the beginning of the growing season.

Gas exchange for photosynthesis occurs through small aperatures in the leaf called

stomata. Evaporation from leaves also occurs mainly through these stomata. Trees can control water loss by closing the stomata but this stops photosynthesis. On sites where evaporation of water from leaf surfaces during the growing season is greater than water stored in soil, the stand must strike a balance between maximizing photosynthesis and maintaining a suitable internal water status. This balance is struck more-or-less automatically by death of less competitive trees in the stand. Normal growth of a stand in the early growing season causes leaf area to overshoot levels the climate can support. As soil water levels become low later in the growing season trees react by closing their stomata. This halts photosynthesis without stopping other necessary life processes of individual trees. These life processes are sustained by photosynthate reserves stored in trees. If the reserves of a tree are exhausted the tree dies lowering total stands leaf area. Weaker trees have smaller reserves thus are more likely to die than the dominant trees in a stand. This is one of the reasons for a continuing decline in stand density with increasing tree size.

Other factors also having a potential influence on maximum leaf area are winter water balance and nutrient deficits or imbalance (Waring et al. 1978) and mechanical damage by wind or snow (Grier 1977).

Nutrition

Rate at which a stand achieves maximum leaf area for a given site (canopy closure) is an important factor regulating stand productivity. Peak production by a stand occurs at canopy closure - management practices which hasten canopy closure also hasten the point during a rotation at which maximum production is achieved.

Biome studies have shown the rate at which a forest canopy closes on a given site is related to three primary factors: 1) initial stocking density, 2) soil nutrient status, and 3) competition from brushy and herbaceous species. The influence of brush competition on tree growth is obvious - seedling growth is suppressed by heavy competition for light, water and nutrients. In some parts of the Pacific Northwest, reliable stand regeneration is virtually impossible without pre- or post-planting herbicide treatment (Newton 1978).

The influence of initial stocking density on canopy closure rate is relatively straightforward. In a stand with low initial stocking each individual tree contributes a relatively large proportion of the total crown. The time required for each tree to develop its proportion of the total canopy is greater than in a dense stand where much less growth is required before between-tree competition begins. Figure 6 (from Turner and Long 1975) shows the influence of stocking density on the time required for canopy closure in low-site Doulgasfir stands. The influence of stocking density on rate of canopy closure is obvious in this diagram.

Figure 6. Leaf biomass development in Site IV Douglas-fir stands in relation to initial

stocking and stand age (Turner and Long 1975)



Nutrition is another important factor influencing the rate of canopy closure and, at least over the short-term, leaf area. Foliage of a tree contains large amounts of nutrients. Figure 7 shows the amount of nitrogen contained in foliage of old- and younggrowth Douglas-fir stands relative to other parts of the stand. For a stand to reach

Figure 7. Nitrogen distribution and pathways of nitrogen movement in a 37-year-old (A) and a 450-year-old (B) Douglas-fir stand(kg/ha).



maximum productivity it must take up enough of the various nutrients required to develop a full canopy. A part of the nutrients required to grow a year's new foliage and increase canopy each year are supplied by the soil--the remainder are translocated to the new foliage from older parts of the tree. If nutrients are only sparingly available from the soil, then the amount translocated from older tissues is large, if nutrients are readily available then translocation is small. Thus translocation serves to conserve within the tree nutrients that are in short supply.

In spite of translocation, if nutrients such as nitrogen are in short supply, amount of new foliage that can be produced each year is less than could be produced if nutrients were more available. Hence, rate at which a full canopy can develop is in many cases limited by the rate at which nutrients are made available to the trees.

Even a short-term change in nutrient availability can have a dramatic effect on forest canopy. One Biome study involved changing nitrogen availability in moderately nitrogen-deficient stands and observing the results (Turner 1975). In one treatment, nitrogen fertilizer was applied to increase nitrogen availability. In another treatment, sugar and sawdust were spread on the forest floor to tie up nitrogen. Instead of the normal loss of older foliage from each tree, the stand that was treated with fertilizer had no leaf litterfall that autumn. In contrast, the stand treated with sugar and sawdust lost two years of foliage rather than the normal one year's foliage.

