AN ABSTRACT OF THE THESIS OF

Richard P. Summers for the degree of Master of Science

in Forest Engineering presented on July 30, 1982

Title: Trends in Riparian Vegetation Regrowth Following Timber Harvesting in Western Oregon Watersheds

Abstract approved: Henry A. Froehlich
Dr. Henry A. Froehlich

This study investigated the development of riparian zone vegetation at varying stand ages from one to 29 years following clearcut timber harvesting in western Oregon. Vegetation was classified into three layers for observation including the ground (less than 13 cm), the understory (less than 2.5 m), and the overstory (greater than 2.5 m) layers. Variables observed included cover by vegetation types, vegetation directly overhanging the stream channel, canopy density and angular canopy density (an effective estimate of stream shade).

Five vegetational zones as presented by Franklin and Dyrness (1973) were selected for study. The primary sampling unit for this study was the transect with ten transects at each site located along the stream reach. A site in an unmanaged old growth stand in each zone was measured in the same manner to provide a comparison with the several harvested sites. A total of 40 sites were sampled during the course of the study.

Equations relating the development of angular canopy density (ACD) with the period since harvesting are presented for each of the five vegetation zones. These equations may be used to predict the percent ACD within a given zone for a proposed time period which may be useful to the resource manager in harvest planning. In three of the vegetational zones, seventyfive percent ACD can be expected in eight to 20 years following harvesting. The maximum ACD value observed in two of the zones averaged approximately 60

percent in the 29 year period since harvesting.

Depending upon the vegetation zone, deciduous cover provided approximately 40 percent cover in the understory layer after a period of three to 14 years. Litter cover (organic material greater than 1 mm in diamter) generally dominated the ground layer at all the harvested sites with approximately 45 percent of the ground surface in that cover type. Coniferous vegetation was generally less than 20 percent in both the understory and overstory layers during the two and one-half decade period since timber harvesting.

The tendency for the riparian zone to develop dense corridors of deciduous vegetation at some sites was noted. In terms of the number of stems per acre, some Alnus rubra corridors in the Coast range zones were ninety times more dense than the unmanaged forested sites in that area. In contrast, the high elevation Cascade range zone only had 40 percent of the unmanaged forested site stand density after a period of 19 to 24 years following harvesting.

The large organic debris loading in the harvested streams was generally lower than in the unmanaged forested sites. The LOD load averaged 13.4 pieces per 100 feet (30.5 m) for the five forested sites. The harvested sites had an average of only 10.4 pieces. A few harvested streams had unusually high loadings while 77 percent of the streams contained less than the forested streams.

ACKNOWLEDGMENTS

I would like to express my appreciation to Drs. Henry Froehlich, Robert Beschta, Susan Stafford, and Paul Adams for their help and suggestions made during the course of this study.

Special thanks go out to all the TRI data managers at the many U.S.F.S. ranger districts I visited while looking for sites. Bill Henry of the Hebo district deserves special mention for his tireless efforts to help locate Coast range sites.

Thanks to Frank Gaweda who provided field assistance at some nasty, dense Coast range sites.

Ultimate thanks go to Laurie Summers who tirelessly (moreso than myself at times) collected data at nearly all the sites during her summer break from teaching school, corrected manuscripts, prepared tables and graphs and made me laugh and go fishing occasionally during this research.

Finally, I'd like to thank my father who taught me to love wildland streams and both my parents for providing me with the integrity and skills to complete this research.

APPROVED:

Professor of Forest Engineering in charge of major

Head of Department of Forest Engineering

Dean of Graduate School

Date thesis is presented July 30, 1982

Typed by Donna Lee Norvell-Race for Richard P. Summers

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Trends in Riparian Vegetation Regrowth
Following Timber Harvesting in
Western Oregon Watersheds

I. INTRODUCTION

The riparian zone is an important component of small headwater streams in the Pacific Northwest. Structure and composition of riparian vegetation are dominant factors influencing both structure and function of stream ecosystems. Vegetation is this zone produces detrital debris which provides the majority of the energy base in these small heterotrophic streams. The plant cover cycles nutrients, provides bank stabilizing protective cover, provides shading to control stream temperatures, provides fish habitat cover, acts as a filter to reduce sediment and debris from management activities from entering the stream, and is a primary source of large organic debris for the stream ecosystem.

The numerous small streams in western Oregon forested lands that may be subjected to the impacts of timber harvesting requires that the relationship between the riparian vegetation and the stream system be well understood. Harr (1976) defines small streams as those of stream orders 1, 2, or 3. He conservatively estimates that there are 250,000 small stream segments in western Oregon which collectively drain more than 80 percent of the forested acreage.

The rate of riparian vegetation regrowth following a disturbance such as harvesting has been of interest to scientists and resource managers for some time. As early as 1936, Saurer made a call for natural recovery rates of vegetation to be observed and documented. Steinblums (1977), in his work on the effectiveness of buffer strips to control stream temperatures, noted that the rates of riparian regrowth are not well understood and suggested future research on this topic. Lisle (1981) while working on the recovery of aggraded stream channels found that he could not assess when channels would recover from severe flood flows without knowing the duration of establishing riparian vegetation on the channel margins.

Improved knowledge about the rate of riparian vegetation regrowth can aid the resource manager with long-term and on-site harvest plans and will provide a framework from which the scientist can identify a given stage of development and conduct his research accordingly.

Study Objective

The objective of this study was to document the rate of riparian vegetation regrowth following clearcut timber harvesting along small streams in western Oregon. Specific objectives are as follows:

1. To stratify the Cascade and Coast ranges of western Oregon into zones where riparian vegetation regrowth would follow similar patterns.
2. To document the condition in riparian vegatation at sites with various time periods since the harvesting impact.
3. To develop equations describing the rate of stream shade development following harvesting as a function of the period since harvesting.
4. To document several physical stream characteristics which may be affected by timber harvesting.

II. THE RIPARIAN ZONE

Definition of the Riparian Zone

The riparian zone has historically been thought of as that zone of vegetation that requires free or unbounded water and riparian vegetation defined as vegetation rooted at the water's edge (Hobbs, 1981). Bowman (1975) referred to a stream corridor which was defined as that area occupied at high flow. More recently, the emphasis of the riparian zone has focused on the riparian zone as a functional link or interface between the terrestrial and aquatic environments.

Meehan and others (1977) defined the riparian zone from a functional perspective. The Meehan definition includes all extra-aquatic vegetation that directly influences the stream environment. Another view of the extent of the riparian zone influence includes approximately the area upslope from stream center to a distance equal to the height of the tallest tree in the stand (Cummins, personal communication). The rationale for this definition is that organic inputs can easily occur from this distance and that large wood is the most important stabilizer for stream and zone structure in forested, mountainous streams.

Campbell and Franklin (1979) identify what they term the riparian break as the border of the riparian zone. This break is the point beyond which shrubby vegetation no longer interacts with the stream. This point is frequently identifiable by a change in slope, a pile of debris, the top of a cliff, a change in vegetation or an abruptly more xeric community. They further classify the zone into three subzones parallel to the stream on the basis of habitat and function. These subzones are: the active zone, the border zone, and the outer zone. The active zone is subject to annual stream flow and includes any area from which vegetation could fall directly into the stream at high flow. Plants in this zone are permanently placed, but the water-covered area expands and contracts such that a portion of the streambed is sometimes active and at other times not. The border zone includes any area from which organic inputs such as leaves and debris can reach the stream after some delay. Dissolved and suspended material wash into the stream and surface creep can be a source for larger particles. The outer zone is defined as that area within the riparian influence from which leaves cannot reach the stream due to topography or vegetation, yet vegetation still influences the stream either directly or indirectly. The authors note that any single plant can occupy two or possibly all three subzones. As an example, *Acer circinatum* may be rooted well upslope in the border zone yet still overhang the stream in the active zone. They also observe that the riparian break will be located further from the stream in a stand with a developed overstory relative to the same stand in an open condition. Therefore, the riparian zone tends to be narrowly confined in clearcut stream sections and somewhat broader in mature stands.

From these definitions it is clear that the riparian zone is not static and that this dynamic corridor changes with time as the development of streamside vegetation proceeds. Therefore, any examination of the riparian zone must begin at the functional level and consider the stage of development and character of the streamside vegetation in order to accurately establish the limits of the zone. In addition, a designated streamside management zone of a standard width is not the optimally preferred management unit.

Stream Size and the Relative Intimacy of the Riparian Zone

The relative importance of the influence of the streamside vegetation on the stream environment is strongly related to stream size. The river continuum concept as proposed by Vannote and others (1980) describes the stream system as a continuum from the headwaters to the mouth. They propose that the biological organization in rivers conforms structurally and functionally to the kinetic energy dissipation pattern of the physical stream system. The physical stream variables follow a continuous gradient from headwaters downstream and the biology of the stream follows this continuum by rapidly adjusting to any changes in the redistribution of the use of kinetic energy by the physical system. In light of such a concept, the authors propose that streams can be roughly grouped into headwaters (orders 1-3), medium-sized rivers (orders 4-6), and large rivers (orders greater than 6).

Headwater streams represent the maximum interface with the terrestrial environment. They tend to be strongly influenced by riparian vegetation, have primary production to community respiration ratios (P/R ratios) of less than one, are dominated by coarse particulate organic matter (CPOM), and have distinctly fewer grazer-type stream invertebrates than autotrophic mid-sized streams. These streams, in an unperturbed state, are heavily influenced by the riparian vegetation which reduces autotrophic production by shading and contributes large amounts of allochthonous detritus. These small streams can be considered to be predominantly accumulators, processors, and transporters of materials from the terrestrial environment.

As stream size increases, the reduced reliance upon terrestrial organic inputs for the stream energy base coincides with increasing reliance on autochthonous primary production and organic transport from upstream. The change from heterotrophic headwaters to autotrophic medium-sized rivers is considered to be where the ratio of gross primary productivity to community respiration changes from less than one to greater than one. This generally occurs in about third-order streams. The authors caution that this is a generalized scenario and that in extreme environments the transition from heterotrophy to autotrophy may occur in even first-order streams (e.g., at high elevations where riparian vegetation may be sparse).

Meehan and others (1977) also emphasizes the importance of the riparian vegetation to headwater streams. The ratio of the area of river bottom to the length of streambank is a measure of the influence of the riparian vegetation on the system. Headwater streams are maximally influenced by riparian vegetation as indicated by a high shoreline to stream bottom ratio when compared to larger stream systems. Again, the authors report that the change from heterotrophy to autotrophy usually occurs in the third- to fourth-order streams.

Even within the broad class of headwaters, streams can be characterized to some degree by their stream order. First-order streams are typically small, rich in debris, and very steep with a stairstep type series of small pools created by accumulations of organic debris separated by small falls or cascades (Campbell and Franklin, 1979). They also tend to be totally dominated by the forest canopy. Second-order streams are somewhat larger with a more gentle gradient and usually have less debris accumulation which allows a relatively freer flow. Third-order streams are large enough to influence the terrestrial environment and create and maintain open spaces in the forest canopy. The stream gradients are typically less than the smaller order streams and organic debris remaining in the channel must be very large in order to stay in place during the high winter flows experienced by these reaches.

Recognizing the importance of the riparian zone in relation to small headwater streams, it is interesting to further note the importance of small headwater stream upon the entire stream system. Harr (1976) defines small headwater streams as those of stream orders 1, 2, and 3. He conservatively estimates that there are 250,000 small stream segments in western Oregon which collectively drain more than 80 percent of the forested acreage. Leopold and others (1964) report that the extensive networks of small first- to third-order streams make up approximately 85 percent of the total length of running waters. Platts (1979) concluded after a study of the south fork of the Salmon River in Idaho that first- and second-order comprised 78 percent of the total stream mileage. He also noted a relationship between stream order and the number of fish species, total numbers of fish, summer water space for fish, and several stream morphology variables. Christner (1981) reports that over 50 percent of all stream miles on the Willamette National Forest in western Oregon are less than 15 feet in width. Due to the relative importance of riparian vegetation on first- through third-order streams and the relative abundance of these channels, this study was restricted to streams of orders 1, 2, and 3.

III. FUNCTIONS OF RIPARIAN VEGETATION

Overall View

Riparian vegetation plays an important role in the quality of the aquatic habitat. In western Oregon, this vegetation consists of herbaceous ground cover, shrubby understory, deciduous understory or canopy, and coniferous canopy vegetation. The functions of the riparian vegetation as they relate to aquatic ecosystems can be classified according to the location of the vegetation relative to the stream as presented by Meehan et al. (1977). The above channel, above-ground vegetation (canopy and stems) function to control stream temperatures (and thus, primary productivity), provide a source for large and fine plant detritus, and provide a source of terrestrial insects utilized by anadromous and resident fish populations. Large organic debris in the stream channel derived from riparian vegetation functions to control routing of water and sediment in the channel, shape aquatic habitat by providing pool-riffle sequences and stream cover, and provide a substrate for biological activity. Vegetation at the streambank creates a root mat which increases bank stability and provides cover in the form of overhanging banks. Stems and low-lying canopy on the floodplain tend to retard movement of sediment, water, and floatable organic debris during flood flows.

The removal of streamside vegetation as the result of clearcut timber harvesting can significantly alter the aquatic habitat. Likes and Bormann (1974) stress the importance of the linkage between the aquatic and terrestrial ecosystems and discuss the need for land managers to consider the various influences of the terrestrial ecosystem on the aquatic habitat when making management decisions. For example, the authors cite the response of nutrient cycles to disturbance to the terrestrial environment.

Mature terrestrial ecosystems tend toward a steady state where the transport and erosion of particulate matter and dissolved substances are kept at a minimum. The distrubance of the terrestrial environment can significantly accelerate the ecosystem output of particulate and dissolved substances and thus, the input to the aquatic ecosystem.

Cline and Swanson (in press) also stressed the importance of the hillslope terrestrial environment upon the riparian zone. After noting that hillslope revegetation controlled the frequency of landslides that caused debris torrents, they concluded that timber management of the hillslope zone is effectively management of the riparian zone and that hillslope management must be designed and carried out to be sensitive to both terrestrial and aquatic ecosystems. The functions of the riparian vegetation and the influence upon the stream habitat are complex and are just recently being explored in detail. The following discussion on the functions of riparian vegetation is by no means exhaustive, but it should acquaint the reader with the importance of the various roles of the streamside vegetation.

Energy Base of Small Streams

Fischer and Likens (1972) report that 99 percent of the energy input for a first order stream is derived from allochthonous sources while only one percent is the result of primary production within the stream. A study of two small streams in the Oregon Cascade range showed similar results with 99 percent of the particulate organic input resulting from detritus or litter, and one percent or less contributed by primary production (Sedell et al., 1974). In both studies, it is estimated that two-thirds of the detrital inputs were processed within the stream while only one third was exported downstream. Meehan and others (1977) estimate that only 18-35 percent of the organic inputs are flushed downstream to higher order streams and emphasized the highly retentive nature of these small streams. These data indicate that small headwater streams are significant detrital processing units and not simply conduits whereby stream inputs are transported downstream. The Oregon study indicated that organic matter entering the stream by lateral movement from the bank was one and one-half the direct litterfall input.

A study from the Coniferous Forest Biome (Edmonds, 1974) investigated the changes in stream production between a forested and clearcut section in an Oregon Cascade stream. The resulting data indicated that mean algal colonization rates (a measure of autotrophic production) were approximately two times greater in the clearcut section than in the forested section. This increase in algal production was also accompanied by an increase in the standing crop of grazing-type aquatic insects, a four-fold increase in insect emergence, and increase in the mean size of emergence insects (0.86 mg in the clearcut versus 0.54 mg in the forested section), and an increase in the numbers and biomass of cutthroat trout populations. A shift in the community structure of primary producers occurred as light intensity increased. Shaded streams support a dominant community of periphyton and as light intensity increased a shift was observed to an intermediate mixed diatom community in a clearcut, and lastly to a green, filamentous algae in a natrually open stream. The removal of terrestrial vegetation as a result of clearcutting resulted in a drastic shift in the coarse (< 1 mm in diameter) and fine (> 1 mm) organic debris. Coarse debris in the forested and clearcut sections were reported as 19.3 kg/m^2 and 0.7 kg/m^2 (a 96% decrease), respectively, and fine particulate debris were 0.7 kg/m^2 and 0.3 kg/m^2, respectively (a 57% decrease).

Small headwater streams are typically biologically characterized by minimal algae and instream plant life with an abundance of invertebrates which feed on detritus originating from the riparian vegetation. Sixty to 70 percent of the organic inputs are utilized by the stream organisms in small headwater streams (Hobbs, 1981). Franklin and Waring (1980) characterize old growth ecosystems as highly retentive with the release of energy and nutrients from dead organic matter a very slow process. This results in relatively low levels of nutrients and other dissolved and suspended materials in streams in old growth coniferous forests. Sedell and others (in press) report that concentrations of nitrogen and phosphorus may increase 20 to 100 times for a period of one to three years following clearcutting. Sollins and McCorison (1981) sampled nitrate concentrations in a stream for one to two years before and for three years after clearcutting in the Oregon Cascade range. The results show that nitrate N concentrations increased from one microgram/liter prior to harvest to a maximum of 67 micrograms/liter two years following harvest. Although the total loss of dissolved N increased by 1.2 kg/ha/yr, the authors stress that this may be insignificant when compared to the nearly 400 kg N ha^{-1} removed from the watershed in boles and branches during logging.

The rate of revegetation largely controls the rate of reestablishment of nutrient conservation following clearcut logging (Vitousek et al., 1979). Marks and Borman (1972) report that forest regrowth tends to minimize nutrient losses through time following harvest, although the time to complete recovery is largely unknown.

The type of organic input to the stream determines the quality of food for instream detritus-processing organisms (Meehan et al., 1977). Conifer leaves take 180-200 days after entering the stream to be processed fully by stream microbes and insects. Deciduous leaves are high in fiber content and may take 60 to 90 days to be utilized. Herbaceous vegetation is high in nutrient content, low in fiber and relatively utilizable by the stream organisms upon entry into the stream. A riparian zone with distinct and fully developed herbaceous, deciduous and coniferous vegetation layers will therefore have the greatest variation in the quality of food reaching the stream organisms. This variation in timing and quality of inputs results in rich and diverse populations of aquatic insects which are linked to this varied detrital food base.

Bank Stability and Sediment Impacts

Streambank erosion and bank failures are a source of sediment that can have an adverse effect on fish spawning gravels, increase turbidity, and elevate suspended sediment concentrations in the stream system. The literature supports the value of streamside vegetation in reducing suspended sediment loads in streams, although a buffer strip of vegetation will have little effect on reducing sediment concentrated in rills or channels or sediment resulting from mass movements and debris torrests. Meehan et al. (1977) states that the herbaceous communities within the riparian zone are effective in reducing the transportation of sediment to the stream from hearby natural or man-caused sources.

The impact of increased sediment levels on salmonids can be linked to two primary forms of sediment (Meehan et al., 1977). Suspended sediment, in persistent and high concentrations, may accumulate on the gill filaments of fish and reduce the ability of the gills to aerate the blood thereby causing death by anoxemia and carbon dioxide poisoning. Increases in bedload sediment can inhibit the flow of intragravel water and dissolved oxygen exchange, act as a physical barrier to fry emergence, alter the habitat of aquatic insects which are utilized by the fish populations, and reduce available rearing habitat due to the filling in of pools (Meehan et al., 1977; Hall and Lantz, 1969; Hobbs, 1981).

The adverse effect of fine sediment on fish habitat by reducing the intragravel water exchange may reduce the dissolved oxygen available to the salmonid embryo beyond the level required relative to the stage of growth (Koski, 1966). After pooling data from several sources, Shirazi (1979) found that as the geometric mean particle diameter of the stream substrate (an effective measure of the entire particle size distribution) decreased from 30 to 5 mm, the percent survival of salmonid embryos decreased from approximately 90 to 10 percent. High suspended sediment loads in streams can result in migrating salmon avoiding or ceasing migration in those waters (Reiser and Bjornn, 1979). Streams having maximum suspended sediment loads less than 25 mg/l and a substrate composition with less than 20 percent of fine sediments (less than 6.4 mm) can be expected to support good freshwater fisheries (Reiser and Bjornn, 1979).

Sheridan and McNeil (1968) reported that the percent fines in spawning beds in an Alaskan stream increased following logging, but recovered to the pre-logging level in five years. Platts and Megahan (1975) found that the large increases of fine sediments in stream channels created unusable salmonid spawning areas in the Idaho batholith. In that study, the authors report that percent fines were reduced from a maximum of 80 percent to 26 percent in nine years following a moritorium on logging and road construction. This and other studies (Packer, 1967) conclude that the majority of sediment is due to the construction of logging roads. Hall and Lantz (1969) report that significant increases in sediment levels occurred for two years following logging on a clearcut watershed and that the average concentration of suspended sediment increased three to four times over pre-logging levels. Meehan (1969) reports that suspended sediment concentrations were only slightly elevated for a brief period after clearcutting on two southeast Alaska streams.

Stream Shade and Stream Temperatures

The removal of streamside vegetation can result in the loss of shade cover, thereby increasing the potential for increased stream temperatures as the result of increased solar energy inputs. Brown (1969) determined that the principal source of heat for small headwater streams is solar energy received directly at the stream surface with very little (less than 10%) of the total energy exchange due to evaporation or convection. Conduction of heat into the stream bottom is important when the stream channel is composed primarily of bedrock and the stream is shallow. This component of the energy balance acts as a heat sink during the midday hours with up to 25 percent of the energy absorbed by the stream transferred into the bed and functions as an energy source during later hours.

The effects of streamside vegetation removal on stream temperatures has been the objective of numerous studies. Brown and Krygier (1970) report that a 28°F (15.6°C) increase in diurnal temperature fluctuation occurred in a clearcut watershed in western Oregon. The prelogging fluctuation was exceeded 82 percent of the time in the year following logging, burning and stream cleanup. After a period of four years, during which streamside vegetation began to regrow, the prelogging fluctuation was exceeded 36 percent of the time. The annual maximum temperature increased 28°F in the clear-cut stream while a patch-cut watershed showed no significant changes in temperature attributable to timber harvesting. Levno and Rothacher (1967) found that a 4°F (2.2°C) increase above a predicted average of weekly maximums of 58°F (14.4°C) occurred after complete clearcutting but prior to burning and stream cleanup. After slash burning, the summer mean monthly temperature increased seven to 12°F (3.9-6.7°C) (Levno and Rothacher, 1969).

In a study in the Steamboat drainage, Oregon, Brown et al. (1971) recorded a 13°F (7.2°C) increase in a 150-foot (46 m) exposed clearcut stream section. Clearcutting in alternative blocks of 600 feet (183 m) as an attempt to reduce high temperatures attained in the exposed sections as the stream passed through the shaded sections indicated that this method cannot be relied upon to sufficiently cool heated streams. Hall and Lantz (1969) reported that temperatures decreased about 3°C (5.4°F) as a stream passed through 200 m (656 ft.) of residual slash and vegetation left following a clearcut harvest.

Brown (1966) used energy balance techniques to successfully (90% of the time) predict hourly temperatures of small streams. He reports that removal of streamside vegetation allowed a six-fold increase in heat input. In another journal, he presents (1970) a detailed technique for predicting the expected increases in stream temperature for complete exposure to sunlight. The increase in water temperature is proportional to the area exposed and the heat received from the sun, and is inversely related to the discharge rate of the stream.

Ringler and Hall (1975) investigated the effects of timber harvesting on the intragravel water temperature and dissolved oxygen in salmon and trout spawning beds. High intragravel water temperatures increased the biological oxygen demand in the gravels, decreased the solubility of atmospheric oxygen in water and shortened the embryonic development period of small fry. A 13 percent decrease in dissolved oxygen in spawning redds was reported for a patch-cut, buffer-stripped stream and a 37 percent decrease occurred in a clearcut stream. They report that a one to six-hour lag occurs from times of maximum surface and intragravel temperatures and that temperatures as high as 20°C (93.6°F) were recorded during alevin-stage development of coho salmon. The population of coho salmon appears to have been unaffected by the temperature and oxygen changes, while the population of resident cutthroat trout was reduced to about one-third of the pre-logging level.

Hall and Lantz (1969) conducted a study on the effects of timber harvesting on the salmon and cutthroat trout habitats in the Coast range of Oregon. Lowered dissolved oxygen levels were concluded to be the cause of increased fish mortality during the summer in which harvesting took place. Juvenile coho salmon survived less than forty minutes when placed in the study stream in live-boxes. Pre-logging dissolved oxygen levels were attained by autumn of that same year.

Meehan (1969) reports that on two Alaska streams, significant increases in water temperature due to clearcutting occurred and the maximum increase in mean monthly temperature was 4-9°F (2.2-5.0°C). This study indicated that salmon populations did not decrease following logging, although external factors (removal of fish traps) may have masked any changes. Based on data of returning spawners to the study stream in years during and following logging, the author concludes that clearcutting did not adversely affect the salmon spawning habitat.

Buffer strips of vegetation along stream channels have commonly been used to reduce the possibility of increased stream temperatures. Steinblums (1978) found that in the Oregon Cascades the survival of the buffer strip in relation to blowdown was a function of seven factors that were measured. These factors include three factors related to the position of the buffer strip relative to the surrounding topography, the elevation of the site, the orientation of the stream channel, the natural stability of the streamside soils, and a factor involving the original volume of timber in the strip and a site wetness classification. It is interesting to note that he found that buffer strip width was not a significant factor in buffer strip survival.

Steinblums (1978) also sampled stream shade as measured by an Angular Canopy Densiometer or ACD (see Methods section). He found that 68 percent of the streams with a buffer strip had ACD values between 30 and 70 percent, 18 percent had ACD's greater than

70 percent and 14 percent had ACD's of less than 30 percent. He also used a non-linear regression to analyze the relationship between strip width and ACD. The results show that increasing a buffer strip beyond a value of 85 feet does not substantially increase stream shading and that a strip of this width will have an ACD value of approximately 64 percent. He also found significant positive correlations between ACD and the original basal area in the buffer and between the slope of the cut unit. ACD values for control (uncut) stands ranged from 10 to 90 percent with 50 percent of the stands having ACD's between 30 and 70 percent, 42 percent having ACD's greater than 70 percent and eight percent having ACD's less than 30 percent. This work demonstrates that natural stream shade is variable and that shade values of 100 percent are rare, if not impossible.

Brazier (1973) found that 90 percent of maximum stream shading is obtained within a buffer strip width of 55 feet and that the effectiveness of a buffer strip to control stream temperature is not significantly related to the volume of commercial timber volume remaining in the strip. He stressed the importance of deciduous shrub cover and low level canopy as a component of stream shade, especially during early years following harvest.

The impact of increased light intensity on the drift mechanism of invertebrate aquatic insects is not well understood. Waters (1969) reports that drift behavior is controlled by the intensity of light and/or stream temperature. He reports that one species of the trichoptera order experienced increasing drift with increasing stream temperatures. The relationship between invertebrate drift and fish production is incomplete, but it is hypothesized that the drift phenomenon optimizes the production of invertebrates and maximizes the availability of the food supply to a wider assemblage of fish species with discrete habitats.

Stewart and Skeesick (1981) report that an analysis of 30 years of stream temperature data in the Willamette National Forest, Oregon revealed that all the gaged streams have increased maximum temperatures and greater duration of maximum temperatures. Several streams had periods ranging from 40 to 120 days every year when temperatures exceeded 59°F. They concluded from the analysis that stream shade in tributary streams is very important in the control of stream temperature.

Source of Large ORganic Debris (LOD)

Large organic debris is a primary factor determining the physical and biological character of small headwater streams in the forests of the Pacific Northwest (Swanson and Lienkaemper, 1978). The above ground woody riparian vegetation is an important source for large organic debris in the stream channel (Meehan et al., 1977). Large organic debris in the stream functions to control the routing of sediment and water through the stream system, define aquatic habitat opportunities by forming pools, riffles and depositional sites and providing cover, provide woody substrate for biological activity by microbial and invertebrate organisms, and serve as a retention device for fine organic material allowing time for that material to be processed instream.

Keller and Swanson (1979) found that in western Oregon the concentration of large organic debris (defined as greater than 10 cm in diameter) in a first-order stream is 48 times the amount in a sixth-order channel. In an undisturbed first-order channel 25 percent of the stream area is in wood and another 21 percent is habitat created by woody debris resulting in nearly half of the stream area either in wood or wood-created habitat (Swanson and Lienkaemper, 1978). In contrast, a third-order stream had 11 percent of the stream area in wood and 16 percent in wood-created habitat, roughly one-half the amount of wood habitat in a first-order channel. The residence time for some of this in channel debris has been documented to be more than a century. The distribution of this debris in small channels tends to be random with the pieces located where they initially fell due to the lack of adequate stream flow to redistribute the debris into the distinct accumulations commonly found in higher order (3-5) streams. This results in a characteristic stepped gradient with long, low gradient sections separated by relatively short, steep falls or cascades.

Keller and Swanson (1979) found that in five third-order Oregon streams the mean spacing of debris accumulations was one to two channel widths, which is considerably less than the typical five to seven channel widths spacing of pools and riffles. This pattern provides an energy dissipation mechanism that reduces the available energy for erosion of streambed and banks, provides more sediment storage in the channel, delays routing of organic detritus, and results in a greater habitat diversity than that found in straight, even gradient channels.