The reasons for this behavior are related to ability of trees to translocate nitrogen. In the stand treated with sugar and sawdust soil nitrogen was so deficient that almost all of the nitrogen incorporated in new foliage was translocated from the two oldest years of foliage of each tree. In fact, so much nitrogen was removed from older foliage that it died. In the fertilized stand, enough nitrogen was available from the soil that little or no translocation was needed for new foliage. Thus the older foliage was able to retain its nitrogen and remain alive.

Clearly, nutrition is an important factor in production. As noted, nutrition regulates to a large degree rate of canopy closure. Also, changes in nutrient availability can have dramatic effects on leaf area of a stand. Moreover, foliage containing adequate amounts of nutrients is more efficient at photosynthesis than foliage deficient in one or more essential nutrients.

Probably the most important single factor in mineral nutrition of forests is availability of nutrients to trees. The whole subject of factors influencing nutrient availability was one of the major areas of biome research. Much

of the research in this area is difficult.

Forests may have large amounts of the various plant nutrients present but because they are not in proper chemical form they are not available to the trees.

For a tree to take up nutrients, nutrients must generally be in ionic form. An ion is an atom or group of atoms that carries a positive or negative electric charge. Mineral nutrients required in relatively large amounts by forests and their ionic forms are nitrogen (NH $_{\pm}^{+}$ and NO₃), phosphorus (PO₄⁻²), sulfur (SO₄⁻²), calcium (Ca⁺²), magnesium (Mg⁺²) and potassium (K⁺). In most forest soils amounts of these elements present in ionic form at any one time are limited. Large part of a forest's nutrient requirements are met by recycling of nutrients previously taken up by the stand.

Figure 8 shows the pattern of nutrient cycling in a young coniferous forest ecosystem studied by the Biome. Nutrients in ionic form are taken up by trees and incorporated into organic compounds in various parts of the tree. Eventually parts of trees Figure 8. Nutrient cycling in a coniferous



or even whole trees die and fall to the soil surface as litterfall. Some nutrients are also washed from trees to the soil by rain. In general, nutrients reach the soil surface via litterfall or crown-wash combined in organic matter and must be converted to ionic form before they can be taken up by trees. In this process decomposer organisms play a major role. In a collection of processes called nutrient mineralization, decomposer organisms break down organic matter using it as an energy source. In doing so they utilize some of the nutrients in organic matter for their own life processes. During this process nutrients are also released in ionic form into the soil solution where they can be taken up by trees.

Nutrient mineralization is largely influenced by climate and litter composition or quality. Some of the more important results of Biome research concerned the influence of litter quality on nutrient mineralization. Forests produce a variety of different kinds of litter ranging from tree needles to whole logs. Nutrient concentrations in these materials are more-or-less inversely proportional to size (Table 1).

Table 1. Average nutrient concentration in various components of Douglas-fir trees from a productive stand in western Oregon (Grier, unpublished data).

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Component	N	Ρ	ĸ
Needles	1.1	0.15	0.30
Twigs	0.3	0.07	0.15
Branches	0.12	0.01	0.03
Stem	0.10	0.01	0.02

Needles have high nutrient concentrations; whole logs have low nutrient concentrations." Organisms that decompose litter require nutrients. Materials with high nutrient concentrations, such as needles, will decompose more rapidly than nutrient-poor materials such as wood. Decomposer organisms also compete with trees for nutrients. If nutrients are readily available to decomposers - as they are in needles - then competition between trees and decomposers for nutrients is not intense. However, if there is an abundance of nutrient-poor woody material in the litter then competition for nutrients can be intense. For example, Biome researchers have shown substantial uptake and immobilization of nitrogen by decomposers inhabiting woody material such as branches and fallen logs (Cromack et al. in press, Grier 1978). These observations imply that addition of woody residues to a forest ecosystem by precommercial thinning or a harvest operation could serve to reduce the availability of nutrients while the material is decomposing. This could serve both to reduce nutrient losses by leaching and reduce mutrient availability for residual trees or seedlings.

Even in undisturbed forests, woody residues have an influence on nutrient availability. Biome researchers have shown substantial shifts in the amount of woody litter produced by coniferous forests. In a 22-year-old Douglas-fir stand only 4% of litterfall was woody material in contrast to about 50% in a 95-year-old stand (Turner 1975). In a 450year-old Douglas-fir stand 80% of annual litterfall was woody material, much of it in tree stems (Grier and Logan 1977). Shifts such as this, in composition of litterfall have a substantial impact on nutrient availability. Studies of decomposition of Douglas-fir needles by Biome researchers show that decomposition and nutrient mineralization rates in Douglas-fir stands peak at time of canopy closure and decline thereafter (Figure 9). Prior to canopy closure, rates

Figure 9. Annual weight loss of Douglas-fir needles in stands of various ages. (Edmonds, in press).



are lower probably because of low moisture and higher temperatures under relatively open canopy. Decline after canopy closure appears to be due to the presence of increasing amounts of nutrient-poor woody material.

Mainly because of nutrient requirements of growing trees and active decomposers, undisturbed coniferous forests are strongly conservative of nutrients that are present in limited amounts. Nitrogen is the most general example of a nutrient limiting forest production. Studies during the Biome have shown that undisturbed coniferous forests of all ages in the Pacific Northwest actually are accumulating nitrogen at rates averaging about 2-4 lb/acre/year (Fredriksen 1972, Cole and Gessel 1965). Nitrogen enters these ecosystems either in rainfall or by nitrogen fixation. Main sites of nitrogen fixation are fallen logs and lichens (Pike et al. 1977). In undisturbed forests, small losses occur, primarily by leaching, although wild fires can cause large nitrogen losses (Grier 1975).

EFFECTS OF DISTURBANCE

If undisturbed forest ecosystems are highly conservative of limiting nutrients, what would be the impact of a major disturbance such as clearcutting on nutrient retention? This question has caused a great deal of controversy in many parts of the U.S. Earlier work (Cole and Gessel 1965, Fredriksen et al. 1975) has shown the impact to be relatively small for coniferous forests in the Pacific Northwest. But because clearcutting is such a major restructuring of a forest, part of the Biome research aimed at measuring losses and examining processes responsible for nutrient conservation after harvest.

Watershed 10 on the H. J. Andrews experimental forest was one of the intensive study sites of the Coniferous Forest Biome. It supported a 450-year-old Douglas-fir stand until it was clearcut in 1975. Response of the watershed to clearcutting was studied through the end of the Biome program at which time studies were continued under other funding. Part of the results of this study will be discussed in another paper in these proceedings (Swanson and Sedell).

Results of the first year of this study confirmed those of earlier studies: that nutrient losses from the watershed were relatively small. Largest loss of nutrients occurred the first winter after harvest when high streamflow from winter storms washed large amounts of nutrient-containing logging residues from stream channel. In spite of large volumes of debris being removed from the watershed, nutrient losses were relatively small. For example, total nitrogen losses the first year were about 10 lb/acre.

Clearcutting caused no increase in dissolved nutrient loss the first year. Total losses the second year after harvest were markedly lower than those of the first year since stream channel had already been cleaned. Dissolved nutrient losses however were slightly above those of the first year. Most of this increase was in the form of nitrate and dissolved organic nitrogen.

Although this study is still in progress early results point to several factors responsible for conservation of nutrients by this disturbed ecosystem. These factors appear to be 1) large amounts of woody residues left on the site especially in root system, 2) rapid recovery of understory vegetation on site due to absence of slash burning, 3) nutrient uptake by riparian zone vegetation, 4) large nutrient retention capacity of soil.

In general terms, two prime factors appear to be involved in nutrient conservation after disturbance. The first is the innate ability of the soil to retain nutrients against leaching. This is related mainly to the physical properties of soil and as such is not amenable to modification in forest management. The other factor is continued nutrient uptake by resurgent understory vegetation and microorganisms inhabiting the decomposing woody residues. Table 2. Examples of total nitrogen loss from forest ecosystems due to various disturbances.