Megahan and Nowlin (1976) emphasized the importance of large woody material as a sediment storage device in small headwater streams in central Idaho. They found that only ten percent of the annual sediment yield was stored in the channel systems as a result of stream obstructions and that large organic debris accounted for approximately 75 percent of these sediment retention obstructions. In addition to the role of instream debris, large organic debris suspended over the channel also can be an important component of the channel structure. Overhanging logs within the high flow limits can act as vertical deflectors which create a downward plunging action during high flow events that results in the scour or formation of pools (Sedell, 1981).

Meehan et al. (1977) note the importance of large wood in the stream as a long-term reserve of essential nutrients and energy. In conjunction with the large pool of readily available organic material in the form of small litter and leaves, the slowly processed wood provides both flexibility and stability within the stream system. Microbial conditioning (a key factor in the availability of the debris as food to invertebrates) of the small detritus is usually accomplished within months, whereas the conditioning of large wood is on the order of years. Aquatic habitat for aquatic organisms and fish is enhanced by large organic debris in the channel, although excessive loading may reduce or impede migrating anadromous fish by creating impassable barriers in the stream. One study cited a 75 percent decrease in spawning in a single stream due to debris blockage (Reiser and Bjornn, 1979). Swanson and Lienkaemper (1978) contend that the character of small streams over large areas of the Pacific Northwest is being substantially altered by forest practices, although the extent and long-term biological consequences are not well understood. Management activities can reduce the existing or potential debris loading below those levels expected in natural old growth channels by thinning or harvest operations which remove the standing streamside boles (the future source of debris) and overzealous cleanup operations following the harvest.

Sedell et al. (1981) documents the historical importance of an abundance of large wood in the evolutionary development of natural stream systems and suggests that streamside zones be managed to develop large trees which are allowed to fall into the stream channel. The authors advocate that the cost of mitigating lost aquatic habitat (due to the removal of a merchantable log) with an artificial structure will exceed the value of that log when the cost of the structure and the cost to remove, buck, yard, and transport that log are compared.

Changes in the size distribution of debris in headwater channels can result in increased debris torrent activity and export of the large organic debris from the channel (Swanson and Lienkaemper, 1978). The authors present a possible scenario for a mechanism which may trigger torrents following timber harvesting. Large organic debris is removed by the timber harvest, while smaller floatable debris is left in the channel. During high flow events, the small debris may accumulate in large enough masses and gain sufficient momentum to move larger pieces of debris and a debris torrent may be initiated. The restabilization of streams after a catastrophic event such as a debris torrent or major flood is greatly accelerated by large organic debris within the channel (Sedell et al., 1981). The down trees provide depositional sites were invading hardwood species and shrubs can sprout and grow and they offer protection of those sites from floating organic debris and moving bedload sediment during subsequent high flow events. The authors conclude that fish habitat recovers more rapidly with a continued supply of large woody debris.

IV. RIPARIAN REVEGETATION FOLLOWING HARVEST

The character and importance of the riparian vegetation varies on a temporal scale following a disturbance such as clearcut timber harvesting. Knowledge of the patterns and rates of riparian zone revegetation is incomplete at best as studies involving this topic have been somewhat rare.

The temporal development of riparian zone vegetation is hypothesized by Meehan et al. (1977) to occur as presented in Figure 1. Invading species such as Alnus rubra and pioneer herbaceous growth occupy the impacted site relatively rapidly. Streamside vegetation increases in height growth and biomass more rapidly than hillslope communities during the first decade or two following harvest. The contribution of shade provided by the riparian vegetation gradually decreases the potential for aquatic primary production until maximum canopy closure. The relative contribution of litter inputs provided by deciduous shrubs and trees increases during early riparian succession and then gradually decreases until the last stage riparian succession wherein inputs are provided by a complex mosaic of coniferous overstory, a deciduous shrub layer, and herbaceous ground cover. It is important here to caution that this is a hypothetical scenario with the time required to various stages of succession largely unknown. Some investigators feel that the riparian zone will not attain a state of climax due to continuous reset mechanisms such as periodic debris scour and thus can be considered essentially a permanent pioneer community (Muckleston, 1982; Franklin, 1982; Campbell and Franklin, 1979).

While studies directed specifically at the rate of riparian revegetation are few, we can glean a few hints about the development of the riparian vegetation from related studies and literature sources. Brown and Krygier (1970) found that the prelogging diurnal temperature fluctuation in a stream in the Oregon Coast range was exceeded 82 percent of the time the first year following harvest

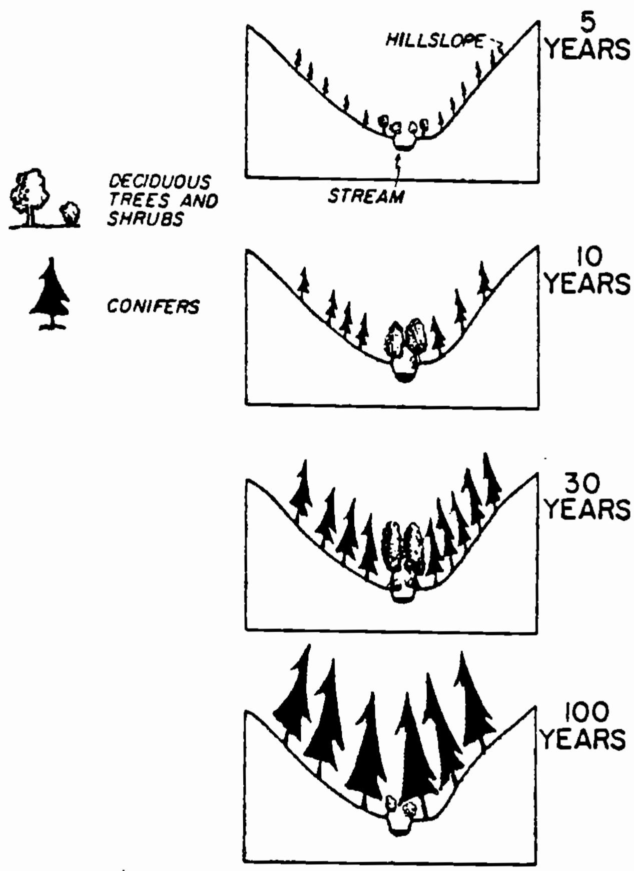


Figure 1. Hypothetical temporal development of riparian zone vegetation (after Meehan, et al., 1977).

and decreased to 36 percent after four years. This indicates that significant stream shade recovery occurs in this area in a period exceeding four years. They propose that maximum stream temperatures may approach natural levels within six years. Moring (1975) found that red alder (Alnus rubra) development in some sections along a clearcut stream in the Coast range reached heights of 15 feet in three years following logging, yet stream temperatures did not return to prelogging maximums and ranges until eight years following harvest.

Miller and Murray (1981) report that on average and good sites in Oregon, red alder seedlings can attain heights of 30 to 40 feet in a period of ten years. On sites located in western Washington, they found that Pseudotsuga menziesii emergence from an alder canopy occurred at a stand age of about 30 years. They noted that as one moves upslope from the stream, the gain in increased height and diameter growth of Douglas-fir attributable to interplanting with Alnus rubra increased. This implies that the soil nitrogen and moisture status were least improved by alder's additions of nitrogen and organic matter in the streamside area.

Fredriksen (1970) reports that revegetation of both clearcut and patch-cut watersheds with pioneer species in the Oregon Cascade range was rapid. Herb-rich vegetation established in two years following site burning gradually diminished as the shrub and tree cover expanded. Within five years the total vegetation cover the study area exceeded the cover measured under the undisturbed forest prior to logging. Long and Turner (1975) studied four stands in an age sequence from 22 to 73 years in western Washington's Tsuga heterophylla zone. They found that the above-ground biomass for tree components increased and that total understory biomass decreased with age. Total above-ground biomass experienced a rapid increase between stand ages of nine and 30 (9.97×10^3 kg/ha to 151.35×10^3 kg/ha) and a relatively less pronounced increase during the next 19 years.

Newton (1981) reports that within five growing seasons after a stream in the eastern Oregon Cascade range received extensive rehabilitation measures such as bank seeding, construction of rock check dams, and stream corridor fencing, a band of alder, willow, and cottonwood along the stream attained heights of 15-20 feet. Alnus rubra (red alder) formed a closed canopy over the stream in a few sections along the stream in only four years following such intensive rehabilitation work.

Campbell and Franklin (1979) examined the riparian zone in the central western Cascade range of Oregon and presented descriptions of communities, timing of leaf fall, rate of decadence of herbs, and vegetation biomass estimates. The characteristic pattern of vegetation in mature Douglas-fir (Pseudotsuga menziesii) stands located in the Tsuga heterophylla zone is one of fairly constant small herb cover (6%) on first- and second-order streams, with third-order streams decreasing to two percent herb cover. Large herbs covered an average of nine percent and shrubs showed an increasing trend with stream order (2-25% for 1-3 orders). A stream that had been scoured by a debris torrent had much higher percent cover for pioneer herb species with 23 percent for small and 39 percent for large herbs.

Riparian succession patterns following a major distrubance such as logging tend to begin with red alder invading the mineral soil next to the stream and willow invading islands. After approximately 100 years of undisturbed growth, the pioneer species are commonly replaced with bigleaf maple (Acer macrophyllum). On many small streams, the establishment of riparian tree species is preceded or prevented by extensive shrub development (commonly salmonberry, Rubus spectabilis).

Biomass was estimated using equations summarized by Gholz et al. (1979). They found that average total foliar biomass per meter of stream length for understory species increased from the scoured stream (560 g/m) to the mature old growth (1,019 g/m) to the clearcut (2,022 g/m). The clearcut stream had more than 50 percent of its total biomass located in the active zone of the stream channel where water may be present at some part of the year, whereas the old-growth section had only 13 percent of the total biomass in this same zone. The authors noted that in the old-growth section, instream (low bars and islands) vegetation biomass was approximately one-half that of the edge biomass which contains most of the characteristic overhanging shrubs (40 versus 90 g/m). Thus, total foliar biomass production is nearly four times as great at the clearcut site relative to the scoured stream and twice that of the old-growth site.

It is interesting to note the variability within the data. Standard deviations approximate or surpass the average estimates of biomass production. Variation in the active zone was the lowest in the clearcut section, while in the old-growth section the active zone was the most variable. The number of transects needed to estimate average transect weights ± ten percent range from 149 for total foliar biomass to 736 for edge zone biomass in the old growth. For a 290 meter stream section, this would require that transects be located 1.9 m and 0.4 m apart, respectively. This emphasizes the highly variable nature of the riparian vegetation, a feature that must be considered when working with riparian vegetation.

Cline and Swanson (1979) studied a set of 35-year chronosequence sites in western Oregon in order to characterize riparian development. Preliminary results indicate that red alder establishment is generally more dense in scoured sites. A scoured section supported approximately two and one-half times the biomass in a 14-year stand as that in an unscoured 20-year-old reach. The difference is due to a greater number of stems rather than large trees on the scoured site. Establishment of alder continues during a 10- to 15-year period following clearcutting. They noted that more frequent small disturbances such as bank cutting and deposition promote establishment of invading (red alder) vegetation as opposed to residual vegetation on a continued basis, thus providing sites for young trees in older stands.

Stewart and Skeesick (1981) studied streams in the Willamette National Forest, Oregon and sampled the percent shade cover which would occur during the July 24 solar arc. They found that stream shade was correlated to time since disturbance on streams less than 15 feet in width. The results indicated that 63 percent of the clearcut streams had less than 50 percent shade with 36 percent of the 5 to 15-year-old units receiving less than 50 percent shade and 29 percent of the 15 to 30-year-old units receiving less than that value. Linear regression was used to analyze the data and the slope of the resulting linear relationship between percent shade and recovery period was computed as 2.23 ($r = 0.56$). This can be interpreted essentially as a recovery rate of 2.23 percent shade per year following disturbance. The authors used this value to estimate that stream shade would recover to 58.8 percent after a period of 15 years (confidence limit = 47.2-70.3%).

The relative contribution of shade provided by coniferous and deciduous species was also analyzed. Deciduous trees had over five times the contribution of shade over the value for coniferous species. Only six percent of the streams had coniferous shade values above 50 percent, while deciduous species provided more than 50 percent shade on 32 percent of the sample streams. It was also noted that the majority of the coniferous shade that was sampled was from adjacent uncut units and not from the development of the coniferous species within the cut stand. On streams less than 15 feet wide, the mean percent conifer shade did not exceed 15 percent in the 32-year period, while deciduous mean percent shade approached 70 percent after 23 years. They stressed the dominance of deciduous vegetation in providing streamside shade for streams in the 32-year period of study and noted that a crossover from deciduous to coniferous dominance did not occur in that period. They also report that streams with south and north aspects had slightly faster growing rates when compared to east flowing streams, while west flowing streams had such extreme variation in the degree of regrowth that an age-dependent relationship was virtually nonexistent.

They conclude from this study that shade recovery is proceeding at a very slow rate and that the majority of the sampled streams were deficient in streamside shade. They estimate that approximately 60 percent of the streams had less than satisfactory shade for temperature control which was considered to be 75 percent of the prelogging existing shade for their analysis.

Zavitkovski and Stevens (1972) studied 50 Alnus rubra communities ranging from one to 65 years in age in the Oregon coast range. The ability of red alder to rapidly occupy disturbed sites and form dense and rapidly developing stands is important to the stabilization of these sites. They report that full occupancy of such sites can be obtained within two years and that dominant trees may reach two meters or more in height. On sites with exposed mineral soils, such as fresh alluvial soils, between several hundred thousand to several million red alder seedlings per hectare appear early in the spring of the first growing season. This phenomenal abundance of seedlings decreases relative to numbers of living trees at a rate approaching the square of their age. After a period of ten years, 98 percent of the seedlings living at age one had died. A high mortality rate continued until it leveled off at the age of approximately 25. Aboveground biomass increased rapidly until an age of about 25 years and reached a plateau (210 mt/ha) between the ages of 40 and 50 years. They noted that the combined dry weights of dead trees and litter produced was significantly higher than dry matter accumulated in living trees at all stand ages. They found that the cumulative quantity of nitrogen from the litter approached six mt/ha at 20 years.

Cline and Swanson (1982) studied the development of riparian vegetation in three stands in the west central Cascades of Oregon. The results indicate that red alder establishment is more dense and more rapid on sites affected by debris torrents. After 14 years, a stream section that had experienced a debris torrent supported approximately two times the aboveground biomass when compared to an unscoured 20-year-old reach. Areas of deposition along that section also experienced faster recovery of red alder relative to the scoured areas. The total aboveground biomass was 2.5 times greater on deposits than on scoured sections.

They also found that during the first 35 years following harvest, hillslope vegetation did not substantially encroach upon and shade the riparian vegetation and thus, the riparian vegetation directly controlled the energy and light inputs to the first-order streams through little deposition and stream shading. Also interesting is the dramatic decrease in understory vegetation with age as the alder canopy approached closure. The percent of aboveground biomass of understory species decreased from 64 to 22 to less than one percent in stands of 8, 20 and 35 years, respectively. This illustrates the importance and dominance of the understory vegetation layer during the early recovery process.

Using aboveground biomass per unit area as an index of the rate of revegetation after clearcutting, the authors conclude that debris torrent deposits in the riparian zone revegetate more rapidly than hillslope clearcut areas which, in turn, revegetate more rapidly than riparian sites without any debris torrent activity.

V. VEGETATION ZONES

Vegetational zones represent a broad area of land that has similar climate, geology, soils and vegetation as expressed by the potential climax vegetation for that zone (Bailey, 1976). As an attempt to stratify the study area into sections that could be expected to have similar riparian vegetation development rates, several vegetation zone classification systems were reviewed.

As early as the turn of the century, Kirkwood (1902) presented a paper which crudely describes the vegetation of northwestern Oregon. He basically recognized similarity in the vegetation in the Willamette valley, the uplands of the Cascade and Coast ranges (200 to 500 feet in elevation), and a remarkably well-defined coastal *Picea sitchensis* area. Cooper (1953) divides the Pacific Northwest province into two altitudinal zones: the Pacific Coastal Forest Complex and the Pacific Subalpine Forest Climax. In the former complex, he recognizes the Western hemlock climax with the associated and much more geographically dominant Douglas-fir subclimax. The Subalpine Forest Climax is not described in great detail, but he depicts this zone as dense forest with large trees with late spring snowpacks found at elevations ranging from approximately 3000 to 8500 feet.

Daubenmire (1969) begins to describe the region based upon climax vegetation types, yet classifies the area based upon the forest climatic types. For example, he describes the high elevation Cascades as cold, subalpine forests of strongly oceanic climates and the Coast and lower elevation Cascades as cool moist forests or montane forests with wet oceanic climates. He presents a map of vegetation for the northwestern U.S. with three different vegetation types mapped for the study area: a cool, moist forest-type which is a broad region encompassing the Coast and lower-elevation western Cascades, a small subalpine forest type along the crest of the Cascades, and a dry forest type located near the Willamette valley and in the southern portion of the Cascade range near the California border.

Holdridge (1947) utilizes climatic data to determine plant formations within geographical areas which he has termed life zones. Precipitation, elevation and temperature data are used to determine the life zone at any given place. Hanson (1976) mapped these life zones for the State of Oregon. He recognizes seven life-zones relative to the study area in western Oregon.

Kuchler (1964) prevents a map and manual describing the potential natural vegetation of the continental United States. He defines potential natural vegetation as that vegetation that would exist today if man were removed from the scene and the resulting plant succession were telescoped into a single moment. This last qualification eliminates the effects of future climatic fluctuations. His units for vegetation mapping are life forms and taxa, the life form pattern gives the plant community its physiognomy and structure and the taxa accounts for the floristic composition. He maps seven vegetation units in western Oregon relative to the study area.

Region 6 of the USDA Forest Service utilizes Kuchler's classification scheme for use in the Total Resource Inventory (TRI) system (Hall, 1979). Ecoclass codes are assigned to a given unit of land according to the following hierarchy: (1) subformation, (2) series, (3) association. Subformations follow Kuchler's map as previously discussed, series are a subdivision of subformation based upon a dominant climax species, and associations are subdivisions of series based upon habitat types. For an example, one unit of land might be classified with a subformation equivalent to Kuchler's Interior Douglas-fir forest, a series comparable to Tsuga heterophylla climax with a shrub understory of the snowberry-oceanspray dry site group, and an association corresponding to a field identified habitat type, plant community type, or site type. Much of the land in the study area has not been completely mapped and described by the Ecoclass system and discrepancies within the existing Ecoclass mapping resulted in the rejection of this method of stratification for this study.

Franklin (1980) gives a brief summary of the ecological site classification efforts currently being conducted in Oregon and Washington. Major programs include the Region 6 TRI system and a National Park Service-directed inventory. The author notes that most classification systems are very similar relative to types recognized and that these programs are largely intended for use by resource managers. He also notes that the emphasis of these programs is on the development of classifications that can be applied by land managers and not on the development of maps for this work. Vegetation maps are generally not available in most areas so the manager must be able to recognize the ecological types in the field.

The idea of establishing broad, yet similar regions of vegetation that reflect the climate and geology of the area was recognized by Bailey (1976). He defines an ecoregion as a continuous geographical area that is characterized by the occurrence of one or more important ecological associations that differ significantly from those of different regions. The ecoregions are characterized by distinct flora, fauna, climate, landform, soil, vegetation, and ecological climax. Within such an ecoregion ecological relationships between species, soil, and climate are essentially similar and similar management treatments can be expected to have similar results. His is a hierarchical classification which utilizes a domain (subcontinental climate similarity), a division (broad vegetation and regional climate similarity), a province (broad landform, vegetation, and zonal soil similarity), and finally, a section in which climax vegetation types are recognized. He maps the three regions relevant to the forested areas of western Oregon as a coastal sitka spruce-hemlock-cedar forest, a mid-elevation cedar-hemlock-Douglas-fir forest, and a high elevation silver fir-Douglas-fir region.

Franklin and Dyrness (1973) integrated much of the available data and information on the vegetation of Oregon and Washington into a very detailed, yet still incomplete, description of the natural vegetation. Their classification scheme utilizes vegetation zones as the basic organizational units within broad physiognomic divisions (forests, steepes, interior valleys, and subalpine-alpine regions). They recognize a vegetational zone as the area in which one plant association is the climatic climax whenever possible, however incomplete data and information for some areas restrict the authors to define the zone as an area in which a single tree species is the major climax dominant. The latter case is the approach used for most of the forested regions of western Oregon.

The thoroughness of Franklin and Dyrness's classification and the state-of-the-art nature of their paper led to the decision to utilize that scheme to stratify western Oregon for sampling for this study.

VI. THE STUDY AREA

Physical Aspects

Study sites were located in the Coast and Cascade ranges of western Oregon between 121°50' and 124°06' west longitude and 42°25' south and 45°10' north latitude. Sites are distributed among five vegetational zones described by Franklin and Dyrness (1973). Figure 2 gives the location and respective zone of the 40 study sites that were selected for study. These sites are characterized by three major physiographic provinces, the Coast Range Province, the Western Cascades Province, and the High Cascades Province which are described extensively by Baldwin (1976). It is important to note that boundaries separating the provinces and zones are arbitrary and gradual transitions exist (Franklin and Dyrness, 1973).

Climate

The climate of western Oregon is maritime and is influenced strongly by the Coast and Cascade Range mountain masses. The climate is characterized by mild temperatures, wet winters, and cool, relatively dry summers. Heavy precipitation is the result of cyclonic, low pressure systems with 75-85 percent of the annual precipitation occurring during the period between October 1 and March 31 (Franklin and Dyrness, 1973). The Coast Range tends to block incoming maritime air masses and creates a drier climate in the interior valleys. Coupled with a general trend of decreasing precipitation as one moves latitudinally from north to south, the interior valleys of southwestern Oregon typically have relatively hot, dry climates.

The amount and type of precipitation is highly related to elevation, especially in the Cascade Range. Precipitation and

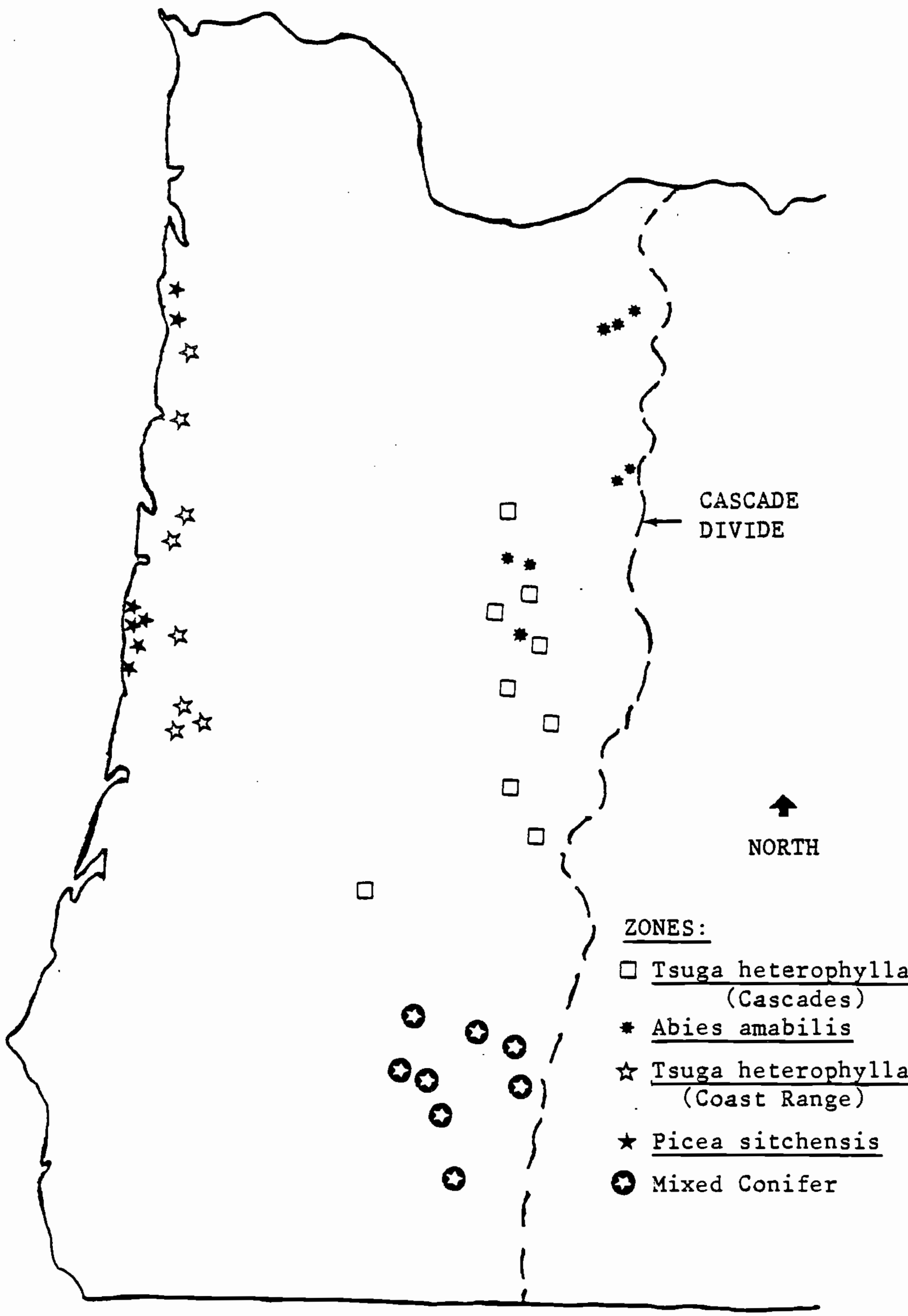


Figure 2. Map showing location of the forty study sites.

snowfall increase, while temperatures rapidly decrease as elevation increases. Temperatures regimes are typically mild with extended cloudy periods. Extremes in temperature are minimal and diurnal fluctuations during the summer months are somewhat narrow (6° to 10°C) (Franklin and Dyrness, 1973). Storm tracks are shifted to the north during the summer months and the resulting high pressure systems often bring clear, dry weather for prolonged periods.

Vegetation

Five vegetational zones were selected for this study with two located in the Coast Range and three found in the Cascade Range. The approximate boundaries of these zones are given in Figure 3. Sites one through nine are located in the Cascade portion of the *Tsuga heterophylla* Zone. Sites ten through 17 are located in the *Abies amabilis* Zone in the upper elevations of the Cascades. Sites 18 through 24 are located in the Coast portion of the *Tsuga heterophylla* Zone. Sites 25 through 32 are found in the narrow *Picea sitchensis* Zone along the Oregon coast. Sites 33 through 40 are located in the southern Cascade Mixed Conifer Zone. These vegetational zones are described in detail by Franklin and Dyrness (1973) from which the majority of the brief zonal descriptions found in the following section are taken.

Tsuga heterophylla Zone

The *Tsuga heterophylla* Zone is the most extensive zone in western Oregon and is considered to be the most important in terms of timber production. Geographically, the zone is divided by the Willamette Valley into a Coast Range segment and a Cascade Range segment. For this study, each segment was treated as a separate zone. The southern boundary of the Cascade segment is the divide between the North and South Umpqua rivers (approximately 43°15' north latitude) while that of the Coast segment is the Klamath Mountains except for a narrow coastal strip. Elevation of the Cascade segment varies from 150 to 1000 m while in the Coast Range the elevation is generally above 150 meters.

The climate of the zone is wet, mild, and maritime with temperature and moisture extremes in the Coast segment somewhat greater than in the adjacent Picea sitchensis Zone. Because the Tsuga zone is geographically widespread, the climate varies considerably with latitude, elevation, and location relative to the mountain masses. Summers are usually dry with six to nine percent of the 150 to 300 cm average annual precipitation occurring during June through September. Temperatures average about 9°C with July maximums averaging between 27° and 30°C. Snow can be important in the upper elevations of the Cascade segment with much of the winter precipitation in that form. Detroit, Oregon (at an elevation of 485 m) receives an average annual precipitation of 193 cm with an average annual snowfall of 156 centimeters.

Soils are varied but have some general characteristics in common. Soil profiles are usually at a minimum moderately deep and of medium acidity with surface horizons well-aggregated and porous. Organic matter content in the Cascade segment is moderate while in the Coast it tends to be high where thick A1 horizons develop. Forest floor depths are usually less than seven cm thick although at higher elevations some may reach 15 cm. Soils are of medium texture, usually ranging from sandy loam to clay loam. Although soils are generally as described in portions of this zone, some poorly developed, shallow soils can be found on sites with steep slopes.

Although this is the Tsuga heterophylla climax zone, the subclimax Pseudotsuga mensiesii is usually the sole dominant species in the seral stands which have developed following the extensive logging and/or burning which has occurred during the last 150 years. The climax overstory usually consists of Tsuga heterophylla and Thuja plicata with associate tree species Abies grandis, Pinus monticola, and the subordinant Taxus brevifolia also present. Abies amabilis is found at the upper elevational limits in the Cascade segment and Picea sitchensis is found near the coast where the zone grades into the Picea sitchensis Zone. Hardwoods are nearly always subordinant and are usually only found on recently disturbed sites and on riparian habitats. Alnus rubra, Acer macrophyllum, Populus trichocarpa and Fraxinus latifolia are common riparian zone species.

Generally, the understory communities can be arranged along a moisture gradient with Holodiscus discolor occupying sites at the drier end of the spectrum and Polystichum munitum and Oxalis oregana typical of the very moist sites. Stands on very moist streamside slopes are generally occupied by the Tsuga heterophylla/Polystichum munitum-Oxalis oregana association. The understory is dominated by a lush growth of herbs such as Polystichum munitum, Oxalis oregana, and Vancouveria hexandra. Acer circinatum, Berberis nervosa, and Vaccinium parvifolium are the most frequently encountered shrub species (each usually less than 20 percent cover).

Sites in the Coastal segment tend to have more favorable moisture regimes than comparable areas in the Cascade segment and as a result tend to have a greater occurrence of fern species. The stony, shallow soils at high elevation headwater areas in the northern portion of the Coast Range tend to be occupied by associations with a Vaccinium membranaceum understory and are characterized by a well-developed shrub layer.

Plant succession following a disturbance such as logging or burning tends toward development of vegetation that is typically very heterogeneous. Much of this variability is associated with site differences as a result of differing types of logging disturbance and especially varying degrees of burning severity (Dyrness, 1965). Available research data indicate that during the first growing season after burning and vegetation consists of sparse residual vegetation and some invading herbaceous species such as *Senecio sylvaticus*, *Epilobium angustifolium*, and *Epilobium paniculatum*. During the second year invading annual herbaceous species become dominant, especially *Senecio sylvaticus*. *Senecio* generally is replaced after a short, one-year dominance by increasing amounts of perennial herbaceous species such as *Epilobium angustifolium* and *Pteridium aquilinum*. The high occurrence of *Senecio* is associated with high nutrient requirements which are typically satisfied only on recentlyburned sites. This stage has been defined as the weed stage and the populations of perennial herbaceous species quickly increase until the fourth or fifth year when the rate of increase slackens. The weed stage is gradually replaced by a shrub-dominated period with such residual species as *Acer circinatum*, *Rubus ursinus*, and *Vaccinium* spp. and invading species such as *Salix* spp. and *Ceanothus velutinus* frequently encountered.

The shrub species dominate the site until they are overtopped by tree saplings, usually *Pseudotsuga* or a combination of *Tsuga heterophylla* and *Pseudotsuga*. *Pseudotsuga menziesii* often develops into dense, even-aged stands which frequently eliminate most of the understory vegetation. *Alnus rubra* is found extensively in seral communities on moist to wet sites in both segments with understories dominated by a *Rubus spectabilis* shrub layer and a *Poystichum munitum* herb layer predominant in the Coast segment.

It has been noted that surviving herbaceous vegetation from the original stand is considerably greater in the Coast segment than in the Cascade segment and that shrub and total plant cover tend to be substantially greater on Coast segment cutting units. Denser weed cover in cutover stands relative to the original stand is also characteristic of sites in the Coast segment.

The climax species *Tsuga heterophylla* frequently invades the stand and reestablishment of the understory occurs at an age of approximately 50 to 100 years as mortality begins to open up the canopy. Stands can exist in a mixed nature for periods of 400 to 600 years. True climax forests of *Tsuga* are rare, yet this is considered to be the climax species because *Tsuga* is able to reproduce beneath the forest canopy while *Pseudotsuga menziesii* is relatively intolerant and does not. The exception to this general pattern is on very dry sites where *Tsuga* is absent and *Pseudotsuga* becomes the climax species.

Abies amabilis Zone

The *Abies amabilis* Zone is found on the western slopes of the Cascade Range at elevations above the *Tsuga heterophylla* Zone. The zone is characterized by a short, cool growing season with a significant winter snowpack. The zone generally extends southward to about 44° north latitude with isolated communities as far south as 43° north latitude. It is found at elevations from 1000 to 1500 m where it grades into the subalpine *Tsuga mertensiana* Zone.

The climate is more moist and cool than the adjacent *Tsuga heterophylla* Zone with much of the annual precipitation in the form of snow, often accumulating in winter snowpacks of one to three meters. The average annual precipitation at Government Camp, Oregon (elevation of 1280 m) is 219 cm with an average annual snowfall of 792 centimeters. Temperatures annually average 5.6°C with July maximums averaging 20.8°C. Soils generally have thin organic matter accumulations which average three to seven cm thick.

Forest composition in this zone is highly variable and is a function of stand age, history and location. Constituent tree species include *Abies amabilis*, *Tsuga heterophylla*, *Abies procera*, *Pseudotsuga menziesii*, *Thuja plicata* and *Pinus monticola*. At the upper margin of the zone, *Tsuga mertensiana* and *Chamaecyparis nootkatensis* appear.

Understories are characterized by well-developed shrub, herbaceous, and moss layers with Vaccinium spp., Cornus canadensis, and Linnaea borealis frequently occurring. It is noted that much of the community composition variation is associated with changes in moisture regimes. As one moves southward, the proportion of communities with an understory dominated by herbs increases while those dominated by Vaccinium spp. decrease. Communities with depauperate understories dominated by Vaccinium membranaceum and Xerophyllum spp. and others with a Rhododendron macrophyllum dominant also become common in the southern portion of this zone.

Early succession on wet sites tends towards development of dense shrub communities of Sambucus spp., Rubus spectabilis, and Ribes spp., while on drier sites the major dominants generally are those species present in the stands before disturbance (Vaccinium spp., Xerophyllum spp., Sorbus spp., and Pteridium aquilinum). Pseudotsuga menziesii or Abies procera are generally the first coniferous species to invade the site with Tsuga heterophylla developing later under the forest canopy. A typical 400 to 500-year-old stand is mixed with Abies amabilis reproducing under a canopy of scattered Pseudotsuga and Tsuga. Eventually, Tsuga is replaced by the climax species Abies amabilis as a result of mechanical factors. The Tsuga seedlings are fragile and are unable to survive the winter accumulations of litter and snow, while the Abies amabilis seedlings are hardier and tend to survive.

Picea sitchensis Zone

The Picea sitchensis Zone is geographically a long, narrow band located along the Oregon coast. This zone is considered to have some of the most productive forests in the world and is characterized by frequent summer fogs, proximity to the ocean, and the mildest climate of any northwestern vegetation zone. The zone is rarely more than a few kilometers wide, except where it extends up river valleys. The zone is generally located at elevations between sea level and 150 m, although some portions of this zone can be found at elevations to 600 m where mountain masses are adjacent to the ocean.

The climate is uniformly wet and mild with minimal extremes in moisture and temperature. Precipitation averages 200 to 300 cm annually with fog drip contributing to this value due to frequent fog and low clouds. Temperatures average approximately 10.5°C annually with summer maximums averaging 20.2°C. Soils are deep, relatively rich and fine-textured with surface soils typically acid (pH of 5.0 to 5.5), high in organic matter (15 to 20%) and total nitrogen (0.50%), and low in base saturation (10%).

Forest composition in this zone consists of constituent tree species *Picea sitchensis*, *Tsuga heterophylla*, *Thuja plicata*, *Pseudotsuga menziesii*, and *Abies grandis* with lush understories in the wetted forest sites of *Polystichum munitum*, *Oxalis oregana*, *Vaccinium parvifolium*, *Oplopanax horridum*, *Sambucus racemosa*, *Blechnum spicant*, and *Dryopteris austriaca*. *Picea*, *Tsuga* and *Thuja* are the most commonly encountered overstory tree species and *Alnus rubra* is abundant on recently disturbed sites.

Two major community types are recognized in this zone. The *Tsuga heterophylla*-*Picea sitchensis*/*Gaultheria shallon*/*Blechnum spicant* type is generally found close to the coast while the *Tsuga heterophylla*-*Picea sitchensis*/*Oplopanax horridum*/*Athyrium filix-femina* type is located further inland. *Pseudotsuga menziesii*, *Thuja plicata* and *Alnus rubra* are infrequent associates with *Tsuga* and *Picea* in both community types with *Pseudotsuga* a frequent associate in the inland community type.

Successional trends following fire or logging tend toward development of dense *Rubus spectabilis*, *Sambucus racemosa* var. *arborescens*, and *Vaccinium* spp. shrub communities. Seral forests are either coniferous, containing differing amounts of *Picea*, Tsuga, and Pseudotsuga, or hardwood, with the fast-growing Alnus rubra invading the disturbed site and reproducing abundantly.

Dense shrub understories (primarily of Rubus spectabilis) can result in very slow replacement of Alnus stands with coniferous tree species. Henderson (1970) reports that succession in the understory of Alnus rubra stands proceeds from a grass-herb to shrub-fern understory over a 60 to 70-year period. Succession in mature conifer forest types tends towards replacement of mixed Picea, Thuja, Tsuga, and Pseudotsuga forests by the more tolerant Tsuga heterophylla. Picea sitchensis generally reproduces best in natural openings created by windthrow or overstory mortality while Tusga reproduces well under mature forest conditions.

Mixed Conifer Zone

The Mixed Conifer Zone is located on the western slopes of the Cascade Range in southwestern Oregon. The recognition of this zone is not based upon a climax species, although Abies concolor is considered to be the major climax species over the entire zone. Franklin and Dyrness (1973) note that history and environmental complexity coupled with a lack of plant community data make zonal distinction very difficult in southwestern Oregon. The zone is located southward from approximately 43° north latitude and is bounded on the west by the Rogue and Umpqua river valleys. The zone is generally found at elevations between 750 to 1400 meters.

The climate is similar to that of the Tsuga heterophylla Zone to the north, but the summers are distinctly warmer and drier. Precipitation averages 90 to 130 cm annually with approximately five percent occurring during June through August. At upper elevations, snow can contribute to the annual precipitation. Average annual snowfall at Prospect, Oregon (elevation of 630 m), for example, is 162 cm where the average annual precipitation is 106 cm. Temperatures average about 10°C with July maximums averaging approximately 31°C.

The complex geological history and topography of this area results in soils that are extremely varied. The Haploxerult soil great group is representative of this area and has thin organic layers (2 to 5 cm), slightly acid surface soils, and strongly acid subsoils. The surface soils are low in organic matter, typically averaging four to five percent.

Mixed forests of Pseudotsuga menziesii, Pinus lambertina, Pinus ponderosa, Libocedrus decurrens, and Abies concolor occur in varying degrees of mixture throughout this zone. The occurrence of Pseudotsuga tends to decrease and Pinus species tends to increase as one moves from north to south within the zone. Pinus ponderosa and Pinus lambertina usually occur as scattered individuals and Libocedrus decurrens is usually found in greatest numbers on xeric sites. Tsuga heterophylla and Thuja plicata are frequently found on the more mesic sites in the northern portion of this zone. Hardwood species such as Acer macrophyllum, Arbutus menziesii, and Castanopsis chrysophylla are also commonly encountered.

Data from the Abbott Creek Research Natural Area along the Rogue-Umpqua River divide indicate that the sites along stream courses in this zone are typically occupied by the Abies concolor-Tsuga heterophylla/Acer circinatum-Taxus brevifolia community type. This community type has a characteristically dense understory and a well-developed shrub layer with Acer spp., Taxus brevifolia, Linnaea borealis and Rubus ursinus commonly found.

Forest succession in this zone is an extremely slow process. Climax forests are rare as Abies concolor (the climax species) has been restrained from attaining overstory dominance in much of the zone due to past fires and present logging activity. Recently logged or burned sites are often invaded by shrub species such as Ceanothus velutinus and can develop extensive brushfields. These brushfield communities can significantly decrease the rate of forest succession. *Ceanothus* reproduction is from seed stored in the forest floor. Heat and increased solar radiation as the result of fire break the seedcoat dormancy. These brushfields are gradually overtopped by seral forests of *Pseudotsuga menziesii*, *Pinus* spp., and *Libocedrus decurrens*.

VII. METHODOLOGY AND STUDY DESIGN

Study Design

This study focused on the development of riparian vegetation following impact due to clearcutting in the Cascade and Coast ranges of western Oregon. Sites were thus restricted to these two ranges and were located primarily on lands managed by the Mount Hood, Willamette, Umpqua, Siuslaw, and Rogue River National Forests. Additional sites were located on lands managed by the Butte Falls Resource Area Unit of the Medford District of the Bureau of Land Management, the Boise-Cascade Corporation and the Georgia-Pacific Corporation.

A total of 40 sites were selected which represented a chronosequence of seven stand ages and one control site in each of five selected vegetational zones. The control site was a stream located in an unmanaged undisturbed stand geographically central to the other sites in a given zone. Exceptions to this design were the *Picea sitchensis* and *Tsuga heterophylla* Cascade segment zones which had six and eight stand ages, respectively. The chronosequence of sites represented units ranging from those recently harvested (1 to 2 years prior to study) to those harvested a maximum of 30 years prior to sampling. These five vegetational zones are described in Section VI. Site measurements were taken during a period from mid-June through September, 1981, such that vegetation was at a summer full-leaf state. Sites were evaluated and selected according to the criteria given in Table 1.

Most potential sites were initially selected by utilizing the Total Resource Inventory System (TRI) at each U.S. Forest Service Ranger District. Ranger districts included in this preliminary selection included the Clackamas, Estacada, Bear Springs, and Zigzag districts of the Mt. Hood National Forest; the Detroit, Sweethome, Blue River, Lowell, and Oakridge districts of the

TABLE 1

Criteria for Selection of Study Sites

Characteristic	Criteria
Type of harvest	Sites were clearcut only.
Stream order	Streams were one through third order.
Streamflow	Streams were perennial.
Extent of impact	Site were clearcut to stream channel on both sides. No evidence of a buffer or leave strip.
Site access	Sites were accessible by motor vehicle to unit boundary. Short hikes were usually required through adjacent stands or down unit slope to stream channel. Sites with roads adjacent to stream channel were eliminated due to the potential additional impact above timber harvesting possible by road construction.
Harvest history	Harvest date, slash disposal date and method, and subsequent stand improvements were available through timber harvest records, literature sources, or personal contacts.
Age	Sites were to span a recovery period approximately 30 years in duration using a sequence of seven stand ages approximately four years apart.
Debris torrent activity	Sites were eliminated if evidence of past debris torrent activity was detectable in air photographs or in the field as an effort to reduce variation introduced by the very different development pattern found in scoured stream channels.

Willamette National Forest; the Waldport, Alsea, Hebo, Mapleton districts of the Siuslaw National Forest; the Butte Falls and Prospect districts of the Rogue River National Forest; and the Tiller district of the Umpqua National Forest.

Compartmental photo mosaics (an air photograph of a portion of the district with each harvest unit identified by a TRI data storage cell number) were used in conjunction with Aquatic Subsystem Overlays to determine which streams flow through clearcut units. The Aquatic Subsystem Overlay is a diazo copy of a map of the compartment with streams and their corresponding class numbers identified.

Potential sites were then plotted on a district fireman's map (scale: 1 inch = 1 mile) to use for field location of the sites. The TRI unit location number, harvest date, fuel disposal method and date, elevation, and ecoclass code were extracted from the cell data base and recorded. Harvest and fuel disposal dates were verified whenever possible for each of the final 40 study sites using Reforestation Activity Record cards (KV cards) because the dates recorded in the TRI cell data base indicate when the activity record cards were microfilmed for storage and not the actual date of the activity.

The remainder of the sites were selected using maps and personal communication with representatives from the Medford District of the Bureau of Land Managmenet and the Boise-Cascade Corporation or from sites described in the literature. One site each from the Tsuga Cascade (No. 4) and Coast portions (No. 22) and Mixed Conifer (No. 34) zones were selected from the literature and are of special interest because of the well-documented nature of the harvest activity and the availability of photographs (except for Site 4) of the immediate post-harvest condition of the site for comparison purposes.

The age of the stand was considered to be the difference in years between the sampling date and the stream impact date. The date of burning was used as the impact date for sites that utilized broadcast burning as a site preparation technique and the date of completed timber harvest was used for sites that were pile-burned or had no slash disposal.

Potential sites were then surveyed in the field to determine their possible utility for this study. Approximately 250 sites were field checked. Some common reasons for site rejection included residual vegetation in the stream zone, flow intermittent through bedload depositions, a scoured channel, too small a stream, large cascades or falls in the channel, excessively steep access, a dry stream, or evidence of beaver activity in the channel. An attempt was made to select sites geographically as widely distributed as possible, yet keep distances within reason to facilitate data collection.

Field data collection was conducted using the sampling scheme presented in Figure 4. Details of the methodology and techniques are discussed in following sections. Five sampling stations were located up the stream channel by using a systematic sampling technique. The length of the channel reach was divided by five to obtain the distance between transects. A random number was chosen between one and that number in order to insure a random location of the first sampling location.

At each sampling location, a sample zone was designated as that area upslope from midstream to a distance equal to two times the average stream width. It was interesting to note how closely this zone corresponded in the field to the definition of the riparian zone as given by Campbell and Franklin (1979) discussed in the literature review. The sampled riparian corridors ranged from 4.8 to 24.3 m (16 to 80 feet) for all sites, with most between 6.1 and 12.2 m (20 and 40 feet).

Figure 5 gives a cross-sectional and plane view of the sampling scheme at each of the five sampling locations. Line-intercept transects were taken up each bank at each sampling

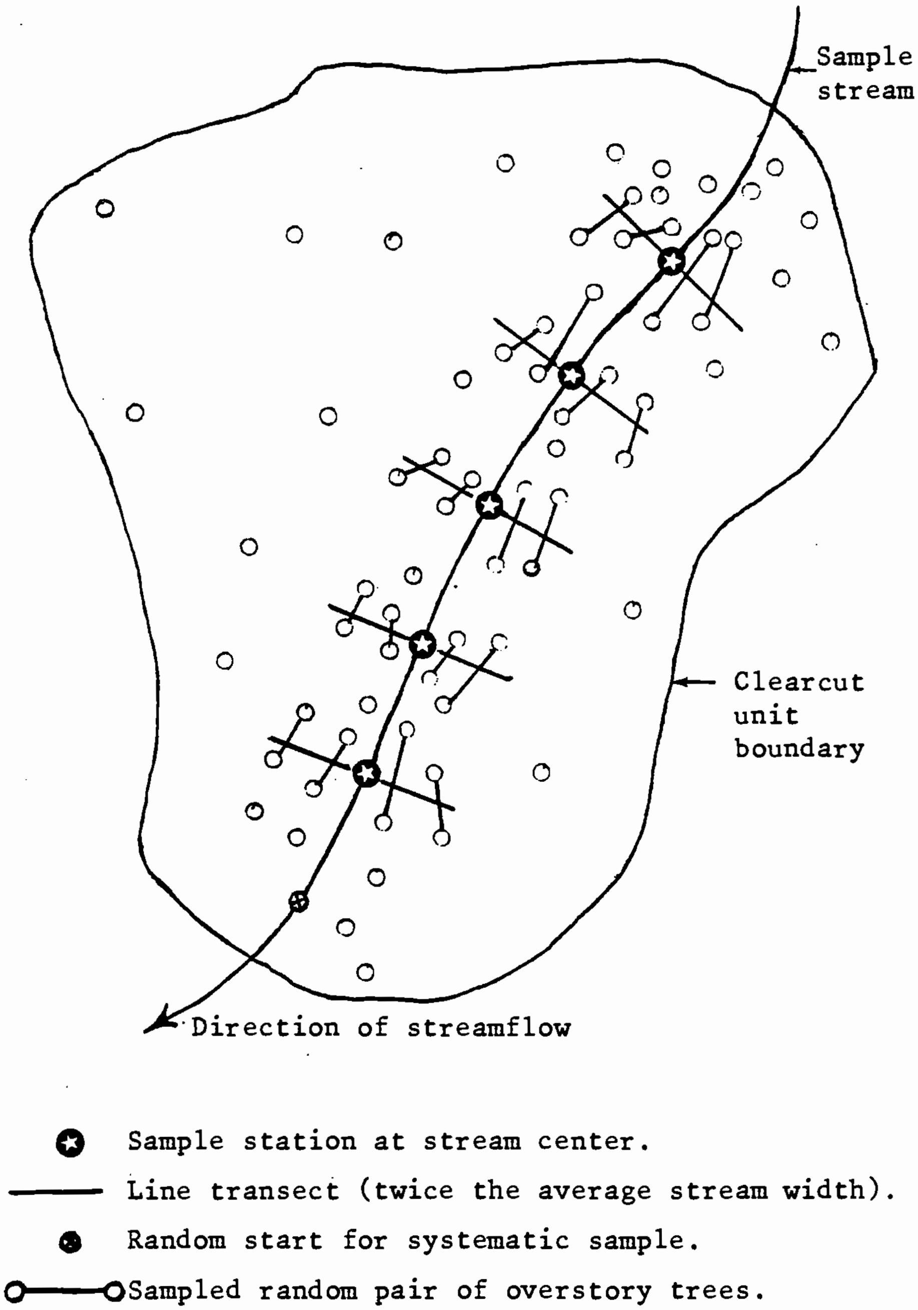
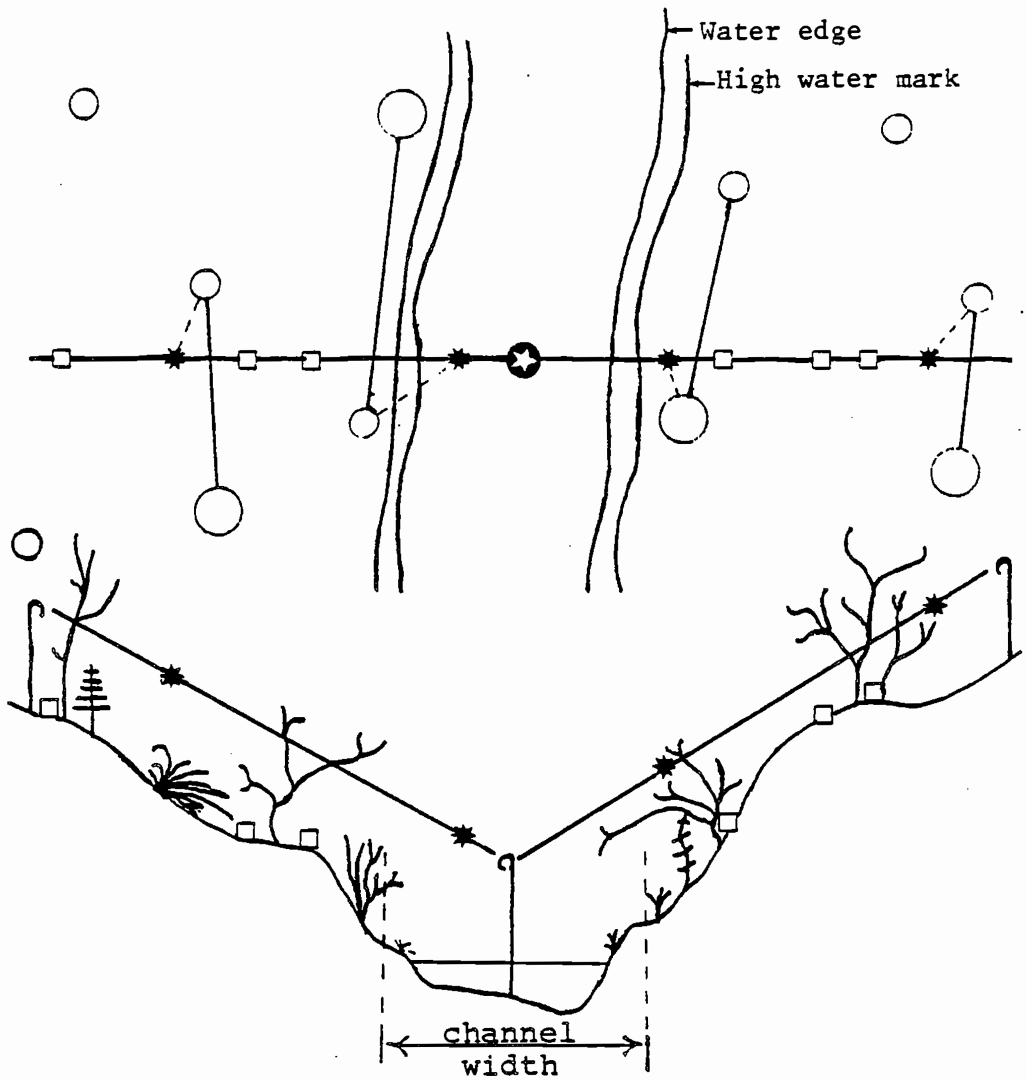


Figure 4 . Schematic of sampling system used in data collection.



Sample station, stream center, ACD and density samples.
Random location for overstory sample.
Random location for ground cover sample.
Tape transect (twice the average stream width).
Random pair of overstory trees sampled.
Line of sight to closest tree from random point on tape.
Distance measured between tree species.

Figure 5. Plan and cross-sectional views of data collection scheme at each sampling station.

location which resulted in ten transects per site. The percent of vegetation overhanging the stream channel was measured for the channel perpendicular to the stream flow at each sampling location. Angular Canopy Density (ACD) and canopy density were each measured at stream center. Ground cover estimates were taken at three random locations for each transect which yielded 30 observations for each site. Four random pairs of trees were sampled at each sampling location which resulted in a maximum of 40 stem diameters and 20 distance measurements per site. Sites without sufficient numbers of trees in the sampling zone had observations less than this maximum. Large organic debris observations were made between each sampling location as the crew progressed up the channel. The resulting potential sample sizes from this sampling scheme are summarized in Table 2.

TABLE 2

Summary of potential sample sizes for study

Observation	Total n for study	Total n per site
Line-intercept transects	400	10
Angular canopy density and canopy density	200	5
Ground cover estimates	1200	30
Stem diameters	1600[1]	40[1]
Distance between random trees	800[1]	20[1]
Large organic debris tally	39	1
Stream gradient	200	5
Stream orientation	200	5
Bank slope	400	10
Overhanging vegetation observation	200	5

[1]Actual number of samples is less than this value because some recently clearcut sites lacked sufficient numbers of trees (2"+) to complete sample.

Methodology

The vegetation within the riparian zone was classified into three categories for sampling. These categories represent three layers of vegetation. The ground layer was defined as that layer extending upward from the soil surface to a distance of 12.7 centimeters (5 in.). The understory layer extended to a distance of 2.5 meters (8.2 ft.) and the overstory was defined as that vegetation layer greater than 2.5 meters (8.2 ft.). This classification scheme provided a sampling framework that would encompass the extremely different stages of riparian development encountered in sites ranging from those recently harvested to those harvested 30 years prior to the study.

Ground Layer

The ground layer was sampled using a ten-point sampling frame as described by Cain and Castro (1949). This sampling method consists of lowering a pin, sharpened to a fine point, through ten notches in a sample frame and recording the ground cover component with which the pin first makes contact. Ground cover was classified into six groups for recording. These groups included grass, plant, moss, rock, soil, and litter. Grass was defined as any narrow-leafed monocotyledonous plant with grass-like plants such as sedges and rushes considered as grass cover. Plant cover was defined as any living vegetation exclusive of grasses and mosses and thus included herbaceous and woody vegetation types. Rock was defined as any cobble greater than 10 mm in diameter as outlined by the USDA Textural classification system (1971) and included exposed bedrock. Soil was defined as exposed mineral soil and litter was defined as any decaying organic matter greater than one millimeter in diameter.

The frame was set at an angle of 45° to the ground surface and the notches were spaced 2.5 cm (1 in.) apart. Percent cover for each component is calculated by dividing the number of contacts for that component by ten (the number of samples per frame) and multiplying by 100. These values were then averaged for each site in order to obtain an estimate of percent ground cover by component for that site.

In use, three sampling frame locations were determined for each bank at each sampling station by obtaining three numbers from a table of random numbers between 0 and 100. These numbers were multiplied by the total transect length and the result divided by 100 in order to obtain the distance from stream center to the sample frame locations. Random numbers which resulted in a sample frame location in the stream channel were eliminated.

Understory Layer

The understory layer was sampled using the line intercept method as outlined by Larson (1958). At each sampling station, a cloth tape was suspended between two 1.25 cm in diameter by 2 m long steel poles using modified vise-grips as clamps. Point zero on the tape was positioned at stream center and the tape was extended up the bankslope and perpendicularly to the streamflow for a distance equal to two times the average stream width. A plumb-bob was used to traverse the length of the tape to determine the intersection distance of the dominant vegetation in an imaginary plane above and below the transect. The dominant vegetation species and points of interception on the tape were recorded. If an unknown species was encountered, a sample was collected and sealed in a poly bag for future identification. All species were recorded according to growth form and species using alpha codes as presented by Garrison and Skovlin (1976). These growth forms included grass, grass-like plants, forbs and ferns, shrubs and trees. Shrubs and trees were also distinguished relative to their potential nitrogen-fixing capabilities, and trees were additionally coded as either coniferous or deciduous.

Cover other than live vegetation was also observed and recorded. These other cover types were categorized as follows:

1. Logs: logs greater than 10 cm (4 in.) diameter including stumps and slash piles.
2. Rock: exposed bedrock or talus.
3. Streambed: stream channel below the high water mark.
4. Soil: exposed mineral soil.
5. Litter: organic matter less than 10 cm in diameter.

If the cover was not homogeneous, i.e., consisting of two or more of these cover types, the cover was recorded as mixed/dominant. Cover was considered to be mixed when no single cover type occupied more than 75 percent of the cover. This type of cover was recorded as mixed/dominant with the single most apparent cover type recorded as the dominant.

At each of the five sampling stations, two line intercept samples were taken by locating a transect on each bank. Interception points were measured and recorded to the nearest 3.05 cm (0.1 ft.). Percent cover at each transect for a given cover type was calculated by dividing the sum of the intersection distances by the total transect length and multiplying the result by 100.