Treatment	Undisturbed	Clearcut only	Slash-burned clearcut	Intense wildfire
Forest type	Douglas-fir	Douglas-fir	Douglas-fir	Ponderosa pine, Douglas-fir
Age	450	42	42	>150
Total nitrogen loss (lb/acre)	-0.51/	130 ^{2/}	325 ^{3/}	8004/
Loss as % of eco- system total	NA	3.8	9.5	27
Mechanisms of loss ^{5/}	Accumulation, no loss	 tree stem removal, leaching 	 volatilization tree stem re moval, leaching 	 volatilization tree stem re- moval,

1/Fredriksen 1975
2/
Cole and Gessel 1965, Cole, Gessel and Dice 1967
3/Grier 1972, Cole, Gessel and Dice 1967
4/
Grier 1975
5/
Mechanisms of loss are listed in decreasing order of importance

Table 2 summarizes results of some of the Biome studies of the effect of disturbance on ecosystem nitrogen status. These results are a synthesis both of studies on nitrogen cycling and distribution and of various mancaused and natural disturbances. Values listed are the result of case studies. As such, variation around the amount and percent of nitrogen loss can be expected.

For the clearcut and clearcut-slash burn a major pathway for nitrogen loss was tree stem removal. Variation in this pathway is related mainly to the amount of tree stem removed. Figure 7 gives some indication of the differences that might be expected between small-young and large-old stands.

The major pathway of nitrogen loss from slash-burned clearcut was by volatilization of nitrogen in fire. The magnitude of this loss is primarily related to amount of fuel actually consumed. Most of the nitrogen in slash is contained in branches and foliage. (Figure 7). Forest floor material, another fuel, also contains considerable nitrogen (Figure 7). A severe fire could conceivably result in loss of much of this nitrogen from the ecosystem. For old-growth forest described in Figure 7 loss approached 600 lb/acre. Even so, loss would be less than has been observed in a naturally occurring wildfire. In all cases, leaching losses of mitrogen were small compared with other losses.

MANAGEMENT IMPLICATIONS

It is difficult in a short paper to deal with the full range of potential management implications of a program as large and complex as the Coniferous Forest Biome. One reason is that the results of many of the Biome studies are still being evaluated and synthesized. Thus the picture of scientific progress by the Biome is not yet complete. In spite of this, it appears as though research by the Coniferous Biome will make a number of important contributions to the scientific basis for land management.

Some of the contributions are indirect. Problem-solving methods and analytical tools developed by the Biome are being incorporated into the training of young foresters. At the same time, scientists who have learned to deal with structure and function of ecosystems are now addressing themselves to specific problem areas of forest management.

Direct contributions of Biome research to our understanding of the function of forests have been far ranging. Another paper in this section describes studies of the influence forests have on streams and on stability of physical landscape. Other studies have clarified the processes involved in regulating nutrient availability. Overall, studies by the Coniferous Biome have resulted in a clearer, more rigorous description of the forest structure and the processes responsible for forest growth and development. The implications of Biome research for forest managers evolve from a clearer understanding of how forests grow and mechanisms by which management influences their growth. Studies of forest productivity may point the way for research resulting in more accurate classification of the production potential of forest sites and ability to predict growth response to various thinning regimes.

Research in forest nutrition has yielded a clearer understanding of the relation between growth and nutrition. Further research in this area could easily result in 1) the ability to predict growth response to fertilizer applications, or 2) develop management techniques that can increase nutrient availability without the need for fertilization.

As research results from programs such as the Biome's begin to be directly applied to silvicultural problems, new methods of assessing site potential and forest growth will probably emerge. The forester of the future will likely be as familiar with the meaning of plant and soil analysis, degree days and rainfall patterns as agronomists are today.

But in the future, forests will be even more of a crop than they are today. Maintaining consistently high yields from these forests will require the best available information on factors influencing growth of this crop.

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