Overhanging Vegetation

The distance from stream center to the estimated annual high water mark was also determined in order to obtain an estimate of the percent of the channel covered by overhanging vegetation. Recognizing that the annual high water mark is somewhat difficult to ascertain, it was felt that this value would give a good relative estimate of the channel width when determined by the same observer for the entire study.

The definition of the stream channel follows that of Pfankuch (1975). For this study, the channel was considered to be the channel bottom and the lower banks. The channel bottom is the submerged portion of the channel cross section and is a totally aquatic environment. The lower banks consist of the intermittently submerged portion of the channel cross section from the normal high water line to the water edge during the summer low flow period (Pfankuch, 1975). The lower banks define the present stream width and encroachment of the water environment into the land environment from year to year is very minor under a given flow regimen. Both terrestrial and aquatic plants may grow on the lower bank, but normally their density is low.

Several indicators were used to determine the upper limit of the lower bank. These included an abrupt, obvious change to a dense terrestrial plant cover, a break in the bank slope, accumulations of small floatable organic debris, an undercut bank, or deposits of sediment on the bank. Percent channel cover by overhanging vegetation was calculated by summing the intersection distances for a given cover type, dividing by the stream width at that sampling station and dividing the result by 100. A sample was taken at each of the five stations which resulted in five observations per site.

Overstory Layer

Overstory cover. Vegetation in the overstory layer (greater than 2.5 meters) was sampled using the line intercept method as described in the understory section. Interception points were recorded to the nearest 15.2 cm (0.5 ft.) and species were coded as coniferous or deciduous and as n-fixing or non-fixing.

Random Pairs method. Overstory vegetation was sampled in order to characterize the development of the tree species within the riparian zone. A tree was sampled if the stem diameter at breast height was five centimeters or greater as defined by Hawk

(1978). The trees were sampled using the Random Pairs method as discussed by Phillips (1959) and presented in Figure 6. This method utilizes spacing distances rather than fixed-area sample plots as a sampling design. Thus, instead of sampling a relatively small plot in terms of abundance, the area occupied by a single individual is determined. The method involves selecting trees to be sampled by means of an exclusion angle. Different angles are used, but Phillips (1959) recommends that 180 degrees be used for best results.

To use the method, a random number was obtained and used to determine a point on the tape transect. From that point, the nearest tree (tree A) was selected and the stem diameter at breast height was measured and recorded along with the species of the tree. The next tree in the pair was selected by choosing the nearest tree to tree A outside the area of exclusion. This area was determined by a 180-degree angle with the vertex of that angle located at the initial random point on the transect and oriented towards the first tree observed (tree A). Essentially, this meant that the next tree (tree B) was selected by choosing the nearest tree from tree A across the tape transect. The distance between the two trees and the stem diameter of tree B was measured and recorded with the tree species. The trees were further coded as coniferous or deciduous and as n-fixing or non-fixing.

Only trees within the defined sample zone were eligible for selection and trees in adjacent stands at the up- and downstream boundaries of the clearcut were excluded. Stem diameters were measured to the nearest 0.25 cm (0.1 in.) and distances to the nearest 15 cm (0.5 ft.). All species were recorded using the Garrison and Skovlin (1976) alpha codes.

At each transect, two random numbers were selected which resulted in four stem diameter and two distance measurements for that transect. Ten transects per site resulted in forty stem

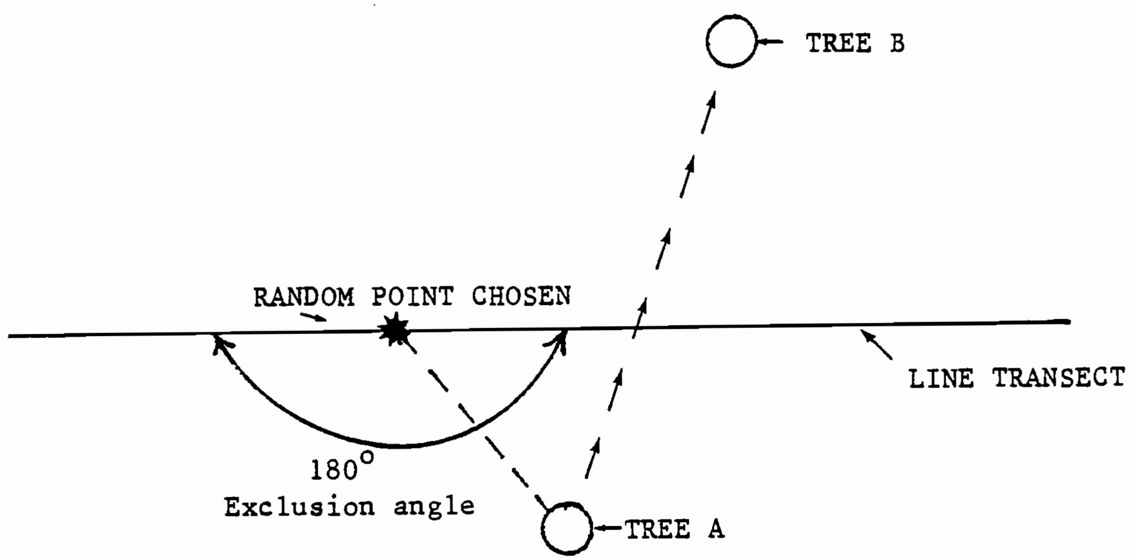


Figure 6. Diagram showing the Random Pairs Method used in data collection.

diameter and 20 distance samples for each site. Recent clearcuts and young stands often did not have sufficient numbers of trees in the appropriate size class and a smaller sample size resulted. The resulting data were summarized using the following equations:

1. Mean distance between individual stems,

$$\bar{d} = \frac{0.8(\Sigma d)}{n_d} \qquad \text{Equation 1}$$

2. Stem density,

$$D = 43560/(0.8)\bar{d}^2 \qquad \text{Equation 2}$$

3. Mean area occupied by a single individual,

$$A = (0.8\bar{d})^2 \qquad \text{Equation 3}$$

4. Total basal area per acre,

$$BA = (\overline{bA})(D) \quad \text{where } \overline{bA} = \frac{\Sigma bA}{n_s} \qquad \text{Equation 4}$$

5. Mean stem diameter,

$$S_d = \frac{\Sigma(DBH)}{n_s} \qquad \text{Equation 5}$$

6. Relative dominance,

$$R = 100 \left[\frac{\text{TOTAL BA of species } \times}{\text{TOTAL BA all species}}\right] \qquad \text{Equation 6}$$

7. Relative density,

$$r = 100 \left[n_i/n_s\right] \qquad \text{Equation 7}$$

where d is the sampled distance, n_d is the total number of sampled distances per site, n_s is the total number of sampled stem diameters per site, n_i is the total number of individuals of a given species i sampled per site and bA is the basal area of a stem with a given diameter at breast height (DBH).

The relative dominance and the relative density were calculated for each site for each species, vegetation type (coniferous or deciduous) and N-fixing type (species grouped according to their nitrogen fixing capabilities). The remaining summary values were computed for each site.

Canopy density. Percent canopy cover was measured at stream center at each sampling station using a spherical canopy densiometer developed by Lemmon (1956). This device consists of a 5.0 cm (2 in.) dome-shaped mirror with a grid of 24 squares etched onto its surface. The device is normally held at breast height and the number of quarter squares (96 possible) covered with the reflection of vegetation are summed and multiplied by 0.96 to give percent cover. This is repeated in the four cardinal directions and averaged to obtain the sample density.

As a result of the curved reflecting surface, the densiometer readings overlap when the device is used to estimate density over a single location. Strickler (1959) estimated that 42, 4, and 20 of the 96 possible quarter squares observed in any one direction would be observed two, three, and five times, respectively, in the other three directional observations. This would result in an overestimation of point averages for the canopy density. He presents the following modifications to this device that were utilized in this study.

As ordinarily used, natural body movement makes it difficult to keep the hand-held instrument level and oriented correctly while the observer takes the reading. Also, difficulty in positioning the densiometer over the same point while the observer changes viewing orientation and problems in maintaining a consistent viewing angle between the densiometer and the observer required physical modification of the device.

The densiometer was fastened to a tripod equippped with a ball and socket head to provide a quick and efficient means to consistently level and orient the densiometer at a height of 61 cm (24 in.).

The problem of overlapping readings was solved by modifying the method of reading the device. Using this modification, canopy density is estimated by counting the number of points created by the intersection of the grid lines that are covered by reflected vegetation in a wedge-shaped area of the densiometer. Twenty-four possible points in each direction each have a value of 4.167 percent when calculating directional densities, and 1.04 percent when calculating the average plot density.

In use, the densiometer was placed at stream center at each sampling station, leveled, and oriented with a hand compass such that the grid lines were parallel and perpendicular to the four cardinal directions. The observer then counted the number of dots covered with reflected vegetation in each of the four cardinal directions as he stood in the four positions around the densiometer. The viewing distance between the observer's eye and the densiometer was kept constant at approximately 75 cm (30 in.) and the angle of viewing remained consistent by adjusting the viewing position to keep the position of the eye reflection in the densiometer at the lower center grid dot.

The average plot density was determined at each of the five sampling stations and then averaged to give an estimate of the canopy density for each site. Vegetation in adjacent stands was excluded from the readings, thus restricting the sample to canopy cover provided by vegetation within the clearcut unit.

Stream shade. Angular canopy density (ACD) is a measure of the percent shade provided to the stream by vegetation directly south of the channel (Brazier, 1973). In western Oregon, streams are most susceptible to temperature increases during a period around August 28, when low stream flows combine with a high solar angle to produce maximum heat loads per unit volume of water. The angular canopy densiometer as described by Brazier (1973) and later modified by Froehlich (1975) was used to measure this quantity. This device consists of a plane mirror 30 cm (12 in.) on a side which is set in a frame and mounted on a tripod using a ball and socket head. The mirror is divided into 16 equal sections 7.5 cm (3 in.) on each side. The mirror is positioned at stream center and oriented such that the grid matches the true north-south and east-west directions. An abney level is used to set the east-west axis horizontal and tilt the north-south axis to the desired viewing angle. The mirror center was held at a height of 65 cm (26 in.)

The proper viewing angle is determined by the maximum solar angle during the critical period around August 28. The angle used is one-half the complement of the maximum solar angle. The maximum solar angle, which occurs at solar noon, is calculated as follows:

$$A = 90 - L + d \qquad \text{Equation 8}$$

where A is the maximum sun angle, L is the latitude of the site and d is the declination angle of the sun for the desired date. The declination of the sun is equal to +10°00' on August 28 and was used as the value for d for this study.

The observer looks vertically down on the mirror and estimates what percent of each of the 16 squares is covered by vegetation. These values are then averaged to get an estimate of the ACD at that stream location. The two types of vegetation providing the majority of the shade and their respective relative contribution to shade cover were also observed and recorded. These species were coded by growth form as described for understory data. The angular canopy density reading was taken at each of the five sampling stations and averaged to obtain the site average. The resulting data were summarized by total percent ACD, and percent of shade provided by species, growth form, and vegetation type (coniferous vs. deciduous).

Froehlich (1975) calculated the field of view for the densiometer assuming a latitude of 44°N, a viewing height of 34 inches (86 cm) and a hemispherical canopy 100 feet (30.5 m) from the center of the mirror. This field of view included canopy that would be observed from solar paths corresponding to July 24 to September 21 viewing dates during a period of the day from approximately 11:40 a.m. to 12:20 p.m. Under these conditions, the field of view covers approximately 1224 square feet (113.7 m^2) of canopy. It should be noted that anytime the latitude or declination angle in Equation 8 changes this field position will change and that any change in viewing height or canopy distance will result in a different field coverage.

Large Organic Debris

The quantity of Large Organic Debris (LOD) in the stream reach was sampled using a simple tally method. Pieces greater than 10 cm (4 in.) in diameter and greater than or equal to the mean stream width were counted. At each site, all pieces of LOD were counted between sampling stations one and five. A piece was tallied if any portion of that piece was in or suspended above the stream channel. The number of pieces counted and the total distance included in the sample were recorded and used to calculate the results in terms of the number of pieces per 30.5 m (100 feet). This method was chosen because the time available at each site would not allow for a more intensive sample of the debris volume and it was felt that the tally would give a good index of any potential time trends in debris loading to the stream channel.

Site Characteristics

Field data. Field and office data were gathered to describe each site as fully as possible. Stream gradient, stream orientation, and the slope of each bank were measured in the field at each site. The stream gradient was measured to the nearest 0.5 percent at each sampling station by sighting downstream to the previous sample station using a clinometer with both observers standing at the stream edge. Stream orientation was determined at each sampling station by using a hand compass oriented in a downstream direction with the north-south axis parallel to the streamflow at that point. The orientation was recorded as an azimuth between 0 and 360°. The bank slope perpendicular to the streamflow was measured for each bank at each sampling station using a clinometer. The slope was measured from the channel edge to the upslope limit of the sampling zone and recorded to the nearest percent. A photograph was taken at each site to document the site for future comparisons.

Office data. Stream order, site elevation, normal annual precipitation, size of harvest unit, watershed aspect, land ownership or managing agency, and public land survey description were determined in the office for each site. Stream order, site elevation, watershed aspect, and the legal description were determined by plotting the approximate unit boundaries on 15-minute U.S. Geological Survey topographic maps with 24.4 m (80 ft.) contours.

Stream order was determined following the definition outlined by Horton (1945) and modified by Strahler (1964). This method is as follows: (1) the uppermost fingertip tributaries as delineated on a given map scale are designated as order one, (2) where two n order channels join, they form a $n+1$ order channel. The 15-minute USGS maps have a scale of 1:62500 and only perennial streams were counted in the stream order determination. Some first-order perennial streams were not depicted on the maps and the stream order was determined by field survey and aerial photographs.

Site elevation was determined by calculating the mean of the highest and lowest elevations of the stream channel in the harvest unit. Watershed aspect was described as one of eight directions (N, NE, E, SE, S, SW, W, NW). The survey description of the site was noted to the section subdivision.

The normal annual precipitation was determined for each site using the state of Oregon precipitation map published by the Soil Conservation Service (1964). This map was developed using a period of record from 1930 to 1957 and isohyetal contours range from two to ten inches (5 cm to 25 cm). Precipitation values for sites in southwest Oregon (mixed conifer zone) were determined using a precipitation map developed by Froehlich et al. (in press). Precipitation values were noted as the average of two adjacent isohyetes.

The size of the harvest unit was found for each site using USFS reforestation activity record cards, the Total Resource Inventory System (TRI), or literature sources which describe the plot.

Statistical Analysis

Mean values and standard error for all the vegetation variables sampled were computed for each site.

Linear-regression was determined to be inappropriate for the angular canopy density versus stand age data. Scattergrams of the data used in conjunction with knowledge about typical biological responses indicated that the data had an approximate sigmoid-shape curve. A procedure outlined by Jensen (1970) was used to transform the variable stand age (the independent variable) such that simple linear regression could be used to develop an equation describing these data.

The transformation on stand age (X) is of the general form as follows:

$$X' = e^{-\left[\frac{X/c_1 - 1.0}{c_2}\right]^{c_3}} \qquad \text{Equation 9}$$

The values of c_1, c_2, and c_3 are determined for each zone by plotting the raw data set on a standardized plot and comparing this curve to a set of given standard curve forms until this plot is reproduced. This first approximation of the values c_1, c_2, and c_3 are then interpolated between given standard values to find the final values used in the transformation.

The resulting model was checked for appropriateness by performing residual analysis, constructing a normal plot of the residuals, calculating the skewness and kurtosis, and conducting an F-test of the hypothesis of slope (β_1) equals zero.

VIII. RESULTS AND DISCUSSION

Descriptive Data for Sites

The data describing the location and characteristics of each site are summarized in Table 3. Mean elevation for sites in the *Tsuga heterophylla* Zone and the *Abies amabilis* Zone in the Cascade Range was 2630 feet (802 m) and 3670 feet (1120 m), respectively. The elevation averaged 960 feet (293 m) for the Coast Range *Tsuga heterophylla* Zone and 520 feet (158 m) for the *Picea sitchensis* Zone, while the southwestern Oregon Mixed Conifer Zone averaged 2850 feet (869 m).

Sites in the Cascade zones covered a period of 24 years and sites in the Mixed Conifer Zone ranged from one to 29 years of age. Coast Range sites spanned 22 years and 16 years in the *Tsuga* and *Picea* zones, respectively.

The study streams are all first- or second-order and stream widths generally average less than 15 feet (4.5 m). Stream gradients ranged between 2.0 and 27.6 percent and averaged 10.7. Bank-slopes ranged between 16.0 and 58.2 percent and averaged 34.4 percent which illustrates the typically steep nature of headwater channels in the Pacific Northwest. It should be emphasized here that the results from this research apply to first- and second-order streams.

All but four sites were clearcut and broadcast burned as a method of slash disposal. Sites 2, 10, 31, and 34 were pile-burned rather than broadcast-burned. The sites were primarily located on lands managed by the U.S.D.A. Forest Service with only three sites located on lands managed by the U.S.D.I. Bureau of Land Management and three on lands owned by private corporations.

TABLE 3

Description and Location of the Study Sites

Site	Legal Description	Managing Agency	Age (yrs)	Stream Order	Elevation in feet (m)	Mean Annual Precipitation in inches (cm)	Mean Stream Orientation (degrees)	Mean Stream Width in feet (m)	Mean Stream Gradient (percent)	Mean Sankslope (percent)
	Tsuga heterophylla Zone. Cascade segment									
1	T11S. R5E. Sec 27	U.S.F.S.	1	1	2760 (841)	110 (279)	209.0	5.04 (1.54)	9.3	30.9
2	T19S. R5E. Sec 12	U.S.F.S.	7	1	3040 (927)	70 (178)	61.6	14.66 (4.47)	8.3	38.6
3	T14S. R5E. Sec 36	U.S.F.S.	10	1	2720 (829)	140 (356)	138.8	15.76 (4.80)	7.2	46.1
4	T24S. R1W. Sec 15	BLM	13	2	2440 (744)	60 (152)	101.4	19.54 (5.96)	7.6	37.4
5	T22S. R5E. Sec 17	U.S.F.S.	15	2	2280 (695)	55 (140)	42.2	7.50 (2.29)	10.4	21.5
6	T17S. R5E. Sec 19	U.S.F.S.	19	2	2720 (829)	85 (216)	93.6	9.62 (2.93)	3.0	23.1
7	T15S. R4E. Sec 20	U.S.F.S.	20	1	2400 (732)	105 (267)	185.8	7.96 (2.43)	27.6	31.8
8	T21S. R4E. Sec 3	U.S.F.S.	24	2	2640 (805)	50 (127)	210.6	8.42 (2.57)	9.0	21.4
9	T15S. R5E. Sec 35	U.S.F.S.	OG	1	2640 (805)	100 (254)	65.6	18.66 (5.69)	23.6	50.3
	Abies amabilis Zone									
10	T13S. R5E. Sec 24	U.S.F.S.	8	1	3520 (1073)	105 (267)	118.2	7.58 (2.31)	23.0	47.6
11	T4S. R8E. Sec 32	U.S.F.S.	8	1	4000 (1219)	70 (178)	283.0	9.64 (2.94)	13.8	18.2
12	T15S. R4E. Sec 28	U.S.F.S.	14	1	3340 (1018)	100 (254)	342.2	11.18 (3.41)	13.6	51.3
13	T5S. R7E. Sec 16	U.S.F.S.	17	2	3560 (1085)	60 (152)	71.4	18.22 (5.55)	6.7	23.0
14	T10S. R8E. Sec 18	U.S.F.S.	19	2	3920 (1195)	85 (216)	244.0	11.34 (3.46)	13.4	42.8
15	T13S. R5E. Sec 6	U.S.F.S.	24	1	3420 (1042)	110 (279)	135.6	11.22 (3.42)	9.6	28.5
16	T5S. R7E. Sec 11	U.S.F.S.	24	1	3600 (1097)	65 (165)	120.6	9.58 (2.92)	10.2	22.7
17	T10S. R8E. Sec 18	U.S.F.S.	OG	1	4000 (1219)	85 (216)	214.4	11.00 (3.35)	13.2	37.6
	Tsuga heterophylla Zone. Coast segment									
18	T19S. R10W. Sec 15	U.S.F.S.	2	1	1300 (396)	95 (241)	324.6	8.96 (2.73)	15.2	34.1
19	T19S. 410W. Sec 14	U.S.F.S.	3	1	1120 (341)	95 (241)	306.8	8.12 (2.47)	13.4	24.0
20	T19S. R10W. Sec 10	U.S.F.S.	9	1	800 (344)	95 (241)	19.4	12.08 (3.68)	5.8	32.4
21	T7S. R10W. Sec 9	U.S.F.S.	9	1	1050 (320)	95 (241)	286.8	6.42 (1.96)	5.0	39.4
22	T12S. R10W. Sec 24	Boise Cascade	15	1	600 (183)	105 (267)	182.6	7.36 (2.24)	2.0	16.0
23	T16S. R9W. Sec 5	U.S.F.S.	18	1	1150 (351)	100 (254)	45.2	13.68 (4.17)	19.9	58.2
24	T12S. R9W. Sec 15	U.S.F.S.	22	1	800 (344)	105 (268)	218.8	5.48 (1.67)	26.6	56.8
25	T8S. R10W. Sec 6	U.S.F.S.	OG	2	870 (265)	90 (229)	209.0	10.36 (3.16)	11.7	52.9

TABLE 3 (continued)

Site	Legal Description	Managing Agency	Age (yrs)	Stream Order	Elevation in feet (m)	Mean Annual Precipitation in inches (cm)	Mean Stream Orientation (degrees)	Mean Stream Width in feet (m)	Mean Stream Gradient (percent)	Mean Bankslope (percent)
	Picea sitchensis Zone									
26	T15S. R12W. Sec 35	U.S.F.S.	2	1	320 (98)	95 (241)	305.0	12.50 (3.81)	4.8	22.8
27	T13S. R11W. Sec 33	U.S.F.S.	3	1	560 (171)	85 (216)	342.0	10.28 (3.13)	6.0	30.6
28	T6S. R10W. Sec 11	U.S.F.S.	5	1	840 (256)	95 (241)	237.8	6.56 (2.00)	9.6	20.0
29	T14S. R11W. Sec 5	U.S.F.S.	8	2	280 (85)	60 (229)	207.4	14.92 (4.55)	2.8	32.3
30	T5S. R10W. Sec 14	U.S.F.S.	10	1	960 (293)	90 (229)	260.4	9.30 (2.83)	7.5	37.1
31	T13S. R11W. Sec 33	U.S.F.S.	16	1	600 (183)	85 (216)	333.2	9.40 (2.87)	5.6	30.6
32	T15S. R12W. Sec 34	U.S.F.S.	OG	1	100 (31)	95 (241)	335.8	15.40 (4.69)	3.6	27.6
	Mixed Conifer Zone									
33	T33S. R1E. Sec 2	Georgia Pacific	1	2	2660 (811)	30 (76)	137.8	5.46 (1.66)	5.1	22.7
34	T29S. R1E. Sec 28	U.S.F.S.	8	1	2530 (771)	35 (89)	69.0	4.76 (1.45)	7.4	52.7
35	T32S. R1W. Sec 36	Georgia Pacific	9	1	2700 (823)	35 (89)	234.2	4.78 (1.46)	22.2	46.8
36	T33S. R2E. Sec 31	BLM	15	1	2620 (800)	19 (48)	267.2	3.86 (1.18)	6.6	20.8
37	T36S. R2E. Sec 3	BLM	16	1	2520 (768)	37 (94)	207.2	8.30 (2.53)	9.2	44.6
38	T30S. R3E. Sec 15	U.S.F.S.	21	2	3470 (1100)	50 (127)	118.6	11.46 (3.49)	12.4	27.5
39	T31S. R3E. Sec 1	U.S.F.S.	29	2	3380 (1030)	50 (127)	252.2	12.78 (3.90)	3.6	17.1
40	T32S. R4E. Sec 31	U.S.F.S.	OG	2	2900 (884)	55 (140)	150.8	12.56 (3.83)	11.6	49.1

The Cascade Range Zones

Ground Cover

The resulting data from the ground cover sample are summarized in Table 4. Values of percent grass and percent plant cover were combined to yield percent total vegetation cover and values for percent rock and percent soil were combined to yield percent background.

In the *Tsuga heterophylla* Zone, grass and moss cover do not exceed nine and 11 percent, respectively, for eight sample sites spanning a 24-year period, and moss cover on the 24-year-old site is only one-half the percentage sampled for the control site. Plant cover shows a fairly strong relation with age ($r^2 = 0.50$), steadily increasing to approximately 45 percent cover after 24 years. This is almost a three-fold increase over the control cover illustrating the shading effect of a closed old-growth canopy on the typically sparse ground layer plant cover.

Percent litter is high initially following harvest (51%) and only drops slightly on older sites in both the *Tsuga* and *Abies* zones. This slight decline is probably attributable in most cases to increases in plant cover in the ground layer which tends to cover the litter at the ground surface.

Percent rock and percent soil exposed are both near 20 percent during the early years following harvest and tend to decrease to values less than five percent after a period of 15 years. In the *Abies* Zone, rock and soil cover are near 10 percent in young stands and decrease to approximately two percent after 24 years.

Total vegetation cover and bareground exposed in the *Tsuga* Zone experienced opposing trends with vegetation cover increasing with age ($r^2 = 0.54$) and bareground decreasing with age ($r^2 = 0.47$). After a 20-year period total vegetation cover was greater than 50 percent and in only 15 years the percent of the ground layer in

TABLE 4

Mean Values and Standard Errors ( ) for Ground Layer Cover for the Cascade Range Zones

Site	Age (yrs)	% Grass Cover	% Plant Cover	% Moss Cover	% Litter Cover	% Rock Cover	% Soil Cover	% Total Vegetation Cover	% Bareground
	Tsuga heterophylla Zone								
1	1	2.0 (1.21)	28.7 (4.17)	0.0	51.0 (4.22)	1.7 (1.67)	16.7 (3.30)	30.7 (4.39)	18.3 (3.43)
2	7	3.7 (2.22)	12.7 (3.21)	3.3 (1.21)	53.0 (5.82)	21.7 (5.63)	5.7 (2.23)	16.3 (3.51)	27.3 (5.73)
3	10	1.7 (1.18)	12.3 (2.94)	9.0 (4.68)	35.7 (5.44)	21.7 (5.05)	19.3 (4.34)	14.0 (3.04)	41.0 (6.13)
4	13	6.0 (2.18)	37.3 (3.80)	1.3 (0.93)	33.3 (2.46)	17.0 (3.62)	4.7 (1.96)	43.3 (3.99)	21.7 (4.13)
5	15	3.0 (2.10)	37.7 (4.49)	1.3 (1.04)	49.7 (5.15)	3.7 (2.00)	4.3 (1.90)	40.7 (4.52)	8.0 (2.56)
6	19	1.3 (1.04)	50.3 (4.19)	1.7 (1.18)	45.7 (4.64)	0.0	0.7 (0.46)	51.7 (4.32)	0.7 (0.46)
7	20	8.7 (2.78)	46.3 (3.64)	4.7 (2.23)	37.0 (3.40)	2.3 (1.24)	1.0 (0.74)	55.0 (4.09)	3.3 (1.38)
8	24	5.7 (1.84)	41.3 (3.74)	10.7 (2.19)	40.0 (4.21)	0.0	2.3 (1.24)	47.0 (4.13)	2.3 (1.24)
9	OG	0.0	15.7 (2.74)	24.3 (4.03)	57.0 (4.24)	2.0 (1.39)	1.0 (0.74)	15.7 (2.74)	3.0 (1.53)
	Abies amabilis Zone								
10	8	0.0	19.3 (3.71)	1.7 (1.08)	62.0 (5.56)	6.0 (3.82)	11.0 (2.55)	19.3 (3.71)	17.0 (4.80)
11	8	3.3 (1.88)	35.7 (4.09)	2.0 (1.11)	54.3 (3.64)	0.0	4.7 (2.08)	39.0 (4.08)	4.7 (2.08)
12	14	3.3 (2.16)	29.3 (4.29)	0.0	53.0 (4.16)	8.0 (3.23)	6.3 (2.69)	32.7 (4.52)	14.3 (4.14)
13	17	2.3 (1.04)	28.0 (2.46)	2.0 (1.01)	62.3 (3.48)	4.3 (1.84)	1.0 (0.74)	30.3 (2.51)	5.3 (2.34)
14	19	2.7 (1.51)	44.7 (3.86)	3.3 (1.68)	44.3 (3.89)	2.3 (1.64)	3.0 (1.37)	47.3 (3.89)	5.3 (2.61)
15	24	0.0	40.0 (4.52)	3.0 (1.37)	50.3 (3.82)	0.7 (0.46)	6.0 (2.33)	40.0 (4.52)	6.7 (2.46)
16	24	2.7 (1.26)	30.7 (4.12)	1.7 (0.84)	61.7 (4.18)	1.0 (1.00)	2.3 (0.92)	33.3 (4.56)	3.3 (1.30)
17	OG	0.0	20.0 (3.56)	13.6 (3.41)	66.3 (5.11)	0.0	0.0	20.0 (3.56)	0.0

exposed soil or rock was less than ten percent. The value for total vegetation cover at the 24-year-old site is again nearly three times the control site cover emphasizing the dominance of low vegetative cover during early successional stages.

In the *Abies amabilis* Zone, grass and moss covers do not exceed four percent during the entire 24-year period and moss cover is only one percent of the control site cover after 24 years. Like the lower elevation *Tsuga* Zone, plant cover increased to approximately 40 percent cover after 24 years, which is nearly twice as high as the undisturbed forest site cover.

Total vegetation cover and percent bareground exposed did not correlate with stand age as well as was seen in the *Tsuga* Zone, but an increasing trend in vegetation cover and a decreasing trend in bareground can be seen. Vegetation cover is approximately 35 percent after a stand age of eight years and bareground exposed is approximately five percent after 14 years.

Understory Vegetation Layer

Vegetation in the understory layer was classified as coniferous, deciduous, and herbaceous cover for analysis. Deciduous cover was further classified as nitrogen-fixing species cover and non-fixing cover. Table 5 presents the total understory cover by all vegetation types combined (grass, herbaceous, deciduous, and coniferous) with this cover subdivided by the coniferous, deciduous, herbaceous and nitrogen-fixing cover for the two Cascade Range zones.

Total cover is highly correlated with stand age in both the *Tsuga* and *Abies* zones ($r^2 = 0.86$ and $r^2 = 0.76$, respectively). The percent cover in the lower elevation *Tsuga* Zone is 37 percent at age one and steadily increases with age to a value greater than 80 percent at age 24. The *Abies* Zone has approximately 50 percent cover after eight years and increases to approximately

TABLE 5

Mean Understory Vegetation Layer Cover Values with Standard Errors ( ) for the Cascade Range Zones

Site	Age (yrs)	Total Cover n of 10	% Total Cover	% Deciduous Cover	% Conifer Cover	% Herbaceous Cover	% Nitrogen-fixing Cover
	Tsuga heterophylla Zone						
1	1	9	37.4 (6.03)	14.3 (3.91)	0.0	23.1 (6.94)	0.0
2	7	10	45.0 (3.97)	27.5 (5.33)	1.6 (1.09)	15.8 (3.67)	1.0 (1.03)
3	10	10	48.3 (4.07)	27.1 (4.11)	0.0	21.2 (5.86)	2.6 (1.67)
4	13	10	57.4 (6.59)	40.4 (8.55)	6.7 (3.64)	10.2 (4.58)	17.4 (7.51)
5	15	10	64.4 (11.31)	41.1 (8.34)	16.9 (7.19)	6.4 (2.56)	25.4 (7.48)
6	19	10	91.9 (6.27)	45.4 (10.92)	23.9 (6.39)	22.6 (7.44)	0.0
7	20	10	85.2 (7.61)	77.8 (5.13)	5.1 (4.64)	2.3 (2.25)	44.2 (9.53)
8	24	10	82.5 (6.56)	47.0 (4.92)	20.6 (5.31)	14.9 (4.66)	4.8 (2.58)
9	OG	10	68.4 (9.44)	34.0 (7.74)	27.0 (7.40)	6.5 (2.26)	0.3 (0.25)
	Abies amabilis Zone						
10	8	10	50.8 (8.27)	34.8 (10.97)	2.4 (2.42)	13.6 (5.48)	6.0 (3.65)
10	8	10	64.1 (6.69)	30.5 (9.44)	1.2 (0.83)	32.4 (4.59)	22.4 (8.57)
12	14	10	60.3 (6.08)	42.2 (7.12)	5.5 (3.88)	12.6 (3.04)	0.0
13	17	10	61.7 (4.50)	39.4 (7.43)	4.8 (2.20)	17.4 (2.30)	18.2 (0.23)
14	19	10	68.9 (5.36)	39.2 (7.11)	10.8 (4.71)	18.9 (3.43)	14.5 (4.48)
15	24	10	80.0 (12.39)	50.4 (10.38)	16.7 (7.42)	12.9 (5.36)	6.9 (4.78)
16	24	10	84.3 (8.67)	70.3 (7.45)	8.5 (6.45)	5.5 (3.34)	35.3 (8.49)
17	OG	10	54.2 (5.73)	31.6 (5.09)	21.4 (6.63)	1.2 (0.89)	0.7 (0.73)

80 percent after 24 years. This is in contrast to the mean bank cover at the control sites for each zone. The mean cover at the *Tsuga* and *Abies* control sites was 68 and 54 percent, respectively.

Herbaceous cover when expressed as a percent of the total vegetation cover is high during the first ten years following harvest (mean of 46% of the total cover for the first three sites) and relatively low thereafter (mean of 14% of the total cover for stand ages 13 through 24 in *Tsuga* Zone and 20% in the *Abies* Zone).

Deciduous cover dominates the site cover during the entire 24-year span of sites in both zones. Deciduous cover is generally less than 50 percent with values approaching 40 percent after a period of 13 years, although each zone has a site with greater than 70 percent deciduous cover after a period of 20 years. The percent of this deciduous cover in nitrogen-fixing species ranges between zero and 62 percent for the *Tsuga* Zone and zero and 73 percent for the *Abies* Zone and averages 26 and 33 percent, respectively.

Coniferous cover is not present in the *Tsuga* Zone except at sites at least seven years old and is relatively low until a stand age of 10 years (1.6 and 6.7 percent cover, respectively). After a period of 15 years, coniferous cover provided approximately 25 percent of the total cover and generally remained at this value (except Site 7 at 20 years) for the remainder of the sites.

In contrast, the *Abies* Zone generally had low coniferous cover for the entire 24-year chronosequence of sites. Sites less than 19 years all had approximately five percent coniferous cover which contributed less than 10 percent to the total understory layer cover. Sites 14 and 15 at stand ages of 19 and 24 years had 11 and 17 percent coniferous cover which represented 16 and 21 percent of the total cover. It is interesting to note the variability in the coniferous cover between sites 15 and 16 at 24 years. Site 15 has nearly twice the coniferous cover as Site 16 which had a dense development of deciduous shrubs and Alnus sinuata saplings.

The total percent understory layer cover at the control sites was 68 percent for the Tsuga Zone and 54 percent for the Abies Zone. This cover consists of approximately 50 percent deciduous cover, 40 percent coniferous cover and less than 10 percent herbaceous cover. This diverse pattern of understory cover was not observed in either zone during the entire 24-year period that the sites covered.

Overstory Vegetation Layer

The resulting data from the overstory vegetation layer cover estimates obtained using the line-intercept sampling for the two Cascade Range zones are summarized in Table 6. Although coniferous species may begin to attain sizes of two inches or greater on sites as early as 13 years as indicated by the random pairs data, these data show that the influence of those trees on overstory cover (greater than 8 ft. or 2.5 m) is marginal throughout the entire 24-year period.

In both zones, the data indicate that the understory layer dominates throughout the first two to three decades following harvest. The Abies Zone did not have a developed overstory layer in the entire 24-year chronosequence and the Tsuga Zone did not have any overstory vegetation until Site 8 at 24 years of age which had an overstory layer with less than 50 percent cover. Three-fourths of this cover was deciduous with 23.5 percent cover provided by the nitrogen-fixing Alnus rubra and the remainder predominatly Acer circinatum.

It is interesting to note that the control sites had a total percent cover of 68 and 61 percent for the Tsuga and Abies zones, respectively, with only less than five percent cover in deciduous species. The dominance of the coniferous overstory is quite

TABLE 6

Mean Overstory Vegetation Layer Cover
Values with Standard Errors ( )
for the Cascade Range Zones

Site	Age (yrs)	Total Cover n of 10	% Total Mean Cover	% Coniferous Cover	% Deciduous Cover	% Nitrogen-fixing Cover
	Tsuga heterophylla					
1	1	0	0.0	0.0	0.0	0.0
2	7	0	0.0	0.0	0.0	0.0
3	10	0	0.0	0.0	0.0	0.0
4	13	0	0.0	0.0	0.0	0.0
5	15	0	0.0	0.0	0.0	0.0
6	19	0	0.0	0.0	0.0	0.0
7	20	0	0.0	0.0	0.0	0.0
8	24	5	46.2 (15.8)	13.1 (8.7)	33.1 (14.9)	23.5 (13.2)
9	OG	10	68.0 (6.3)	63.3 (7.5)	4.8 (3.4)	0.0
	Abies amabilis Zone					
10	8	0	0.0	0.0	0.0	0.0
11	8	0	0.0	0.0	0.0	0.0
12	14	0	0.0	0.0	0.0	0.0
13	17	0	0.0	0.0	0.0	0.0
14	19	0	0.0	0.0	0.0	0.0
15	24	0	0.0	0.0	0.0	0.0
16	24	0	0.0	0.0	0.0	0.0
17	OG	9	61.3 (11.2)	58.7 (12.4)	2.7 (2.7)	2.7 (2.7)

evident with very few deciduous species developing a distinct layer greater than eight feet (2.5 m) in height. Also, the overstory layer in the riparian zone is demonstrated to be somewhat open and not a dense, completely closed canopy.

It is important here to note the reliability of some of these overstory layer estimates. The standard error estimate approaches one-half of the mean value at Site 8 at 24 years. This is due largely to a number of transects having a zero cover value. Typically, if one encountered a developed overstory on any given transect the percent cover for that transect would be very high (85%) while the remaining transects were either open or dominated by an understory layer. Site 8 had five out of ten transects with an overstory layer which averaged over 90 percent cover and had a standard error of less than 8.0. This illustrates the spotty, clumped pattern of development of the riparian zone overstory vegetation layer. As cover becomes more developed and continuous, as in the control sites, the standard error values decrease to very acceptable levels (68 percent cover with a standard error of 1.9 percent).

Random Pairs Data

The resulting data from the random pairs sampling are summarized in Table 7. At an age of seven years in the *Tsuga* Zone only one random pair of *Acer macrophyllum* trees existed and was sampled in the study reach. This resulted in the extremely high values for mean distance and area occupied by a single individual. At Site 3 at ten years, the site was still occupied by deciduous species (predominantly *Alnus rubra*) at relatively high distances apart from each other (49.5 ft.) with an individual tree occupying a large area (1565 ft^2/tree).

After 13 years, the mean distance between trees and the area occupied values decline and tend to stabilize approximately at

TABLE 7

Summary of Random Pairs of Trees Two Inches or Larger for the Cascade Range Zones

Site	Age (yrs)	Mean Distance Between Trees (feet)	Mean Basal Area/Tree (ft^2/tree)	Area Occupied by Single Individual (ft^2/tree)	Stem Density/Acre (stems/acre)	Basal Area/Acre (ft^2/acre)	Mean DBH (inches)	Relative Dominance Coniferous	Relative Density Coniferous	Relative Dominance Deciduous	Relative Density Deciduous	Relative Dominance Nitrogen Fixing	Relative Density Nitrogen Fixing
Tsuga heterophylla Zone													
1	1	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
2	7	293.6	0.042	44168.6	0.8	0.03	2.75	0.0	0.0	100.0	100.0	0.0	0.0
3	10	49.5	0.045	1565.6	27.8	1.26	2.82	0.0	0.0	100.0	100.0	92.7	87.5
4	13	16.9	0.041	181.8	239.6	9.75	2.65	10.6	12.5	89.5	87.5	77.7	72.5
5	15	12.2	0.048	95.4	456.7	22.01	2.85	8.3	15.0	91.7	85.0	88.1	77.5
6	19	18.8	0.065	225.7	193.0	12.58	3.29	93.0	85.0	7.0	15.0	0.0	0.0
7	20	22.9	0.053	337.0	129.3	6.81	2.99	25.2	25.0	74.8	75.0	73.7	72.5
8	24	16.6	0.179	176.2	247.2	44.18	5.00	56.2	47.5	43.8	52.5	14.1	25.0
9	OG	30.1	3.503	578.6	75.3	262.98	18.32	98.1	85.0	1.9	15.0	0.0	0.0
Abies amabilis Zone													
10	8	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
11	8	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
12	14	101.8	.044	6633.5	6.7	0.29	2.81	85.7	80.0	14.3	20.0	14.3	20.0
13	17	50.1	.058	1609.2	27.1	1.56	3.05	96.0	89.1	10.7	10.9	2.7	7.1
14	19	33.3	.055	710.7	61.3	3.37	3.03	99.0	97.5	1.0	2.5	0.0	0.0
15	24	32.1	.059	658.5	66.2	3.93	3.07	92.7	87.5	7.3	12.5	0.0	0.0
16	24	22.3	.063	317.8	137.1	8.64	3.10	62.4	50.0	37.6	50.0	37.6	50.0
17	OG	20.0	2.223	254.9	171.0	379.96	15.40	99.9	97.5	0.3	2.5	0.3	2.5

NOTE: NT = no trees two inches or larger in riparian zone.

values of 20 feet (6.1 m) and 200 square feet per tree (18.6 m^2/tree), respectively. Coniferous species (Pseudotsuga mensiezii) larger than two inches diameter at breast height (DBH) also begin to appear and occupy the site with a relative dominance of 10.5 percent. The density of trees has increased markedly from 27 stems/acre to 240 stems/acre (67 stems/ha to 593 stems/ha) and the total basal area per acre has increased to 9.7 ft^2 per acre (2.2 m^2/ha).

The establishment of coniferous species in the riparian zone is a relatively slow process and can be highly variable on a site-to-site basis. Site 6, at an age of 19 years, has very good coniferous establishment relative to deciduous species (relative dominance = 93 percent) while Site 7 at 20 years has slow establishment of conifers with a relative dominance of only 25 percent. After 24 years (Site 8) the relative dominance of coniferous species was greater than 50 percent and nearly 50 percent of all stems were coniferous species.

The stem density data in the Tsuga Zone indicates the highly dense nature (in terms of number of stems) of the riparian zone during the years following harvest when compared to the less dense natural condition. The 24-year-old site was more than three times more dense and had nearly five times less area occupied by a single individual when compared to the control site.

The mean DBH for the chronosequence was approximately three inches for the majority of the first 20 years following harvest. After 24 years, the DBH value increased to five inches in the Tsuga Zone which was three and one-half times less than the average control DBH. It is interesting to note the small DBH and the high standard error for that measurement for the control sites. This illustrates the mixed nature of the riparian overstory trees. The sites are occupied by a wide range of size classes with some trees at 60 inches (152.4 cm) and a relatively greater number with sizes less than five inches (12.7 cm).

The relative dominance and relative density values emphasize the strong development of nitrogen-fixing Alnus species in the riparian zone during the first two decades in the lower elevation Tsuga Zone. Both variables are generally approximately 80 percent between the years 10 and 20, while the control site had no nitrogen-fixing species observed in the entire study reach.

In contrast to the Tsuga heterophylla Zone, primarily coniferous species in the Abies amabilis Zone form a sparse tree layer during the entire 24-year period. Relative dominance and relative density of the coniferous species are both generally close to 90 percent and are both greater than 50 percent after a stand age of 14 years. It is important here to remember that relative dominance and relative density are values expressing the percent of the total basal area and total stem density that are a given vegetation type (coniferous in this case) and not an estimate of percent total cover or other similar variables.

Tree cover in the Abies Zone is sparser than that in the Tsuga Zone, as evident by the lower stems/acre and total basal area/acre values and the greater area occupied by a single individual and mean distance between trees values for a given age. At a stand age of 19 years, the mean distance and area occupied by a single stem values are approximately three and 10 times greater than those of the Tsuga Zone. Stem density and total basal area per acre values are less than 100 stems/acre and 10 ft^2/acre (247.1 stems/ha and 2.3 m^2/ha), respectively, during the entire 24-year period. In contrast, the Tsuga Zone has approximately four times the stem density and total basal area/acre in the same period.

Note that while the stem density values differ greatly between the two zones, the size of the trees is relatively similar with DBH values less than five inches for all the sites. In the Abies Zone, the relative dominance and relative density of nitrogen-fixing species are both low, but this is a result of the very sparse deciduous tree layer. These two values are similar in both zones when expressed as a percent of the relative dominance and relative density of deciduous species indicating a proportionally similar occurrence of n-fixing species in these two zones.

Vegetation Overhanging the Stream Channel

Measured vegetation directly overhanging the stream channel is summarized in Table 8. In the *Tsuga* zone, the understory provided between 0.4 and 100.0 percent cover overhanging the channel for the set of sites, although cover was generally approximately 25 percent for the sites less than 19 years in age and greater than 60 percent for sites after that age.

It is important to note the type of vegetation providing the overhanging cover if inferences are to be made about the quality and potential residence time in the stream of this aquatic food source. Herbaceous cover dominates the overhanging vegetation only during the early years following harvest (26 percent cover at age one) with about equal parts of grass and herbaceous forbs contributing to that value. Deciduous vegetation, primarily *Alnus*, begins to dominate at Site 3 at 10 years with 22 percent cover overhanging the channel. The deciduous vegetation dominates the cover during the entire 24-year period.

At an age of 19 years, the coniferous species begin to provide a portion (27 percent) of the increased cover (70 percent), although at Site 7 at 20 years the percent coniferous overhanging vegetation is again zero. A heavy *Alnus* and *Salix* corridor along the channel at Site 7 provides heavy overhanging cover and precluded the establishment of coniferous cover along the streamside. Coniferous cover over the channel after 24 years was only 10 percent in the understory layer which emphasizes the dominance of the deciduous vegetation during this period.

The data for the control sites illustrate the relatively

TABLE 8

Mean Values for Vegetation Cover Overhanging the Streamchannel with Standard Errors ( ) for the Cascade Range Zones

Site	Age (yrs)	Total Understory Cover n of 5	% Total Understory Overhanging Cover	% Understory Overhanging Coniferous Cover	% Understory Overhanging Deciduous Cover	% Understory Overhanging Herbaceous Cover	Total Overstory Cover n of 5	% Total Overstory Overhanging Cover	% Overstory Overhanging Coniferous Cover	% Overstory Overhanging Deciduous Cover
	Tsuga heterophylla Zone									
1	1	4	32.0 (11.5)	0.0	6.2 (6.2)	25.8 (11.8)	0	0.0	0.0	0.0
2	7	1	0.4 (0.4)	0.0	0.4 (0.4)	0.0 (0.0)	0	0.0	0.0	0.0
3	10	5	22.3 (5.5)	0.0	21.3 (8.5)	0.8 (0.8)	0	0.0	0.0	0.0
4	13	3	21.3 (10.6)	0.0	21.3 (10.6)	0.0 (0.0)	0	0.0	0.0	0.0
5	15	3	32.1 (14.0)	0.0	28.3 (14.3)	3.8 (3.8)	0	0.0	0.0	0.0
6	19	5	69.9 (15.3)	27.4 (15.3)	92.1 (15.4)	0.4 (0.4)	0	0.0	0.0	0.0
7	20	5	100.0 (0.0)	0.0	100.0 (0.0)	0.0 (0.0)	0	0.0	0.0	0.0
8	24	5	64.3 (12.3)	10.4 (6.5)	47.8 (17.2)	6.2 (5.0)	3	49.2 (22.4)	10.2 (9.0)	39.0 (23.9)
9	OG	5	36.8 (10.2)	8.4 (8.4)	19.9 (9.0)	8.5 (6.8)	2	21.7 (19.6)	20.0 (20.0)	1.7 (1.7)
	Abies amabilis Zone									
10	8	4	40.9 (20.0)	0.0	34.9 (18.4)	6.0 (2.6)	0	0.0	0.0	0.0
11	8	5	36.8 (11.7)	0.0	30.5 (14.2)	6.3 (3.1)	0	0.0	0.0	0.0
12	14	5	36.2 (17.5)	0.0	34.8 (18.1)	1.4 (1.4)	0	0.0	0.0	0.0
13	17	5	27.9 (8.9)	0.0	24.0 (9.2)	3.9 (2.6)	0	0.0	0.0	0.0
14	19	5	49.3 (4.8)	0.7 (0.7)	45.9 (3.5)	2.7 (1.6)	0	0.0	0.0	0.0
15	24	5	67.3 (13.9)	0.4 (0.4)	44.5 (19.7)	22.4 (11.6)	0	0.0	0.0	0.0
16	24	5	66.7 (14.7)	0.0	62.0 (17.2)	4.7 (3.5)	0	0.0	0.0	0.0
17	OG	5	17.0 (3.3)	0.0	14.5 (3.2)	2.5 (2.5)	4	61.4 (18.6)	61.4 (18.6)	0.0

sparse natural condition of the understory layer at the streamside in undisturbed stands. Vegetation at the 24-year-old sites provided approximately two and four times more overhanging vegetation than the control sites in the *Tsuga* and *Abies* zones, respectively.

In the *Tsuga* Zone, the control site had a diverse pattern of overhanging vegetation with coniferous, deciduous, and herbaceous vegetation all contributing to the channel cover (8, 20 and 9 percent, respecitvely). This pattern of overhanging vegetation was similar at Site 8 at a stand age of 24 years except for a two-fold increase in deciduous cover (10, 48, and 6 percent cover).

In contrast, the *Abies* Zone has no coniferous overhanging understory vegetation at the control site and a relatively sparse total overhanging cover relative to the other control sites in the study. Cover in the *Abies* Zone was only one-half the overhanging cover value of the *Tsuga* control site.

Overhanging understory vegetation in the *Abies* Zone ranged between 27.9 and 66.7 percent during the 24-year period with sites less than 19 years of age having less than 50 percent overhanging cover and sites greater than that age having nearly 70 percent overhanging understory cover. Deciduous cover overhanging the channel is greater than 30 percent at sites 10 and 11 each at age eight. Like the *Tsuga* Zone, deciduous vegetation dominates this cover during the entire period, but unlike the *Tsuga* Zone, coniferous vegetation does not provide a significant overhanging channel cover during the entire 24-year period (conifer cover less than one percent at all sites). Herbaceous cover is less than 10 percent for all the sites except Site 15 at 24 years which had an unexpected 22.4 percent herbaceous cover.

The overstory layer in both zones provided marginal overhanging cover for the entire set of sites. In the *Tsuga* Zone, the overstory layer contributed no overhanging cover on sites less than 24 years of age. At this point the overstory provided about 50 percent cover, the majority of which was deciduous (39 percent with 10 percent coniferous). In the *Abies* Zone, overstory vegetation overhanging the channel had not developed at any harvested site.

The *Tsuga* control site had less than 25 percent overstory overhanging cover indicating a very open canopy directly above the channel. This site was very different than the other control sites in the study which typically had two to three times this amount of channel cover provided by the overstory vegetation layer (43 to 61 percent).

The *Abies* Zone had no overstory vegetation overhanging the stream channel develop during the entire 24-year period. The control site had nearly three times more overhanging overstory vegetation than the *Tsuga* Zone with 61 percent of the channel covered by overhanging coniferous vegetation. This value is more typical of the percent overhanging overstory vegetation values that were observed at the control sites for the remaining zones in the study.

Canopy Density

The canopy density data for the two Cascade zones are summarized in Table 9. Control site canopy density values of each of the two Cascade zones averaged 86.9 percent which was not attained in any of the sites in the 24-year chronosequence of sites. In the *Tsuga* Zone, canopy density values approached this value at a stand age of 15 years (84 percent) but was only 59 percent at site 6 at 19 years. The sites had density values less than 50 percent prior to age 15 and greater values thereafter.

Canopy density values were correlated with stand age in both the *Tsuga* Zone (r^2 = 0.77) and the *Abies Zone* (r^2 = 0.59). As the riparian zone revegetation occurs, the percent density values become more constant along the stream reach as indicated

TABLE 9

Mean Canopy Density Values with Standard Errors ( ) for the Cascade Range Zones

Site	Age (yrs)	Canopy Density in %
	Tsuga heterophylla Zone	
1	1	8.8 (5.6)
2	7	4.6 (2.3)
3	10	16.5 (5.4)
4	13	36.2 (7.9)
5	15	83.8 (3.9)
6	19	58.5 (8.3)
7	20	82.7 (1.6)
8	24	83.5 (5.4)
9	OG	86.9 (1.3)
	Abies amabilis Zone	
10	8	29.2 (12.0)
11	8	28.1 (9.8)
12	14	27.3 (8.3)
13	17	24.2 (11.5)
14	20	42.1 (4.9)
15	24	46.3 (8.6)
16	24	63.8 (15.0)
17	OG	86.9 (2.8)

by the proportionally lower standard error relative to the mean density. Density values greater than 80 percent all had standard errors less than 5.4 percent (6.5 percent of the mean), while young stands had standard errors ten times as high when expressed as a percent of the mean canopy density (64 percent of the mean for site one at one year of age).

As expected, the higher elevation *Abies* Zone experiences a slower rate in the increase of canopy density when compared to the *Tsuga* Zone at lower elevations in the Cascade Range. A canopy density value greater than 50 percent is probably not achieved until about 22 years after clearcutting.

The high variation between sites of similar stand ages can be seen when data for sites 15 and 16 at 24 years are compared. A difference approaching twenty percent exists between the two sites with 46.3 and 63.8 percent density, respectively. Since shade cover values for these two sites are essentially the same, this difference in canopy density can be attributable to differences in the vegetation density to the north, west and east of the streams.

Canopy density in the *Abies* Zone at 17 years is still less than 30 percent, whereas the density in the *Tsuga* Zone is greater than 30 percent after only 13 years. It is also interesting to note that the *Abies* Zone has a higher canopy density at sites 10 and 11 at a stand age of eight years than the *Tsuga* Zone sites 2 and 3 at seven and 10 years of age. This unexpected discrepancy could be attributed to two major factors. First, natural variation between sites of similar ages can be very high within a given zone which could mask differences between zones. Second, at high elevations site preparation burns may not be as intense as those experienced at lower elevations which may result in incomplete, spotty coverage of the riparian zone. This may result in more residual vegetation in the *Abies* riparian zone when compared to the *Tsuga* riparian zone during the early years following harvest impact.

Angular Canopy Density and Shade Cover

The angular canopy density data (ACD) with species and vegetation types providing the shade cover are summarized in Table 10. In the *Tsuga* Zone, the percent shade cover steadily increases with age from 6.8 percent at age one to 75.8 percent at age 24. Shrubs and herbaceous cover provide the shade at Site 1 with 5.8 and 1.0 percent shade cover, respectively, and deciduous trees (*Alnus rubra* and *Salix* spp.) and coniferous species provide 63.9 percent and 5.6 percent shade cover at Site 8 at 24 years. We can see that even after a period of 24 years, the stream shade is still dominated by deciduous shade cover with coniferous cover only a minor contributor to the streamshade.

Herbaceous cover (primarily *Epibolium augustafolium*) provides minor shade cover to the stream as early as age one and still significantly contributes to the shade at a stand age of seven years. Deciduous species dominate the shade cover during the entire period in both zones with coniferous species generally not contributing more than 10 percent shade in the *Tsuga* Zone and 20 percent in the *Abies* Zone. In contrast, the control site for the *Tsuga* Zone had an ACD value of 93.9 percent with 54 percent coniferous shade and the *Abies* Zone had 81.4 percent ACD which was all coniferous shade.

It is interesting to note that sites 6 and 7 in the *Tsuga* Zone with similar stand ages (19 and 20 years) have essentially the same ACD values although Site 6 is primarily an east-west flowing stream and Site 7 is a north-south flowing stream. This can be explained by the denser cover overhanging the stream channel at Site 7 (100 percent) when compared to Site 6 at 69.9 percent (see Vegetation Overhanging the Stream Channel section).

Site 6 at a stand age of 19 years had an ACD value of 68.9 percent with 23.5 percent coniferous shade. Although there is more coniferous cover overhanging the channel at this site, the

TABLE 10

Summary of Angular Canopy Density (ACD) Data for the Cascade Range Zones

Site	Age (yrs)	ACD (%)	ACD by Given Species (%)		ACD by Coniferous Species (%)	ACD by Deciduous Species (%)	ACD by Herbaceous Species (%)
	Tsuga heterophylla Zone						
1	1	6.8 (5.6)	VAOV	5.8	0.0	5.8	1.0
			EPAN	1.0			
2	7	0.6 (0.4)	ALSI	0.3	0.0	0.5	0.2
			ACCI	0.2			
			EPAN	0.2			
3	10	16.5 (10.0)	SALIX	4.1	0.0	16.5	0.0
			ACCI	7.3			
			ALRU	5.1			
4	13	46.3 (11.5)	ALRU	37.7	0.0	46.3	0.0
			SALIX	5.4			
			POTR2	3.2			
4	15	92.9 (1.1)	PSMEM	3.8	3.8	89.2	0.0
			ALRU	62.5			
			ACMA	11.4			
			SALIX	15.3			
6	19	68.8 (8.5)	PSMEM	23.5	23.5	45.3	0.0
			SALIX	45.3			
7	20	68.9 (9.7)	PSMEM	6.6	6.6	62.3	0.0
			ALRU	52.5			
			SALIX	9.8			
8	24	75.8 (15.0)	PSMEM	5.6	5.6	70.3	0.0
			ACRU	27.9			
			SALIX	36.0			
			ACCI	5.4			
			RUPA	1.0			

TABLE 10 (continued)

Site	Age (yrs)	ACD (%)	ACD by Given Species (%)		ACD by Coniferous Species (%)	ACD by Deciduous Species (%)	ACD by Herbaceous Species (%)
9	OG	93.9 (0.8)	TSHE	54.1	54.1	39.9	0.0
			ACCI	22.9			
			OPHO	17.0			
	Abies amabilis Zone						
10	8	26.9 (14.1)	ALTE	4.5	0.0	26.5	0.3
			ACCI	0.3			
			SALIX	18.8			
			VAPA	2.9			
			PEFR	0.3			
11	8	22.6 (8.8)	ALRU	12.9	0.0	20.4	2.3
			ALSI	7.5			
			EPAN	2.3			
12	14	35.5 (16.6)	ACCI	13.4	0.0	35.5	0.0
			SALIX	22.1			
13	17	13.7 (9.5)	ALSI	12.9	0.0	13.7	0.0
			SALIX	0.8			
14	19	33.1 (9.8)	ABAM	11.7	11.7	21.2	0.3
			ALSI	9.5			
			ACCI	1.9			
			SALIX	9.8			
			EPAN	0.3			
15	24	60.2 (14.0)	PSMEM	19.1	19.1	41.1	0.0
			ACCI	24.1			
			SALIX	17.0			
16	24	60.8 (18.7)	PSMEM	1.1	1.1	59.8	0.0
			ALRU	41.1			
			ALSI	18.7			
17	OG	81.4 (5.1)	TSHE	54.8	81.5	0.0	0.0
			PSMEM	17.3			
			ABAM	9.4			

east-west nature of the stream probably accounts for the high coniferous shade value. On east-west streams the ACD is oriented directly to the southbank and coniferous species need not be as tall as those that would be required directly at the streambank in north-south flowing streams in order to be a portion of the sampled ACD value.

In the higher elevation Abies Zone, we can see a tendency towards a much slower development rate for shade cover following harvest. In the entire 24-year chronosequence of sites, ACD values did not exceed 61 percent and were generally less than 35 percent. The ACD values for younger sites (eight years) are quite high (25 percent) relative to the Tsuga Zone (17 percent at 10 years). This could be due to the same differences in slash burning and natural variation discussed previously.

Herbaceous cover provides a small portion of the ACD value at sites 10 and 11 at a stand age of eight years (0.3 and 2.3 percent, respectively). This was much lower than the contribution of herbaceous shade that was found in the Tsuga Zone but similar in respect to the time period since harvest that herbaceous cover contributes to the ACD value. It was interesting to note that Site 14 at a stand age of 19 years still had Epibolium augustifolium (fireweed) present that contributed to the ACD value for that stream.

Although the shade cover development in the higher elevation Abies Zone is relatively slow, this may not be nearly as critical in terms of stream temperature as in the lower elevation Tsuga Zone.

A sigmoid-shape curve was fit to these data for each zone and the results are graphically presented in Figures 7 and 8. The proportion of the variation in ACD values explained by stand age is somewhat higher in the Tsuga Zone ($r^2 = 0.78$) relative to the Abies Zone ($r^2 = 0.55$). Some other variables must explain relatively more of the variation in the higher elevation Abies Zone,

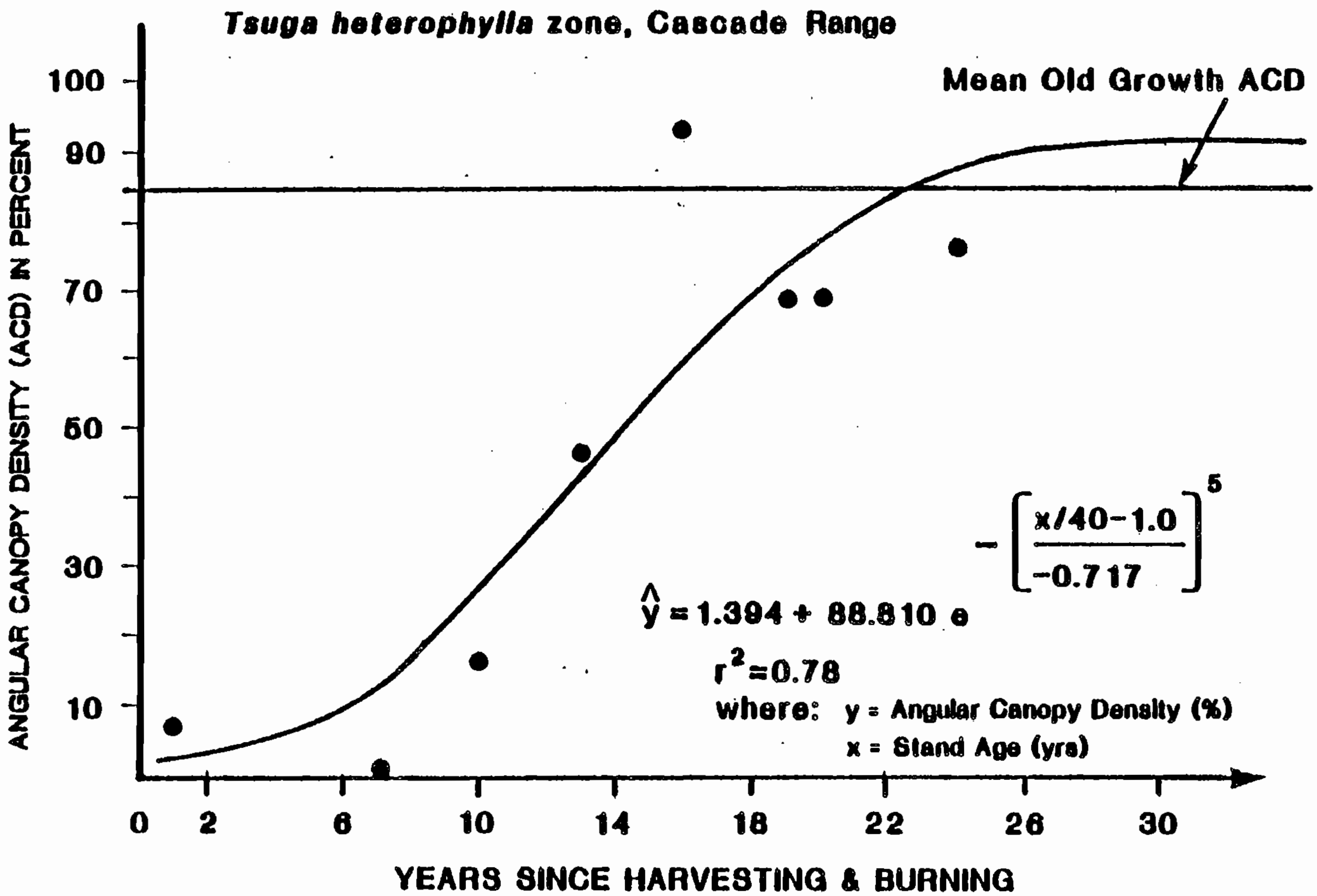


Figure 7. Relationship between angular canopy density (ACD) and stand age for the <u>Tsuga heterophylla</u> zone, Cascade Range.

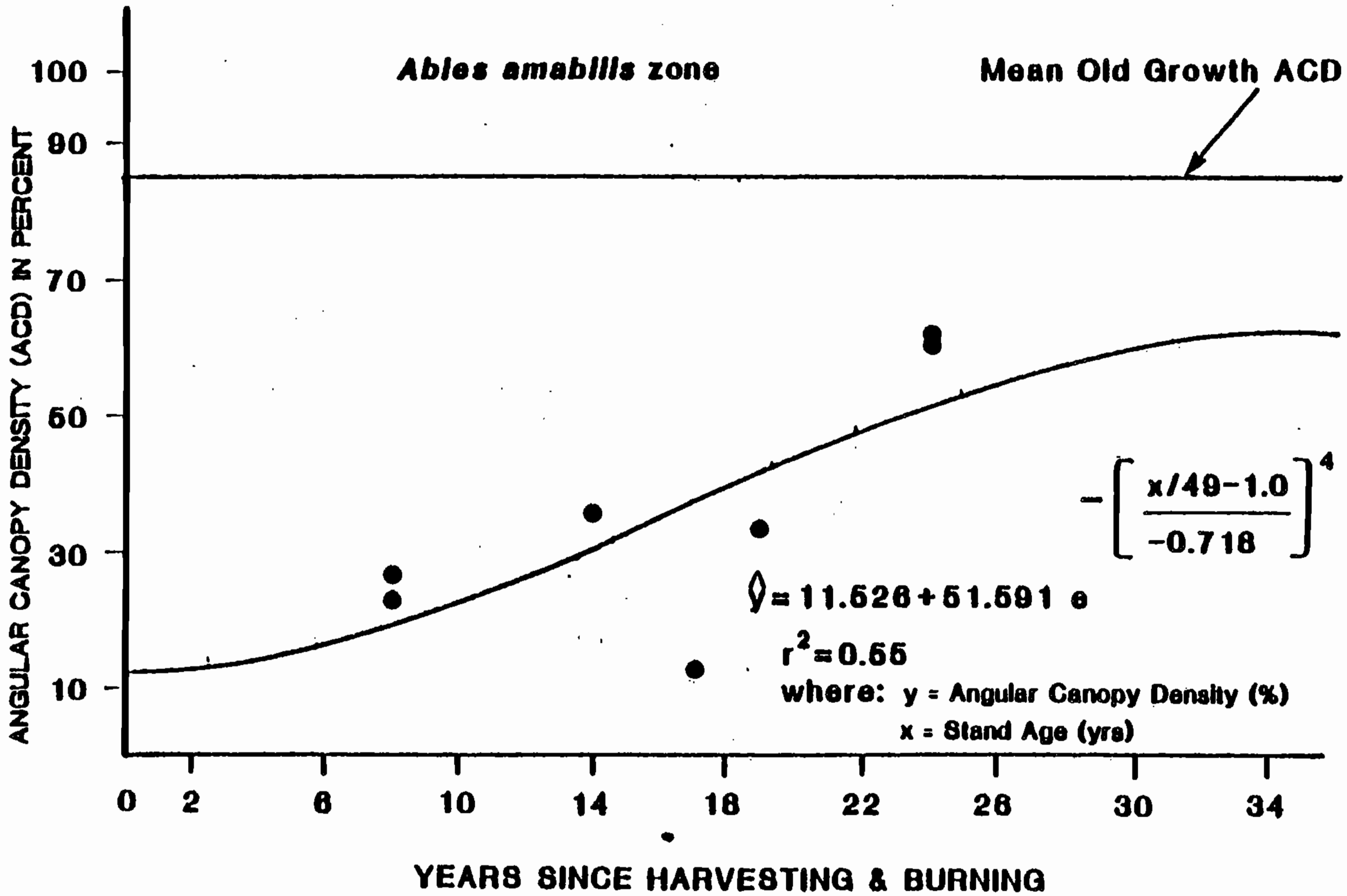


Figure 8. Relationship between angular canopy density (ACD) and stand age for the *Abies amabilis* zone.

but the relatively small sample sizes of these data restricted the inclusion of more variables into the model for each zone.

The resulting models for the two Cascade Range zones are as follows:

<u>Tsuga</u>

$$\hat{Y} = 1.394 + 88.810e^{-\left[\left(\frac{X/40 - 1.0}{-0.717}\right)^5\right]} \quad \text{Equation 10} \quad (r^2 = 0.78)$$

<u>Abies</u>

$$\hat{Y} = 11.526 + 51.591e^{-\left[\left(\frac{X/49 - 1.0}{-0.718}\right)^4\right]} \quad \text{Equation 11} \quad (r^2 = 0.55)$$

where:

Y = angular canopy density (percent)

X = stand age in years

The statistical test for significance of the regression relationship between the two variables ACD and age yielded significance at the $\alpha = 0.005$ and $\alpha = 0.1$ levels for the <u>Tsuga</u> and <u>Abies</u> zones, respectively. The results of this test including the calculated F-values are included in the Appendix.

An attempt to statistically test the similarity of the two regression lines was prohibited due to the different transformation on age that resulted when the data was pooled for the reduced model fit required for that test. However, a visual examination of the two lines reveals a relatively steeper slope and lower y-intercept for the <u>Tsuga</u> Zone model. Interpretations about the y-intercept are not valid as the original data set does not include sites with ages equal to zero, but the steeper slope of the <u>Tsuga</u> curve between the years eight and 22 can be interpreted as a more rapid rate of shade development.

The percent shade required before a stream will not experience an unacceptable increase stream temperature is dependent on several variables. Stream orientation, stream width, and surrounding topography determine the amount of stream surface area exposed to solar radiation. Atmospheric conditions, latitude of the site, and time of the year affect the amount of incoming solar energy. Turbidity and stream color can affect the rate of heat absorbed by the stream and stream discharge determines the volume of water that is influenced by the increased solar load. Streambed composition (i.e., bedrock vs. gravels) can determine the potential for increased stream temperatures via heat transfer by conduction. Therefore, the shade requirement for temperature control can vary on a site-to-site basis, and as a result minimum acceptable levels of percent shade cover had not been well-defined.

The State of Oregon Forest Practice Rules (629-24-541) require that 75 percent of the original prelogging shade be left along Class I and II streams. Using this requirement and the mean of the five control site ACD values, we find that (0.75)(84.45%) = 63.3 percent ACD is required to meet this directive.

The State of Washington (WAC 222-30-040) has a more complex requirement in that if the maximum midsummer daily ambient water temperature for a seven-day period would not naturally exceed 60°F before logging, 50 percent of the midday, midsummer shade (a value approximated very well by the ACD) must be left. If the water temperature would naturally exceed 60°F then 75 percent shade must be left.

Using equations 10 and 11, the following time periods to meet these required shade values can be calculated:

Percent Shade Requirement (%)	Tsuga heterophylla Zone: Time (years) to Shade Value	Abies amabilis Zone: Time (years) to Shade Value
50 (Wash. State)	14.1	23.1
63 (Oregon State)	16.5	**
75 (Wash. State)	19.5	**
84 (Control site shade)	23.0	**

**Data values beyond limits of original data set.

An alternate approach to the interpretation of these data would be to review available data on percent shade cover provided by buffer strips of vegetation of varying widths and make comparisons about the time period required to achieve a similar percent shade value. Although a standard buffer strip width for all streams is generally not recognized as an adequate standard for stream temperature control, various agencies and forest practice rules utilize this variable as a guideline for stream protection work (Brown et al., 1977). The State of Washington requires that streamside management zones are to be 50 feet in width alongside Type 1 and 2 waters. Streams in that state are designated as Type 1 or 2 waters if they have high beneficial uses and are determined to be highly significant from a water quality standpoint.

Steinblums (1978) conducted a study in the western Cascade mountains of Oregon to determine (among other objectives) the relationship between ACD and buffer strip width. The resulting nonlinear equation from that study can be used to determine the percent angular canopy density for a given buffer strip width. The time period that the stream would have less than the predicted ACD from a given proposed buffer strip can then be determined to assist decisions about the buffer strip based upon this additional information. Steinblums equation is as follows:

$$Y = 100 - 100 * e^{(-0.01141 * X)} \quad (r^2 = 0.45) \qquad \text{Equation 12}$$

where: Y = angular canopy density (percent)

X = buffer strip width (feet)

Using this equation and equations 10 and 11 from this research, we can develop the following table:

Buffer Strip Width (feet)	Predicted Shade from Buffer in Col. 1 (%)	*Tsuga* Zone Time with Less than Given Shade (years)	*Abies* Zone Time with Less than Given Shade (years)
50 (Wash.)	43.5	13.0	10.7
61	50.0 (Wash.)	14.1	23.1
87	63.0 (Oregon)	16.5	**
100 (common buffer)	68.5	17.8	**
121	75.0 (Wash.)	19.5	**
160	84.0 (Control shade)	23.0	**

**Data values beyond limits of original data set.

From this table we can see that shade cover values of 50 and 75 percent require buffer strip widths of 61 and 121 feet, respectively, and that the time that a stream would have less than these values would be 14.1 and 19.5 years in the *Tsuga* Zone and 23.1 years in the *Abies* Zone (75 percent shade is beyond the data limits for this zone).

Coupled with information about the sensitivity of the stream resource at the site and downstream resources, the extent of current impacts on the stream, and acceptable levels of impact, the manager will now be able to make a more sound decision about whether or not to leave a buffer strip, especially in areas of highly probable blowdown or other conditions which might limit buffer strip survival. Steinblums (1977) presents a method for determining the survival of buffer strips when given a set of site conditions (see Section III) which may be helpful in identifying these problem areas.

The Coast Range Zones

Ground Cover

Data from the ground layer sample for the *Tsuga heterophylla* and *Picea sitchensis* zones in the Coast range are summarized in Table 11. In both zones, the percent grass and moss cover were less than 20 percent at all harvested sites and were generally less than 10 percent. Like the Cascade zones, the percent grass cover in the control sites was very low (less than two percent) and percent moss cover was either 25 or 13 percent, depending upon the zone. In the *Picea* Zone, grass and moss cover were correlated with stand age (r^2 = 0.58 and 0.85) with grass cover decreasing and moss cover increasing over time.

Percent plant cover ranged between 15 and 43 percent in each zone. In the *Tsuga* Zone, plant cover did not correlate with stand age while in the *Picea* Zone this correlation was quite strong (r^2 = 0.88) with the percent plant cover decreasing with stand age. This decrease in plant cover at the ground layer may possibly be the result of the typically dense shrub cover that develops in the riparian understory which tends to provide intolerably heavy shade at the ground surface. Plant cover at site 31 at 16 years of age was only 16 percent which was 2½ times lower than the plant cover at the ground layer at Site 26 at two years. Control sites in the Coast zones tended to have a higher (approximately two times) percent plant cover than those in the Cascades.

TABLE 11

Mean Values and Standard Errors ( ) for Ground Layer Cover for the Coast Range Zones

Site	Age (yrs)	% Grass Cover	% Plant Cover	% Moss Cover	% Litter Cover	% Rock Cover	% Soil Cover	% Total Vegetation Cover	% Bareground
Tsuga heterophylla Zone									
18	2	8.3 (2.45)	31.7 (3.99)	1.7 (0.84)	52.3 (3.34)	0.3 (0.33)	5.7 (2.57)	40.0 (3.80)	6.0 (2.82)
19	3	19.3 (3.52)	26.3 (3.47)	3.0 (1.09)	45.3 (2.70)	3.7 (1.82)	2.3 (1.14)	45.7 (3.55)	6.0 (2.33)
20	9	0.3 (0.33)	30.7 (4.15)	9.7 (2.22)	56.3 (3.51)	0.0	3.3 (1.38)	31.0 (4.11)	3.3 (1.38)
21	9	2.7 (1.35)	39.7 (3.44)	8.0 (2.17)	49.3 (3.46)	0.0	0.3 (0.33)	42.3 (3.74)	0.3 (0.33)
22	15	9.0 (2.37)	39.3 (4.29)	11.3 (2.61)	38.7 (4.79)	0.0	1.7 (0.69)	48.3 (4.87)	1.7 (0.69)
23	18	6.0 (2.23)	27.7 (3.31)	6.3 (2.73)	43.7 (4.51)	4.0 (1.49)	12.3 (3.06)	33.7 (4.03)	16.3 (3.20)
24	22	9.3 (2.83)	15.3 (3.42)	11.0 (2.21)	47.7 (5.52)	0.3 (0.33)	16.3 (3.85)	24.7 (5.46)	16.7 (3.93)
25	OG	0.7 (0.67)	38.3 (5.03)	25.7 (3.02)	33.0 (3.62)	0.0	2.0 (1.11)	39.0 (5.08)	2.0 (1.11)
Picea sitchensis Zone									
26	2	7.7 (2.61)	40.0 (5.10)	1.3 (0.79)	49.3 (4.70)	0.3 (0.33)	1.3 (0.92)	47.7 (4.93)	1.7 (0.97)
27	3	9.3 (3.07)	43.0 (3.96)	0.3 (0.33)	45.3 (3.71)	0.0	2.0 (0.88)	52.3 (3.89)	2.0 (0.82)
28	5	1.3 (0.93)	32.0 (3.91)	10.3 (2.86)	52.0 (3.91)	0.7 (0.46)	3.7 (1.76)	33.3 (4.05)	4.3 (1.77)
29	8	4.0 (2.12)	27.7 (3.02)	8.0 (2.22)	57.3 (3.83)	0.0	2.3 (1.04)	31.7 (3.49)	2.3 (1.04)
30	10	4.0 (1.56)	31.3 (4.14)	10.7 (2.49)	48.7 (3.86)	4.0 (1.56)	1.3 (1.04)	35.3 (4.23)	5.3 (1.96)
31	16	0.0	15.7 (3.02)	18.3 (3.11)	64.3 (3.67)	0.0	1.3 (0.79)	15.7 (3.02)	1.3 (0.79)
32	OG	1.3 (1.04)	28.7 (4.81)	12.7 (2.62)	54.3 (4.39)	0.0	3.0 (1.53)	30.0 (4.96)	3.0 (1.53)

Like the Cascade zones, the percent litter was high (50 percent) throughout the entire chronosequence of sites in both zones. Percent rock and soil exposed in each Coast zone was less than 20 pemcent at all sites. These values were generally less than those of the Cascade zones during first decade followng harvest. The percent soil exposed in the Picea Zone was very low (less than four percent) at all sites. This data, when coupled with the plant cover results, indicate a rapid occupancy of the site by vegetation.

Total vegetation cover and bareground exposed values had opposite trends with stand age. Vegetation cover at the ground layer tends to decrease and bareground tends to increase up to a stand age of 16 to 22 years. This is opposite to the trends observed in the Cascade range zones which had increasing vegetation and decreasing bareground values with stand age. Again, this may be the result of the dense understory layer that typically develops in the Coast range zones following timber harvesting.

Understory Vegetation Layer

Data for vegetation in the understory layer are summarized by total coniferous, deciduous, herbaceous, and nitrogen-fixing cover categories in Table 12. Total cover ranged between 42 and 85 percent in the Tsuga Zone and 54 and 99 percent in the Picea Zone. Total cover did not correlate with stand age in the Tsuga Zone (r^2 = 0.19), although it correlated very well in the Picea Zone (r^2 = 0.88).

Sites in the coast zones had a higher percent cover at an early age relative to the Cascade zones which was primarily due to herbaceous vegetation. Control sites averaged 72 and 85 percent total cover in the Tsuga and Picea zones. This cover was primarily deciduous with less than 10 percent coniferous cover. In contrast, the Cascade Zone control sites tended to have a significant portion of the total cover provided by coniferous vegetation.

TABLE 12

Mean Understory Vegetation Layer Cover Values with Standard Errors ( ) for the Coast Range Zones

Site	Age (yrs)	Total Cover n of 10	% Total Cover	% Deciduous Cover	% Conifer Cover	% Herbaceous Cover	% Nitrogen-fixing Cover
	Tsuga heterophylla Zone						
18	2	10	52.9 (5.87)	9.4 (2.42)	0.0	43.5 (4.66)	0.3 (0.25)
19	3	10	77.5 (6.74)	39.3 (7.61)	0.0	38.2 (7.73)	23.9 (8.89)
20	9	10	83.3 (7.64)	72.7 (3.99)	2.4 (2.41)	8.2 (2.80)	8.0 (4.40)
21	9	10	85.0 (7.80)	55.7 (9.97)	3.3 (2.43)	26.0 (7.64)	0.0
22	15	10	64.9 (4.54)	39.4 (6.71)	0.0	20.4 (4.44)	5.8 (3.24)
23	18	10	42.0 (4.64)	25.7 (5.48)	3.3 (1.69)	13.1 (3.61)	0.0
24	22	9	54.6 (8.18)	36.2 (9.80)	0.0	18.4 (7.35)	0.0
25	OG	10	72.5 (6.75)	26.0 (6.43)	3.8 (2.25)	42.8 (5.53)	0.0
	Picea sitchensis Zone						
26	2	10	66.4 (8.07)	28.5 (8.10)	0.9 (0.91)	37.0 (5.68)	2.0 (1.95)
27	3	10	53.6 (4.27)	13.7 (3.03)	1.0 (0.71)	38.9 (3.27)	3.3 (1.75)
28	5	10	69.8 (11.77)	58.7 (11.05)	0.8 (0.75)	10.4 (4.67)	12.4 (5.37)
29	8	10	73.9 (7.25)	62.8 (8.40)	0.8 (0.52)	10.3 (4.92)	18.3 (8.51)
30	10	10	86.4 (7.31)	76.4 (6.97)	4.8 (2.66)	5.2 (1.99)	42.8 (9.94)
31	16	10	98.8 (12.30)	86.7 (3.46)	11.5 (3.60)	0.6 (0.61)	10.0 (3.31)
32	OG	10	85.3 (7.94)	56.6 (6.47)	8.2 (4.15)	20.6 (3.80)	2.2 (2.23)

This indicates that Coast range zones tend to have a stronger initial development of deciduous species in the riparian zone relative to the Cascade range zones.

Herbaceous cover in each Coast Range zone was high initially following harvest (approximately 40 percent) and decreased through the chronosequences of sites to 18 and one percent in the *Tsuga* and *Picea* zones, respectively. Herbaceous cover in the control sites was also greater in the Coast zones relative to the Cascade zones. Average herbaceous cover in the Coast Zone control sites was over eight times greater than that of the Cascade range zones (32 and four percent, respectively).

As in the Cascade zones, deciduous cover dominated the understory layer at all harvested sites in each zone. Coniferous cover was less than 11 percent and was generally less than four percent at all sites in both zones. This coniferous cover represented a lower contribution to the total cover relative to the Cascade Zone sites. Dense understory and overstory development may preclude the establishment of coniferous species in the riparian zone at these sites during the first two decades following harvest.

Nitrogen-fixing species (primarily *Alnus rubra*) development in the understory layer is generally lower in terms of percent contribution to the total cover than the Cascade range zones. This is primarily due to the rapid development of an *Alnus* overstory corridor in the Coast zones, whereas the Cascade zones had little or no development of an overstory layer. Therefore, understory sampling in the Cascade zones tended to sample all the vegetation as one layer and sampling in the Coast range tended to partition the cover into two layers at a much earlier stand age.

Overstory Vegetation Layer

The overstory vegetation layer data for the Coast range zones are summarized in Table 13. The overstory layer in the Coast

TABLE 13

Mean Overstory Vegetation Layer Cover
Values with Standard Errors ( )
for the Coast Range Zones

Site	Age (yrs)	Total Cover n of 10	% Total Mean Cover	% Conifer-ous Cover	% Decidu-ous Cover	% Nitrogen-fixing Cover
	Tsuga heterophylla Zone					
18	2	0	0.0	0.0	0.0	0.0
19	3	0	0.0	0.0	0.0	0.0
20	9	9	71.4 (10.4)	3.6 (3.6)	67.8 (10.1)	67.7 (10.1)
21	9	0	0.0	0.0	0.0	0.0
22	15	10	87.0 (2.1)	0.0	87.0 (9.9)	67.0 (14.8)
23	18	10	99.0 (1.0)	2.0 (1.3)	97.0 (2.1)	97.0 (2.1)
24	22	10	74.2 (9.1)	18.3 (7.6)	55.9 (13.3)	29.6 (13.4)
25	OG	9	66.1 (9.9)	66.1 (9.9)	0.0	0.0
	Picea sitchensis Zone					
26	2	0	0.0	0.0	0.0	0.0
27	3	0	0.0	0.0	0.0	0.0
28	5	9	75.0 (11.8)	0.0	75.0 (11.8)	75.0 (11.8)
29	8	10	58.3 (7.9)	0.0	58.3 (7.9)	58.3 (7.9)
30	10	9	82.2 (10.8)	0.0	82.2 (10.8)	82.2 (10.8)
31	16	9	57.2 (9.2)	11.1 (4.9)	46.1 (8.0)	46.1 (8.0)
32	OG	10	70.5 (9.8)	61.5 (11.3)	9.0 (8.0)	9.0 (8.0)

range zones develops earlier and is more developed than the sites in the Cascade range zones. The Cascade range zones had marginal or no development of the overstory layer, while the Coast zones had an overstory layer at sites as young as nine years. These Coast range overstory layers are typically fairly dense with greater than 50 percent cover at all sites with a developed overstory layer. This cover is usually relatively constant along the stream reach as indicated by the low standard error values for the total mean cover.

Deciduous vegetation dominated the overstory vegetation layer during the entire chronosequence of sites in both Coast range zones. This deciduous vegetation was primarily the nitrogen-fixing *Alnus rubra* which is reflected in the high nitrogen-fixing cover values relative to the deciduous cover values.

Coniferous vegetation in the overstory layer at harvested sites was typically very limited, averaging less than 20 percent cover at all sites. Control sites averaged 66 and 71 percent total overstory vegetation with coniferous cover 100 and 87 percent of those values in the *Tsuga* and *Picea* zones, respectively. This high percentage of coniferous overstory vegetation was not observed at any of the harvested sites examined in these zones.

These data again reflect the typically dense deciduous corridors that tend to rapidly develop in these riparian zones following harvesting impact. It is interesting to note that at Site 31 at age 16 in the *Picea* zone, an overstory of *Alnus rubra* with nearly 50 percent cover had developed although a very dense deciduous (*Rubus spectabilis*) understory shrub layer was established at the site (87 percent cover).

Random Pairs Data

The resulting data from the random pair overstory sample in the Coast range zones are summarized in Table 14. Sites in the

TABLE 14

Summary of Random Pairs Sample of Trees Two Inches or Larger for the Coast Range Zones

Site	Age (yrs)	Mean Distance Between Trees (feet)	Mean Basal Area/Tree (ft²/tree)	Area Occupied by Single Individual (ft²/tree)	Stem Density/Acre (stems/acre)	Basal Area/Acre (ft²/acre)	Mean DBH (inches)	Relative Dominance Coniferous	Relative Density Coniferous	Relative Dominance Deciduous	Relative Density Deciduous	Relative Dominance Nitrogen Fixing	Relative Density Nitrogen Fixing
***Tsuga heterophylla* Zone**													
18	2	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
19	3	41.2	0.030	1085.5	40.1	1.19	2.28	0.0	0.0	100.0	100.0	100.0	100.0
20	9	7.0	0.069	31.6	1379.6	94.78	3.42	1.3	2.5	98.7	97.5	98.7	97.5
21	9	95.1	0.084	5788.2	7.5	0.63	3.76	0.0	0.0	100.0	100.0	100.0	100.0
22	15	7.8	0.130	39.2	1110.7	144.28	4.47	0.0	0.0	100.0	100.0	87.9	70.0
23	18	14.3	0.230	130.7	333.4	76.65	6.03	2.3	10.0	97.7	90.0	97.7	90.0
24	22	51.6	0.297	1704.8	25.6	7.58	6.77	25.7	32.5	74.3	67.5	68.5	50.0
25	OG	71.7	2.704	3292.0	13.2	35.78	19.75	100.0	100.0	0.0	0.0	0.0	0.0
***Picea sitchensis* Zone**													
26	2	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
27	3	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
28	5	10.9	0.031	75.4	577.9	17.69	2.34	0.0	0.0	100.0	100.0	100.0	100.0
29	8	17.7	0.050	201.6	216.1	10.73	4.91	0.0	0.0	100.0	100.0	100.0	100.0
30	10	19.2	0.062	235.7	184.8	11.42	3.18	10.1	15.0	90.0	85.0	88.9	82.5
31	16	14.5	0.121	133.8	325.5	39.35	4.33	21.9	32.5	78.1	67.5	77.1	62.5
32	OG	39.9	5.015	1016.6	42.8	214.87	25.90	97.2	87.5	2.8	12.5	2.8	7.5

NOTE: NT = no trees two inches or larger in riparian zone.

Coast zones tend to have trees greater than two inches in diameter at breast height at relatively young stand ages and these trees tend to increase in diameter more rapidly than those of the Cascade zones. Sites at three and five years of age in the *Tsuga* and *Picea* zones, respectively, had established trees (primarily *Alnus*) that averaged 2.3 inches (5.8 cm) DBH. In the *Tsuga* Zone, stem diameter was correlated with stand age ($r^2 = 0.97$) with the average stem diameter increasing to 6.8 inches (17.3 cm) at Site 24 at a stand age of 22 years.

The high variation between sites with similar stand ages can be illustrated by comparing sites 20 and 21 in the *Tsuga* Zone. Although both are dominated by *Alnus rubra*, Site 20 has developed a dense thicket of stems along the reach while Site 21 has relatively few stems per acre (1380 vs. 8 stems/acre). Site 22 at age 15 also had developed a dense (1110 stems/acre) deciduous corridor in this zone. These *Alnus rubra* corridors are approximately ninety times more dense in terms of stems per acre than the control site for this zone.

The relative dominance and relative density of the coniferous species is quite low throughout these sites with values all less than ten percent. This is probably the result of the dense deciduous understory and overstory layers which preclude the early establishment of coniferous species. As an interesting contrast, the Cascade *Abies amabilis* Zone with sparse development of deciduous vegetation in the overstory layer had close to 90 percent relative dominance and density coniferous values.

Relative dominance and relative density values for nitrogen-fixing species emphasize the dominance of *Alnus rubra* in the riparian zone during the first two decades following harvesting. These values are all greater than 50 percent and are generally greater than 90 percent at all sites with two-inch, or larger, trees in the Coast zones.

Vegetation Overhanding the Stream Channel

Vegetation directly overhanging the stream channel data are summarized in Table 15. Understory vegetation overhanging the channel ranged between 2.9 and 100.0 percent in the two Coast range zones. In the Tsuga Zone, the understory overhanging cover was not correlated with stand age. Cover was 33 percent with 28 percent herbaceous vegetation cover at Site 18 at only two years of age. Generally sites in the Tsuga zone had greater than 40 percent and reached a maximum of 70 percent overhanging understory cover.

Herbaceous vegetation contributed more to the total cover in the Tsuga Zone relative to the Picea and Cascade range zones. Herbaceous cover in the Tsuga Zone was greater than 20 percent at three of the six sites while in the Picea Zone, the value was less than 10 percent at all sites. This cover in the Tsuga Zone provided one-third of the total cover at sites as old as nine years. Note again the extreme variation between sites of similar ages within a zone illustrated by sites 20 and 21 at nine years. Herbaceous cover was ten times greater at Site 21 relative to Site 20.

Deciduous vegetation dominated the overhanging vegetation in both the understory and overstory layers at sites greater than three years of age in both zones. Coniferous vegetation contributed no overhanging cover in either the understory or overstory at all sites in the Tsuga Zone. In the Picea Zone, no coniferous vegetation in the overstory layer was observed overhanging the channel and coniferous overhanging cover in the understory layer was minimal at all sites (less than five percent).

In the Picea Zone, total understory overhanging vegetation was highly correlated with stand age ($r^2 = 0.90$). Understory overhanging cover was 26 percent at age two and increased to 100.0 percent at a stand age of 16 years. This site had an extremely

TABLE 15

Mean Values for Vegetation Cover Overhanging the Streamchannel with Standard Errors ( ) for the Coast Range Zones

Site	Age (yrs)	Total Understory Cover n of 5	% Total Understory Overhanging Cover	% Understory Overhanging Coniferous Cover	% Understory Overhanging Deciduous Cover	% Understory Overhanging Herbaceous Cover	Total Overstory Cover n of 5	% Total Overstory Overhanging Cover	% Overstory Overhanging Coniferous Cover	% Overstory Overhanging Deciduous Cover
	Tsuga heterophylla Zone									
18	2	5	33.4 (6.6)	0.0	5.6 (3.5)	27.9 (3.7)	0	0.0	0.0	0.0
19	3	5	45.5 (10.4)	0.0	16.4 (12.3)	29.1 (8.0)	0	0.0	0.0	0.0
20	9	5	52.0 (12.0)	0.0	49.9 (11.4)	2.1 (2.1)	5	89.5 (10.5)	0.0	89.5 (10.5)
21	9	5	70.0 (10.0)	0.0	47.4 (16.3)	22.6 (9.5)	0	0.0	0.0	0.0
22	15	5	55.6 (17.4)	0.0	35.7 (9.5)	9.4 (7.6)	5	100.0 (0.0)	0.0	88.7 (11.3)
23	18	3	2.9 (1.4)	0.0	0.6 (0.6)	2.4 (1.5)	5	100.0 (0.0)	0.0	100.0 (0.0)
24	22	3	43.2 (19.3)	0.0	41.8 (18.3)	1.4 (1.4)	4	70.1 (20.0)	0.0	70.1 (20.0)
25	OG	5	72,5 (10.2)	16.6 (16.6)	43.6 (16.1)	12.3 (11.3)	4	56.2 (16.5)	56.2 (16.5)	0.0
	Picea sitchensis Zone									
26	2	5	26.3 (4.7)	3.0 (3.0)	15.0 (4.9)	8.3 (4.7)	0	0.0	0.0	0.0
27	3	5	9.3 (2.2)	0.0	1.8 (1.1)	7.5 (3.1)	0	0.0	0.0	0.0
28	5	5	51.1 (14.2)	0.7 (0.7)	41.8 (16.3)	8.7 (6.0)	5	89.9 (10.1)	0.0	89.9 (10.1)
29	8	5	54.1 (15.3)	0.0	54.1 (15.3)	0.0 (0.0)	5	83.3 (7.1)	0.0	83.3 (7.1)
30	10	5	67.8 (9.2)	1.0 (1.0)	60.4 (12.0)	6.4 (3.5)	5	93.6 (6.4)	0.0	93.6 (6.4)
31	16	5	100.0 (0.0)	0.0	100.0 (0.0)	0.0 (0.0)	4	70.5 (19.8)	0.0	70.5 (19.9)
32	OG	5	44.9 (6.7)	6.6 (6.6)	34.3 (9.2)	4.0 (2.8)	4	43.1 (23.8)	23.8 (19.1)	19.4 (19.4)

dense cover of *Rubus spectabilis* (Salmonberry) on both sides of the channel which dominated the overhanging vegetation along the entire reach.

Control sites in the *Tsuga* and *Picea* zones had 73 and 45 percent overhanging understory cover, respectively. This cover consisted of a mean of 12, 40, and 8 percent coniferous, deciduous, and herbaceous cover for the two sites. This pattern of diverse vegetation was not observed at any of the harvested sites in either zone.

The Coast range zones had relatively more overhanging cover provided by the overstory layer when compared to the Cascade range zones. As early as ages five and nine in the *Tsuga* and *Picea* zones, the overstory provided approximately 90 percent overhanging vegetation cover. In contrast, the Cascade zones had no, or only marginal, overstory layer development within the first 24 years after harvest.

It is interesting to note the substantial difference in overhanging overstory cover between sites 20 and 21 at nine years of age. While Site 21 had no overhanging overstory cover, Site 20 had nearly 90 percent. The development of a dense *Alnus* corridor at Site 20 accounts for this large difference (see Overstory Vegetation).

Canopy Density

The canopy density data for the two Coast range zones are summarized in Table 16. Control site density values averaged 83 and 88 percent in the *Tsuga* and *Picea*, respectively. These values were exceeded at three and two sites in the respective zones. In the *Tsuga* Zone, the control site value was exceeded as early as nine years after harvest, whereas in the *Picea* Zone, the control site density value was exceeded as early as five years after harvest. In both zones, these values decline at the next

TABLE 16

Mean Canopy Density Values with Standard Errors ( ) for the Coast Range Zones

Site	Age (yrs)	Canopy Density in %
Tsuga heterophylla Zone		
18	2	10.0 (2.9)
19	3	32.1 (9.0)
20	9	88.8 (1.2)
21	9	56.7 (11.4)
22	15	79.4 (2.2)
23	18	85.6 (0.6)
24	22	88.5 (1.5)
25	OG	83.3 (2.3)
Picea sitchensis Zone		
26	2	10.8 (2.8)
27	3	5.2 (0.6)
28	5	88.5 (1.3)
29	8	64.8 (15.1)
30	10	75.8 (7.4)
31	16	92.3 (1.0)
32	OG	87.5 (2.2)

consecutive site in the chronosequence, but generally they remain greater than 75 percent.

Canopy density values were correlated with stand age in both the Tsuga (r^2 = 0.71) and the Picea (r^2 = 0.57) zones. Mean values greater than 70 percent all had standard errors less than 7.5 percent which illustrates the nearly continuous, dense nature of the riparian cover that existed at sites greater than 15 and 10 years of age in the Tsuga and Picea zones, respectively.

These values indicate a relatively more rapid rate of vegetation development when compared to the Cascade range zones. Canopy density values in the Cascade zones did not exceed 50 percent until 13 and 24 years following harvest, while the Coast range zones exceeded this value in nine and five years following harvesting for the Tsuga and Picea zones, respectively. Again, high variation can exist between sites of similar stand ages as reflected by the data for sites 20 and 21 at nine years. Site 20 had over 1½-times the canopy density as Site 21 in the Tsuga zone primarily due to the dense Alnus rubra corridor at this site.

Angular Canopy Density

The angular canopy density data (ACD) with species and vegetation types providing the percent cover are summarized in Table 17. In the Tsuga Zone, the percent ACD steadily increases with stand age from 17.5 percent at Site 18 at a stand age of two years to 88.3 percent at age 22. At a stand age of only two years, the herbaceous vegetation already begins to shade the stream (17.5 percent). These data indicate that this herbaceous dominated ACD is short-lived in both zones with only 2.2 percent herbaceous ACD in the Tsuga Zone at age three which declines to less than one percent at nine years. In the Picea Zone, herbaceous cover at age one was less than two percent while the total ACD value was 18.2 percent. Spotty shrub species such as Rubus spectabilis and Ribes sanquineum contribute the other 16.3 percent to the ACD

TABLE 17

Summary of Angular Canopy Density (ACD) Data for the Coast Range Zones

Site	Age (yrs)	ACD (%)	ACD by Given Species (%)		ACD by Conifer-ous Species (%)	ACD by Decidu-ous Species (%)	ACD by Herbace-ous Species (%)
Tsuga heterophylla Zone							
18	2	17.5 (10.7)	ERECH	14.1	0.0	0.0	17.5
			POLYS	0.3			
			DIGIT	3.1			
19	3	31.1 (7.4)	ALRU	25.4	0.0	29.0	2.2
			SALIX	2.0			
			RUSP	1.6			
			POLYS	2.2			
20	9	82.7 (2.5)	ALRU	68.7	0.0	82.7	0.0
			RUSP	14.0			
21	9	64.6 (15.3)	TSHE	3.6	3.6	60.2	0.9
			OPHO	9.8			
			RUPA	7.7			
			RISA	42.7			
			PEFR	0.9			
22	15	85.7 (2.5)	ALRU	60.2	0.0	85.7	0.0
			SALIX	25.5			
23	18	78.9 (3.3)	ALRU	42.0	0.0	78.9	0.0
			RUSP	18.1			
			RUPA	18.8			
24	22	88.3 (2.5)	PSMEM	10.0	10.0	78.3	0.0
			ALRU	25.8			
			SACA	27.6			
			SALIX	19.4			
			RUPA	5.5			

TABLE 17 (continued)

Site	(yrs)	ACD (%)	ACD by Given Species (%)		ACD by Conifer-ous Species (%)	ACD by Decidu-ous Species (%)	ACD by Herbace-ous Species (%)
25	OG	84.6 (2.2)	PSMEM	25.9	57.1	27.5	0.0
			THPL	28.0			
			TSHE	3.2			
			VAPA	27.5			
	Picea sitchensis Zone						
26	2	18.2 (9.3)	RUSP	15.7	0.0	16.3	1.9
			RISA	0.6			
			ERECH	1.9			
27	3	0.5 (0.3)	RUSP	0.3	0.0	0.3	0.2
			ERECH	0.2			
28	5	91.9 (0.6)	ALRU	61.4	0.0	91.9	0.0
			RUSP	26.0			
			RUSP	4.5			
29	8	67.8 (14.3)	ALRU	58.3	0.0	67.8	0.0
			RUSP	9.5			
30	10	66.2 (11.6)	ALRU	66.2	0.0	66.2	0.0
31	16	94.3 (0.9)	ALRU	13.5	0.0	94.3	0.0
			RUSP	80.8			
32	OG	80.1 (2.4)	PISI	65.4	65.4	14.7	0.0
			RUSP	14.7			

at this site.

As in the Cascade zones, deciduous vegetation dominated the ACD observed at all harvested sites except Site 18. This deciduous vegetation consisted primarily of _Alnus rubra_ and _Salix_ spp. with deciduous ACD values greater than 60 percent at all sites with a stand age greater than five years of age.

Coniferous vegetation provided no contribution to the ACD in the _Picea_ Zone and only marginal contribution in the _Tsuga_ Zone. A coniferous ACD value greater than 10 percent was not observed at any site except Site 24 at a stand age of 22 years. In contrast, the control sites in each zone averaged approximately 60 percent coniferous ACD with 20 percent deciduous ACD.

Analysis and interpretation of these data was completed following the procedure described in the Cascade range section previously. The results of this analysis are graphically presented in Figures 9 and 10. The proportion of variation in ACD explained by stand age was again quite high in each zone with r-squared values of 0.95 and 0.61 in the _Tsuga_ and _Picea_ zones, respectively. The resulting equations from this analysis are as follows:

Tsuga heterophylla Zone

$$\hat{Y} = -12.091 + 95.447e^{-\left[\frac{X/22 - 1.0}{-0.804}\right]^{8}}$$

Equation 13 ($r^2 = 0.95$)

Picea sitchensis Zone

$$\hat{Y} = 12.801 + 74.136e^{-\left[\frac{X/22 - 1.0}{-0.804}\right]}$$

Equation 14 ($r^2 = 0.61$)

where: Y = angular canopy density (percent)

X = stand age in years

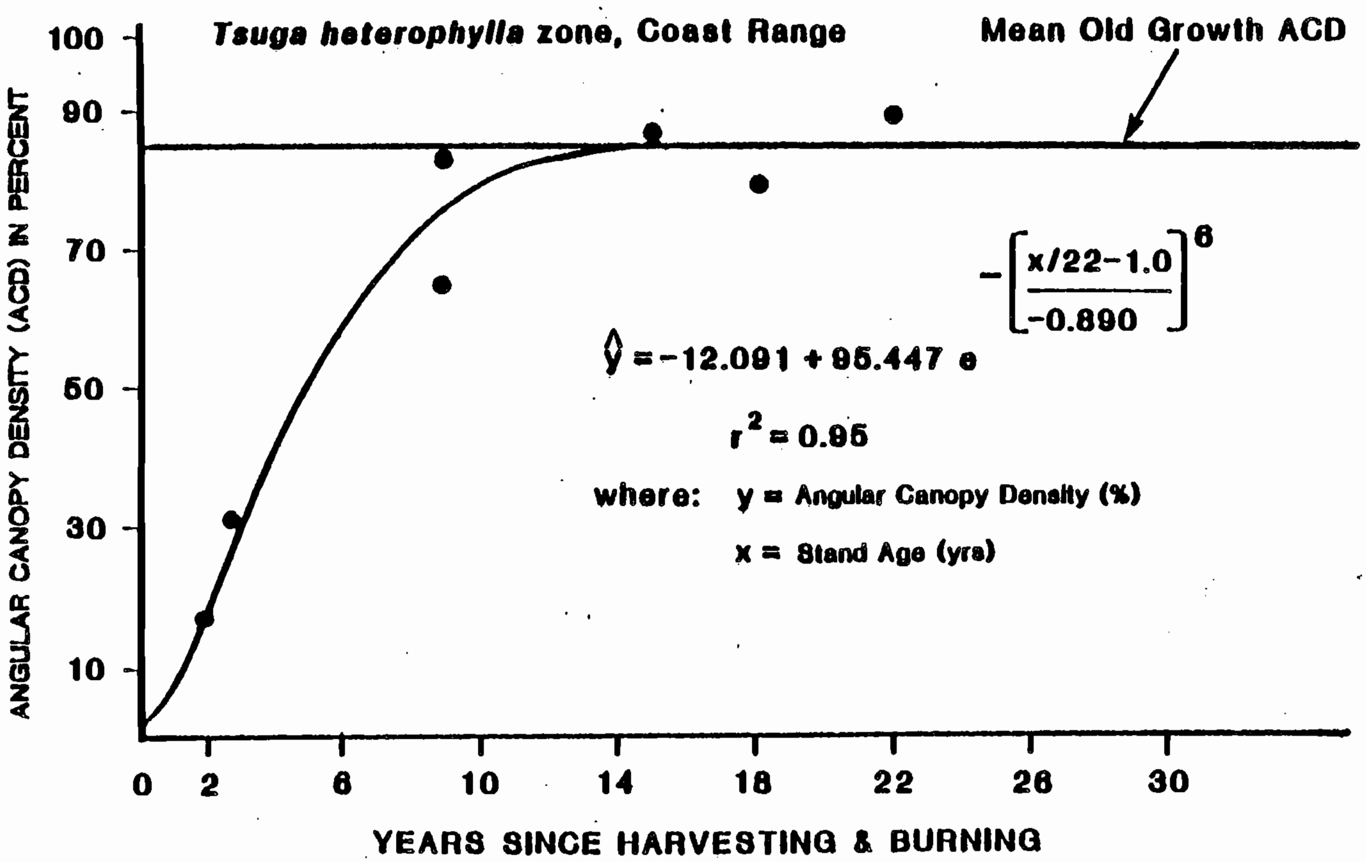


Figure 9. Relationship between angular canopy density (ACD) and stand age for the *Tsuga heterophylla* zone, Coast Range.

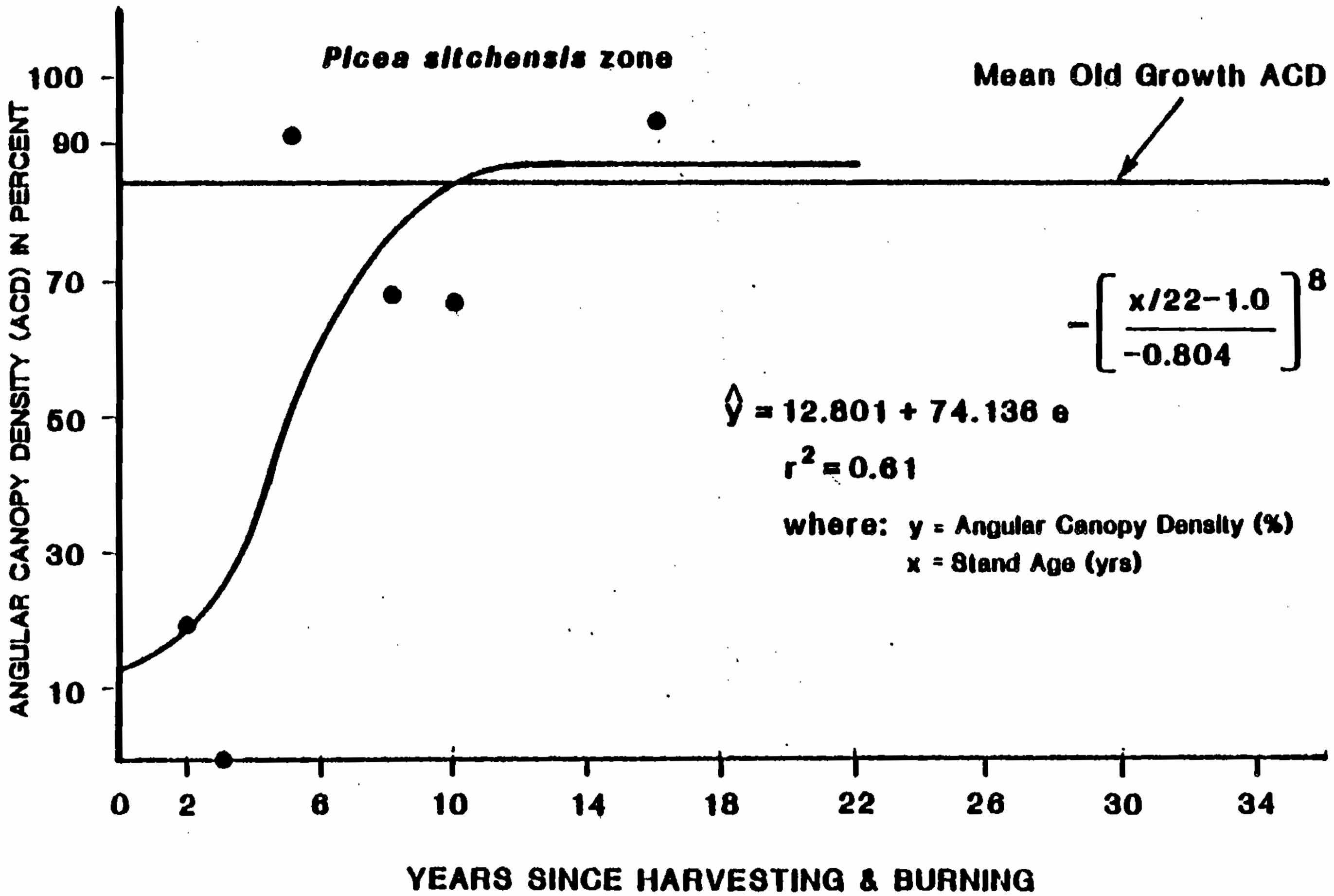


Figure 10. Relationship between angular canopy density (ACD) and stand age for the *Picea sitchensis* zone.

A statistical test for significance of the regression relationship between the two variables ACD and stand age yielded significance at the $\alpha = 0.001$ and $\alpha = 0.10$ levels for the *Tsuga* and *Picea* zones, respectively. The results of the test including the calculated F-values are included in the Appendix.

A statistical test of the similarity of the two zones independent regression lines could not be conducted because of reasons discussed previously. Interpretations about the y-intercept are not valid as the original data set does not include stand age equal to zero. A visual examination of the two curves does not indicate any large differences in slopes between stand ages of two and ten years in the two zones.

Using the rationale for percent shade values required presented in the Results of the Cascade Range Zones section and Equations 13 and 14, the following time periods to meet those required shade values can be calculated:

Percent Shade Requirement (%)	*Tsuga heterophylla* Zone: Time (years) to Shade Value	*Picea sitchensis* Zone: Time (years) to Shade Value
50 (Wash.)	5.0	5.1
63 (Oregon)	6.6	6.3
75 (Wash.)	8.9	7.8
84 (Control)	14.3	9.7

Data from Brazier (1973) were used to develop a similar regression equation as Steinblums ACD versus buffer strip width relation. Since Brazier's study sites were located primarily in the Coast ranges of Oregon, this equation was used in lieu of Steinblum's equation that was utilized for the interpretation of the Cascade range zones. This equation is as follows (Froehlich and Lyons, OSU Department of Forest Engineering):

$$ACD = 100 - 56.6 \ (e^{-0.0106 \ width}) \qquad \text{Equation 15} \quad (r^2 = 0.37)$$

where: Width = feet

ACD = percent

Using this equation and equations 13 and 14, the following table was debeloped:

Buffer Strip Width (ft.)	from Buffer in col. 1 (%)	*Tsuga* Zone: Time with Less than Given ACD (years)	*Picea* Zone: Time with Less than Given ACD (years)
12	50 (Wash.)	5.0	5.1
40	63 (Oregon)	6.6	6.3
77	75 (Wash.)	8.9	7.8
100 (Common width)	80	11.0	8.9
113	83 (Control)	14.3	9.7

From this table we can see the ACD values of 50 and 75 percent require bugger strips 12 and 77 feet in width, respectively, and the time that a stream would have less than these values would be 5.0 and 8.9 years in the *Tsuga* Zone and 5.1 and 7.8 years in the *Picea* Zone. These buffer strip widths are five times and 1½ times less than those calculated for the Cascade zones, respectively. A value of 83 percent was used to approximate the control site ACD because Equation 13 is asymptotic to 84 percent and, therefore, the stand age cannot be predicted.

Although these values are very similar for the Coast range *Tsuga* and *Picea* zones, the results illustrate the large difference in the rate of ACD development between the Coast and Cascade range zones. The time period with less than 75 percent shade is more than two times greater in the Cascade range *Tsuga* Zone relative to the Coast range *Tsuga* Zone. Control site ACD values are reached approximately ten years earlier in the Coast range *Tsuga* Zone when compared to that zone in the Cascades.

As discussed in the Cascade Zone results, it is felt that these results can aid the resource manager with decisions regarding long-term harvest plans and the placement of buffer strips in order to meet stream temperature objectives.

The Mixed Conifer Zone

Ground Cover

The ground cover data for the Mixed Conifer Zone in southwestern Oregon are summarized in Table 18. Grass and moss cover were generally less than 10 percent except at Site 39 at 29 years, which had 21 percent grass cover. As in the previously discussed zones, the percent grass cover in the control site was less than two percent and moss cover was approximately 20 percent. Site 39 appeared to be of a different character than the rest of the streams sampled in this study. This site was a low gradient, meandering, valley bottom stream with relatively low gradient bankslopes which were occupied by grass cover typical of a meadow-type stream. Evidence of cattle presence was also detected which can have a profound effect on the recovery of the streamside vegetation. In contrast, the other sites were typically high gradient with steep bankslopes and deciduous bank cover. For these reasons, this site was dropped from all statistical analysis. Values for this site are still presented for the value they may serve to a manager anticipating work near these types of streams.

Percent plant cover ranged between 22 and 45 percent which was very similar to the other zones in this study. Plant cover was found to be correlated with stand age ($r^2 = 0.54$) with plant cover increasing with stand age. As in the Cascade zones, the plant cover is higher (nearly two times in this zone) than ground layer in the control site at the oldest site in the chronosequence.

Litter cover was 38 percent at Site 33 at age one and remained between 40 to 55 percent for all the remaining sites in this zone. This percent litter cover was very typical relative

TABLE 18

Mean Values with Standard Errors ( ) for Ground Layer Cover for the Mixed Conifer Zone

Site	Age (yrs)	% Grass Cover	% Plant Cover	% Moss Cover	% Litter Cover	% Rock Cover	% Soil Cover	% Total Vegetation Cover	% Bareground
33	1	3.7 (1.40)	22.0 (3.70)	1.0 (1.00)	37.7 (5.11)	9.3 (3.11)	27.3 (4.50)	25.7 (3.58)	36.7 (5.70)
34	8	1.3 (0.79)	38.0 (3.91)	2.0 (1.01)	49.3 (3.95)	0.0	8.7 (3.21)	39.3 (3.83)	8.7 (3.21)
35	9	7.3 (2.87)	32.3 (4.33)	1.7 (0.97)	45.0 (3.83)	2.3 (1.24)	11.3 (3.61)	39.7 (4.19)	13.7 (3.76)
36	15	5.0 (1.90)	27.7 (3.83)	2.3 (1.49)	51.3 (3.97)	0.0	14.3 (2.74)	32.7 (4.07)	14.3 (2.74)
37	16	0.7 (0.46)	36.0 (4.14)	1.7 (0.97)	55.3 (4.06)	2.3 (1.04)	3.7 (1.82)	36.7 (4.22)	6.0 (2.23)
38	21	4.7 (1.42)	45.3 (3.51)	0.0	41.0 (3.37)	1.0 (0.74)	8.0 (2.60)	50.0 (3.95)	9.0 (2.68)
39	29	21.0 (4.13)	22.0 (4.51)	0.0	45.7 (3.74)	2.0 (1.47)	9.3 (2.79)	43.0 (4.37)	11.3 (3.24)
40	OG	1.0 (0.74)	26.0 (3.17)	18.3 (3.07)	50.3 (3.47)	2.3 (1.24)	1.7 (1.18)	27.0 (3.43)	4.0 (1.63)

to the other zones in the study. Rock and soil exposed were less than 15 percent at all but Site 33 (age 1) which had 27 percent soil surface exposed. Percent soil exposed was two to 16 times greater than the value at the control site (less than two percent soil exposed).

Total vegetation cover and bareground exposed were correlated with stand age (r^2 = 0.54 and 0.58, respectively) and experienced opposing trends with total vegetation cover increasing with age and bareground decreasing with age. This is the same pattern observed in the Cascade range zones, while opposite of the pattern observed in the Coast range zones.

Understory Vegetation Layer

Vegetation in the understory layer data is summarized by total vegetation, coniferous, deciduous, herbaceous and nitrogen-fixing cover in Table 19. Total cover ranged between 33 and 67 percent and was correlated with stand age (r^2 = 0.56) with cover increasing with stand age. Total cover in this zone tended to be slightly lower at older sites and similar or slightly higher for younger sites when compared to the Cascade range zones. Sites in the Cascade range zones had maximum cover values of 91 and 84 percent while those in this zone were 69 percent (at sites greater than 19 years).

Herbaceous cover in the Mixed Conifer Zone was similar to that of the Cascade zones with harvested sites ranging from 3.8 to 28.4 percent cover. The percent herbaceous cover at Site 38 at age 21 was 13 times greater than the control site values which was typical, albeit somewhat higher, of the other zones in the study.

Like all zones in this study, the deciduous vegetation dominated the understory layer at all sites. Coniferous cover

TABLE 19

Mean Understory Vegetation Layer Cover Values with Standard Errors ( ) for the Mixed Conifer Zone

Site	(yrs)	Total Cover n of 10	% Total Cover	% Deciduous Cover	% Conifer Cover	% Herbaceous Cover	% Nitrogen-fixing Cover
33	1	10	32.7 (2.69)	18.8 (5.77)	0.0	13.9 (4.17)	0.0
34	8	10	66.8 (5.89)	51.1 (8.68)	0.8 (0.75)	14.9 (4.56)	0.0
35	9	10	61.0 (4.09)	29.5 (4.87)	3.1 (2.28)	28.4 (6.26)	5.7 (3.81)
36	15	10	58.8 (4.86)	21.6 (4.93)	16.4 (8.39)	20.8 (6.05)	1.6 (1.60)
37	16	10	60.9 (8.63)	53.9 (6.37)	3.3 (3.25)	3.8 (1.61)	4.7 (3.66)
38	21	10	68.9 (5.98)	42.7 (7.48)	3.8 (2.22)	22.4 (5.97)	17.2 (9.50)
39	29	10	52.2 (4.14)	25.3 (6.68)	0.9 (0.66)	22.4 (6.11)	1.8 (1.85)
40	OG	10	52.9 (8.09)	32.2 (6.57)	19.0 (4.12)	1.7 (0.72)	0.9 (0.92)

was less than four percent at all harvested sites except Site 36 at age 15 which had 16 percent coniferous cover. The control site had the typical diverse pattern of understory cover found in the other control sites with approximately 30, 20, and 2 percent cover by deciduous, coniferous, and herbaceous species. This pattern of understory vegetation was not observed at any of the harvested sites in this zone.

Nitrogen-fixing cover ranged from 1.6 to 17.2 percent with all but one site having values less than six percent. The maximum percent nitrogen-fixing cover when expressed as a percent of the deciduous cover was nearly three times less than that observed in the Tsuga heterophylla Zone in the Cascades.

Overstory Vegetation Layer

The overstory vegetation layer data for the Mixed Conifer Zone are summarized in Table 20. The overstory layer in this zone was marginal at all but one site in this zone. All except Site 36 at 15 years had less than six percent overstory cover as sampled by the line-intercept method. Site 36 had 30 percent overstory cover which was all coniferous cover. Site 37 at 16 years had only 5.6 percent cover which was all deciduous. This illustrates the high variation between sites of similar ages. These data are similar to the Cascade range zones which contrast sharply with the dense overstory layers that tend to develop on the Coast range sites.

The control site in this zone had 36, 32, and 3 percent coniferous, deciduous, and nitrogen-fixing cover, respectively. Like the other zones in the study, this pattern of overstory development was not duplicated at any of the sites in the 21-year chronosequence.

TABLE 20

Mean Overstory Vegetation Layer Cover
Values with Standard Errors ( )
for the Mixed Conifer Zone

Site	Age (yrs)	Total Cover n of 10	% Total Mean Cover	% Coniferous Cover	% Deciduous Cover	% Nitrogen-fixing
33	1	0	0.0	0.0	0.0	0.0
34	8	0	0.0	0.0	0.0	0.0
35	9	0	0.0	0.0	0.0	0.0
36	15	5	27.0 (10.2)	27.0 (10.2)	5.6 (5.6)	0.0
37	16	1	5.6 (5.6)	0.0	0.0	0.0
38	21	0	0.0	0.0	0.0	0.0
39	29	2	4.8 (3.7)	4.8 (3.7)	0.0	0.0
40	OG	10	68.3 (9.2)	36.0 (9.6)	32.3 (11.8)	2.7 (2.7)

Random Pairs Data

The resulting data from the random pairs sample for the Mixed Conifer Zone are summarized in Table 21. The sites in this zone did not develop significant numbers of trees two inches (5.1 cm) or larger at sites less than 15 years of age. By comparison, the *Tsuga* and *Abies* zones in the Cascades developed trees of that size at stand ages of 10 and 14 years (ignoring the solitary pair of *Acer macrophyllum* trees at Site 2).

Mean distance between trees was less than 51 feet (15.5 m) at all sites with two-inch, or larger, trees. Mean DBH values were less than five inches (12.7 cm) at all the harvested sites except Site 39 (the open, meadow-type stream) which had a well-established *Pinus ponderosa* stand with a mean DBH of 6.8 inches (17.3 cm). The average area occupied by a single individual value in this zone was slightly greater than those of similar ages in the Cascade *Tsuga* Zone and slightly less than those of the *Abies* Zone.

The sites in this zone were more strongly dominated by coniferous species than was observed in the Cascade *Tsuga* Zone and had similar values as those in the *Abies* Zone. Values for the relative dominance and relative density for coniferous species were close to 90 percent at two sites and only three percent at the remaining site. It is again interesting to note the variation between two sites of similar ages. Site 36 at 15 years was nearly all coniferous overstory (92 percent relative dominance) while Site 37 at 16 years was nearly all deciduous (2.7 percent relative dominance of conifers). This may be the result of the generally south-facing nature of Site 37, whereas Site 36 has a general north-facing orientation. Sites in south-facing slopes in southwestern Oregon can be difficult to reforest following harvesting. However, this may also be the result of several variables which were not included in this analysis such as intensity of harvest and site preparation, soil type, intensity of reforestation efforts, or other similar variables.

TABLE 21

Summary of Random Pairs Sample of Trees Two Inches or Larger for the Mixed Conifer Zone

Site	Age (yrs)	Mean Distance Between Trees (feet)	Mean Basal Area/Tree (ft^2/tree)	Area Occupied by Single Individual (ft^2/tree)	Stem Density/Acre (stems/acre)	Basal Area/Acre (ft^2/acre)	Mean DBH (inches)	Relative Dominance Coniferous	Relative Density Coniferous	Relative Dominance Deciduous	Relative Density Deciduous	Relative Dominance Nitrogen Fixing	Relative Density Nitrogen Fixing
33	1	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
34	8	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
35	9	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
36	15	22.1	0.122	311.3	139.90	17.11	4.27	91.9	77.5	8.1	22.5	0.0	0.0
37	16	26.5	0.034	449.1	97.00	3.25	2.44	2.7	3.1	97.3	96.9	0.0	0.0
38	21	50.4	0.069	1624.7	26.80	1.84	3.34	89.0	85.0	11.0	15.0	8.7	7.5
39	29	30.4	0.292	589.9	73.84	21.53	6.88	97.2	95.0	2.8	5.0	0.0	0.0
40	OG	17.4	1.700	196.3	111.73	376.98	10.46	98.1	65.0	1.9	35.0	0.3	15.0

NOTE: NT = no trees two inches or larger in riparian zone.

Vegetation Overhanging the Stream Channel

Vegetation directly overhanging the stream channel data is summarized for the Mixed Conifer Zone in Table 22. Vegetation in the understory layer provided between 6.0 and 58.1 percent cover overhanging the channel for the set of sites. This cover was not well-correlated with stand age ($r^2 = 0.15$). Sites at 9, 16, and 21 years had approximately 25 percent cover and sites at 8 and 15 years averaged approximately 55 percent cover.

Herbaceous vegetation dominated or contributed significantly (approximately half of the total cover) to the overhanging cover at sites 33 through 36 at one and 15 years of age, respectively. Herbaceous overhanging cover in this zone was relatively high when compared to the Cascade range zones at similar young sites and generally lower when compared to the Tsuga zone in the Coast range. Herbaceous overhanging cover at the control site was less than five percent.

Deciduous vegetation dominated at sites older than nine years. Coniferous cover provided no overhanging cover in the understory layer at any of the sites. At the control site 8, 29, and 4 percent cover was contributed by coniferous, deciduous, and herbaceous species, respectively. As in all zones in the study, this diverse pattern of vegetation providing the overhanging cover was not observed at any of the harvested sites.

Overhanging vegetation in the overstory layer was zero or negligable at all sites in this zone. All sites except Site 39 at 29 years had less than one percent overstory overhanging cover except Site 39 at 29 years which had less than 10 percent cover. In contrast, the control site for this zone had 57 percent overstory cover with 22 and 35 percent coniferous and deciduous overhanging cover. This again illustrates the open nature of the control sites with respect to overstory vegetation directly overhanging the channel that was observed at all control sites in the

TABLE 22

Mean Values for Vegetation Cover Overhanging the Streamchannel with Standard Errors ( ) for the Mixed Conifer Zone

Site	Age (yrs)	Total Understory Cover n of 5	% Total Understory Overhanging Cover	% Understory Overhanging Coniferous Cover	% Understory Overhanging Deciduous Cover	% Understory Overhanging Herbaceous Cover	Total Overstory Cover n of 5	% Total Overstory Overhanging Cover	% Overstory Overhanging Coniferous Cover	% Overstory Overhanging Deciduous Cover
33	1	3	6.0 (3.1)	0.0	0.0	6.0 (3.1)	0	0.0	0.0	0.0
34	8	5	50.2 (12.2)	0.0	38.0 (16.7)	12.2 (4.8)	0	0.0	0.0	0.0
35	9	4	25.8 (13.5)	0.0	2.0 (2.0)	23.8 (12.4)	0	0.0	0.0	0.0
36	15	3	58.1 (23.8)	0.0	33.7 (21.2)	24.4 (17.6)	0	0.0	0.0	0.0
37	16	4	23.3 (10.3)	0.0	21.7 (10.8)	1.6 (1.1)	1	0.2 (0.2)	0.0	0.2 (0.2)
38	21	5	30.7 (10.4)	0.0	22.8 (9.6)	8.0 (3.4)	0	0.0	0.0	0.0
39	29	4	22.9 (10.3)	0.0	16.0 (11.0)	0.8 (0.4)	1	9.7 (9.7)	9.7 (9.7)	0.0
40	OG	5	41.8 (7.4)	8.3 (8.3)	29.1 (11.1)	4.3 (2.9)	5	57.4 (13.6)	22.2 (13.6)	35.2 (12.1)

in the study (less than 60 percent overstory overhanging vegetation).

Canopy Density

Canopy density data for sites in the Mixed Conifer Zone are summarized in Table 23. Canopy density values ranged from 3.1 percent at age one to a maximum of 69.8 percent at age 15, although the values were generally greater than 40 percent after age eight (except Site 35 at nine years which had 27.3 percent). Canopy density in the control site averaged 84 percent which was very similar relative to the other four zones in the study. As in the high-elevation Cascade *Abies amabilis* Zone and unlike the other three zones in the study, the control site density value was not attained at any of the harvested sites. After a period of 21 years Site 39 only had less than one-half of the control site density.

Canopy density did not correlate as well with stand age ($r^2 = 0.46$) when compared to the other zones in the study (r^2 values of 0.57 to 0.77). Sites with similar ages can vary greatly with respect to the canopy density observed. For example, Site 34 at eight years has nearly twice as much canopy density as Site 35 at nine years. Although we cannot statistically test the effect of the different treatments due to our experimental design, this could have been an influential factor to the different slash removal techniques employed. Site 34 was pile-burned rather than broadcast-burned which tends to exclude the riparian vegetation from the burning impact.

It is interesting to note the potential for improved stream cover at earlier periods possible by altering the burning technique. These data indicate that the canopy density may be nearly 50 percent after a period of only eight years when a fire-free zone is maintained about the stream, whereas a burn in the riparian zone can result in only 27 percent canopy density.

TABLE 23

Mean Canopy Density Values with Standard Errors ( ) for the Mixed Conifer Zone

Site	Age (yrs)	Canopy Density in %
33	1	3.1 (1.4)
34	8	49.4 (8.9)
35	9	27.3 (3.0)
36	15	69.8 (6.5)
37	16	51.0 (6.7)
38	21	41.0 (3.8)
39	29	44.8 (9.7)
40	OG	84.0 (2.4)

Angular Canopy Density and Shade Cover

The angular canopy density data (ACD) with species and vegetation types providing the shade cover are summarized in Table 24. ACD values ranged from 4.6 at age one to 57.3 at age 15. Herbaceous vegetation provided only a marginal (less than two percent) contribution to the ACD values at stand ages of one and nine years and zero values at the remaining sites.

Deciduous vegetation dominated the ACD at all but Site 36 where it still contributed nearly one-half to the total ACD. At Site 36 the coniferous ACD was slightly greater than 30 percent, while the deciduous ACD was approximately 27 percent.

Control site ACD averaged 82.2 percent with 51.1 percent coniferous ACD and 31.1 percent deciduous ACD. Like the other zones in the study, these coniferous and deciduous values were not attained at any of the harvested sites. As in the *Abies* Zone, the ACD value for this zone was not observed or closely approximated at any harvested site. Maximum ACD attained in this zone was only 70 percent of the control site value.

Analysis and interpretation of these data were completed following the procedure described in the Cascade Zone results discussed previously. The sigmoid-fit of these data yielded the results presented in Figure 11.

The proportion of variation in ACD explained by the variable stand age was similar to that in the *Abies* Zone with an r-squared value of 0.54. The resulting equation from this analysis is as follows:

$$\hat{Y} = -1.419 + 78.655e^{-\left[\left(\frac{X/48 - 1.0}{-0.830}\right)^3\right]} \qquad \text{Equation 16} \quad (r^2 = 0.54)$$

where: Y = angular canopy density (percent)

X = stand age in years

TABLE 24

Summary of Angular Canopy Density (ACD) Data for the Mixed Conifer Zone

Site	Age (yrs)	ACD (%)	ACD by Given Species (%)		ACD by Coniferous Species (%)	ACD by Deciduous Species (%)	ACD by Herbaceous Species (%)
33	1	4.6 (2.3)	SALIX[2]	2.2	0.0	3.4	1.2
			COCOC	1.2			
			GRASS	1.2			
34	8	44.8 (9.2)	ACCI	39.5	0.0	44.8	0.0
			SALIX	5.3			
35	9	15.9 (4.4)	ACMA	2.9	0.0	14.9	1.0
			SALIX	7.7			
			CESA	4.3			
			EPAN	1.0			
36	15	57.3 (10.9)	PSMEM	20.4	30.9	26.5	0.0
			PIPO	5.5			
			ABGR	5.0			
			POTR2	5.5			
			ACCI	2.2			
			SALIX	18.8			
37	16	50.4 (9.3)	ACMA	9.0	0.0	50.3	0.0
			ACCI	5.9			
			COCOC	16.3			
			SALIX	17.7			
			CESA	1.4			
38	21	42.1 (14.9)	ALSI	16.4	0.0	42.1	0.0
			COST	5.6			
			SALIX	20.1			
39[1]	29	27.5 (11.3)	PIPO	15.7	20.0	7.6	0.0
			PSMEM	4.3			
			POTR2	2.8			
			SALIX	4.8			
30	OG	82.2 (2.6)	TSHE	41.2	51.1	31.1	0.0
			PSMEM	9.9			
			ALRU	11.4			
			ACMA	1.5			
			ACCI	18.2			

[1]Excluded from analysis due to possible effects of cattle-grazing and other management impacts.

[2]See Appendix 2 for definition of species codes.

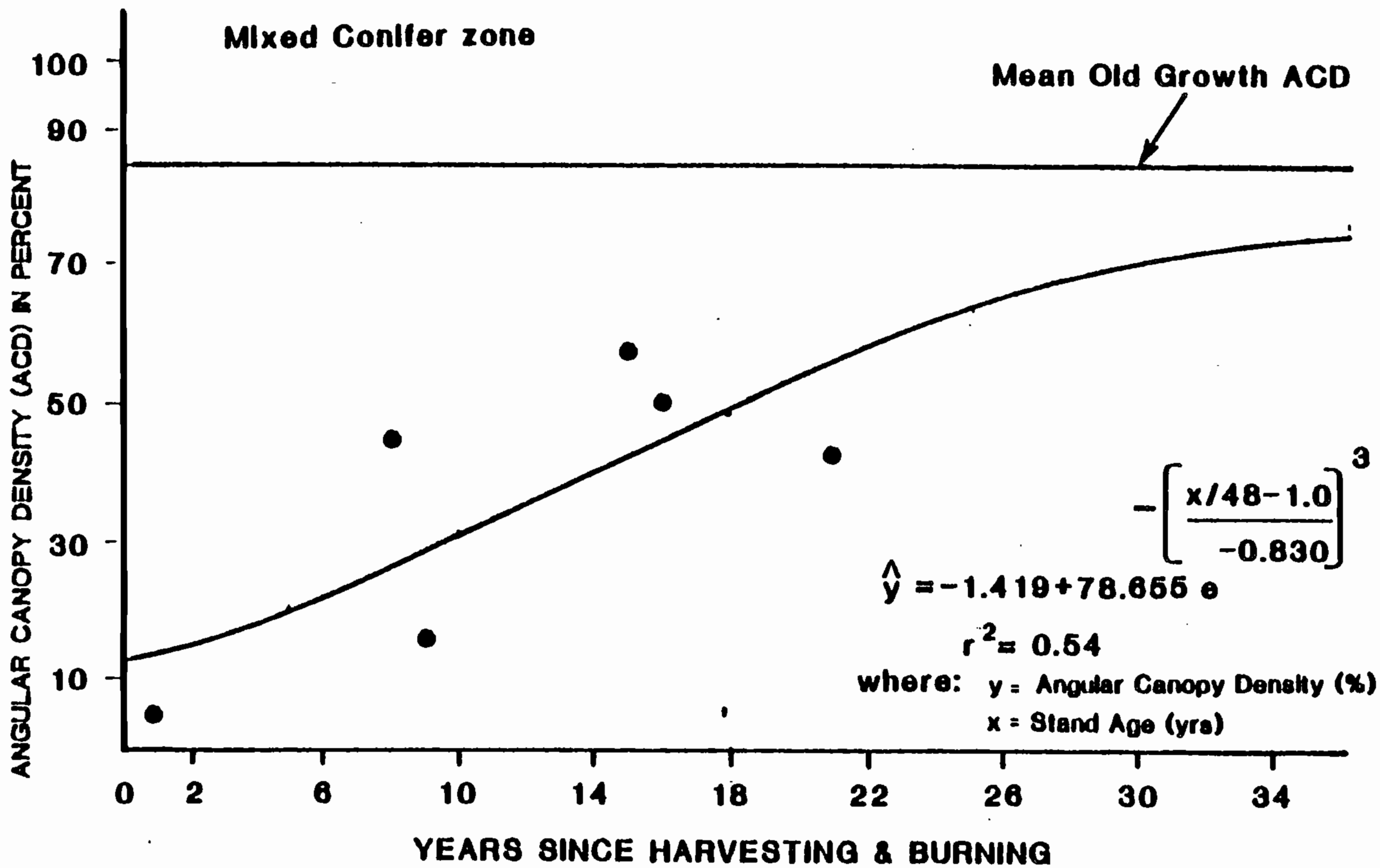


Figure 11. Relationship between angular canopy density (ACD) and stand age for the Mixed Conifer zone.

A statistical test for significance of the regression relationship between the two variables ACD and stand age yielded significance at the $\alpha = 0.10$ level. The results of this test, including the calculated F-value, is included in the Appendix. Using Equation 16 and the rationale for required shade values discussed previously, the following time periods to meet those values can be calculated:

Percent Shade Requirement	Mixed Conifer Zone: Time (years) to Shade Value
50 (Wash.)	18
57 (Data limit)	21
64 (Oregon)	**

**Data beyond limits of original data set.

Using Steinblum's Equation 12 (1978) and Equation 16, we can develop the following table:

Buffer Strip Width (ft.)	Predicted Shade from Buffer in Col. 1 (%)	Mixed Conifer Zone Time with Less Than Given Shade
50 (Wash. SMZ)	43.5	15.2
61	50.0 (Wash.)	18.0
87	63.0	**

**Data beyond limits of original data set.

From these two tables we can see the slow rate of ACD development with stand age in this zone relative to that in the *Tsuga* Zone in both ranges and the Picea Zone in the Coast range. The results of this zone are more similar to the high elevation Abies Zone than the others in the study, although the time period to attain 50 percent shade was calculated to be five years earlier in the Mixed Conifer Zone than the Abies Zone.

It should also be noted that a shade value of 63 percent (Oregon State Forest Practice Rules requirement) was not achieved within 21 years in this zone. Further study in this and the Abies Zone will be necessary in order to determine the time period to meet this value.

As discussed previously, it is felt that these results can aid the resource manager with decisions regarding long-term harvest plans and the placement of buffer strips in order to meet stream temperature objectives.

Large Organic Debris

The results of the large organic debris (LOD) sample are presented in Table 25. These data were plotted against stand age in order to quantify any trends in the amount of large organic debris loading in managed streams during the past two and one-half decades. The resulting plot in presented in Figure 12.

The value of LOD in the control sites was averaged and found to be 13.4 pieces per 100 feet (30.5 m) of stream channel with a standard error of 2.9. We can see from these data and Figure 12 a general trend of fewer pieces of LOD remaining in the harvested sites relative to the control sites. Seventysix percent of the harvested sites had a lower LOD loading than the average for the control forested areas. Thirty out of 39 of the harvested sites had LOD values less than the average for the unmanaged control sites. This indicates that approximately three-fourths of our streams harvested in this two and one-half decade period have less than the average natural amount of LOD found in the control sites. The number of pieces per 100 feet averaged 10.4 with a standard error of 6.5 for the harvested sites.

It is beyond the scope of this paper to attempt to define if this decline is biologically significant or to discuss the consequences of lower LOD amounts on the stream ecosystem. However, since LOD exhibits the aforementioned benefits (see section III), negative impacts might be expected.

TABLE 25

Results of the Large Organic Debris Sample

Site	Site	Age (years)	LOD/100 feet
Tsuga, Cascades Zone	1	1	22.1
	2	7	8.1
	3	10	5.0
	4	13	7.7
	5	15	7.2
	6	19	6.0
	7	20	24.0
	8	24	14.0
	9	OG	8.1
Abies Zone	10	8	26.8
	11	8	17.0
	12	14	13.6
	13	17	9.3
	14	19	10.7
	15	24	18.6
	16	24	23.0
	17	OG	7.7
Tsuga, Coast Zone	18	2	9.9
	19	3	3.1
	20	9	0.3
	21	9	5.5
	22	15	7.2
	23	18	10.0
	24	22	8.0
	25	OG	17.7
Picea Zone	26	2	9.0
	27	3	22.5
	28	5	6.8
	29	8	4.5
	30	10	7.1
	31	16	11.7
	32	OG	11.3
Mixed Conifer Zone	33	1	2.5
	34	8	9.0
	35	9	2.6
	36	15	**
	37	16	9.2
	38	21	3.2
	39	29	7.0
	40	OG	22.3

OG = control site.
** = missing data.

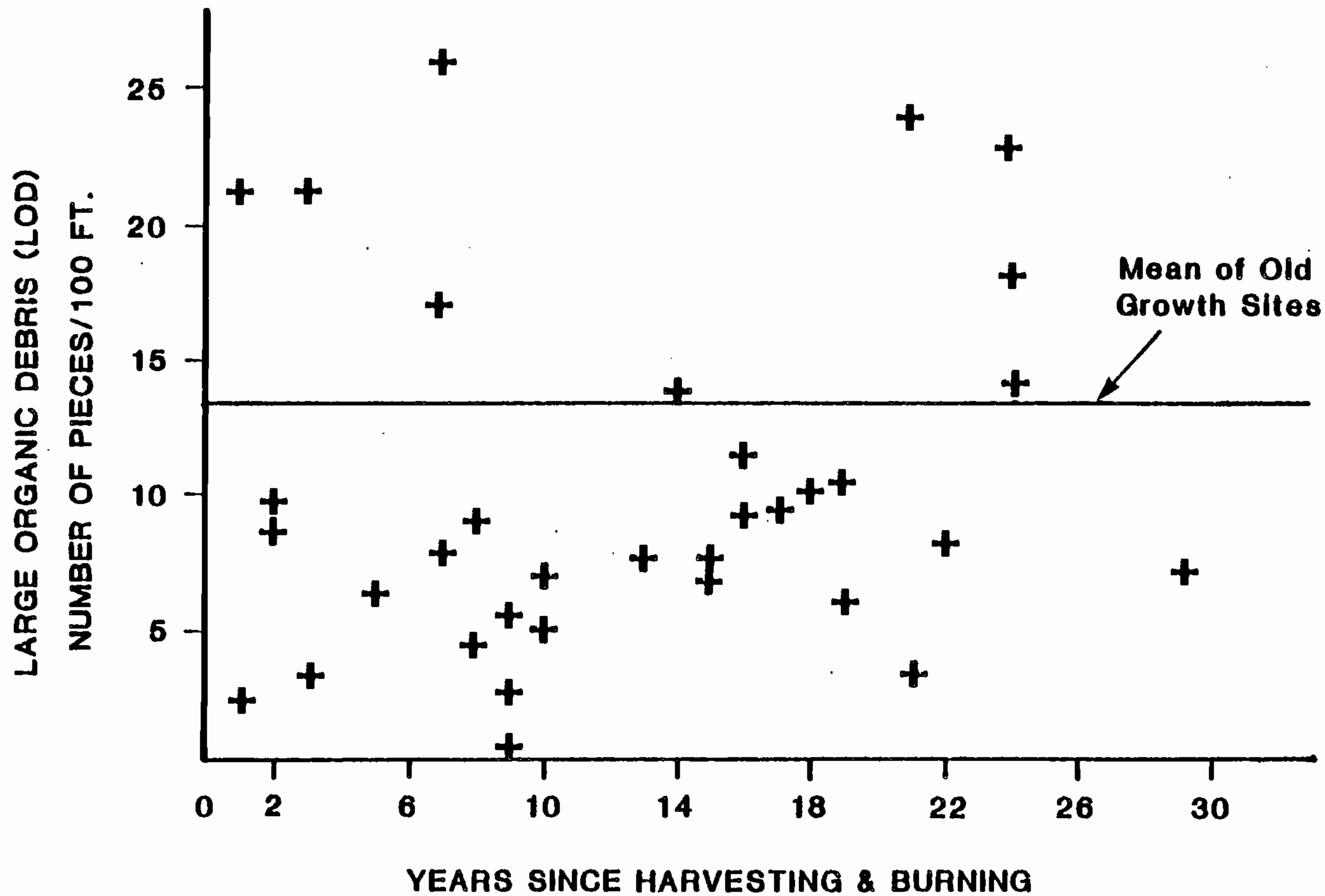


Figure 12. Plot of number of large organic debris (LOD) pieces per 100 feet verses years since harvest.

IX. CONCLUSIONS

The effect of variation in climate between the five vegetation zones could be readily seen in the overall rate of vegetative regrowth and in the general pattern of vegetative succession. In general, zones in the Coast range tended to develop riparian vegetation more rapidly following timber harvesting than the Cascade range zones which, in turn, developed more rapidly than the Mixed Conifer zone in southwestern Oregon. Changes in the development of riparian vegetation with time since timber harvesting could generally be detected for Angular canopy density (ACD), canopy density, total understory vegetation cover, mean distance between stems, stem density, and mean stem DBH. High variation within sites of similar ages makes interpretations about differences between stand ages and zonal differences difficult for many of the other vegetative factors included in this study.

A generalized view of the riparian zone vegetation development following harvesting is presented in Figure 13. Based upon the observations made during the course of the study and the resulting data, four stages of riparian vegetation development can generally be recognized. In any given zone, one or more of these stages can be marginal or absent (i.e. in the *Abies amabilis* zone, a stage of dominating deciduous trees in the riparian zone was not observed at any harvested site). It is also important to note that vegetative cover for any given stage may differ greatly between vegetation zones (i.e. the herbaceous stage in the Mixed Conifer zone tended to have lower percent vegetative cover relative to the Coast zones during that same period).

Litter dominated the ground layer (less than 13 cm) at the majority of the harvested sites in the study. Deciduous vegetation dominated the understory (less than 2.5 m) and overstory (greater than 2.5 m) layers at all the harvested

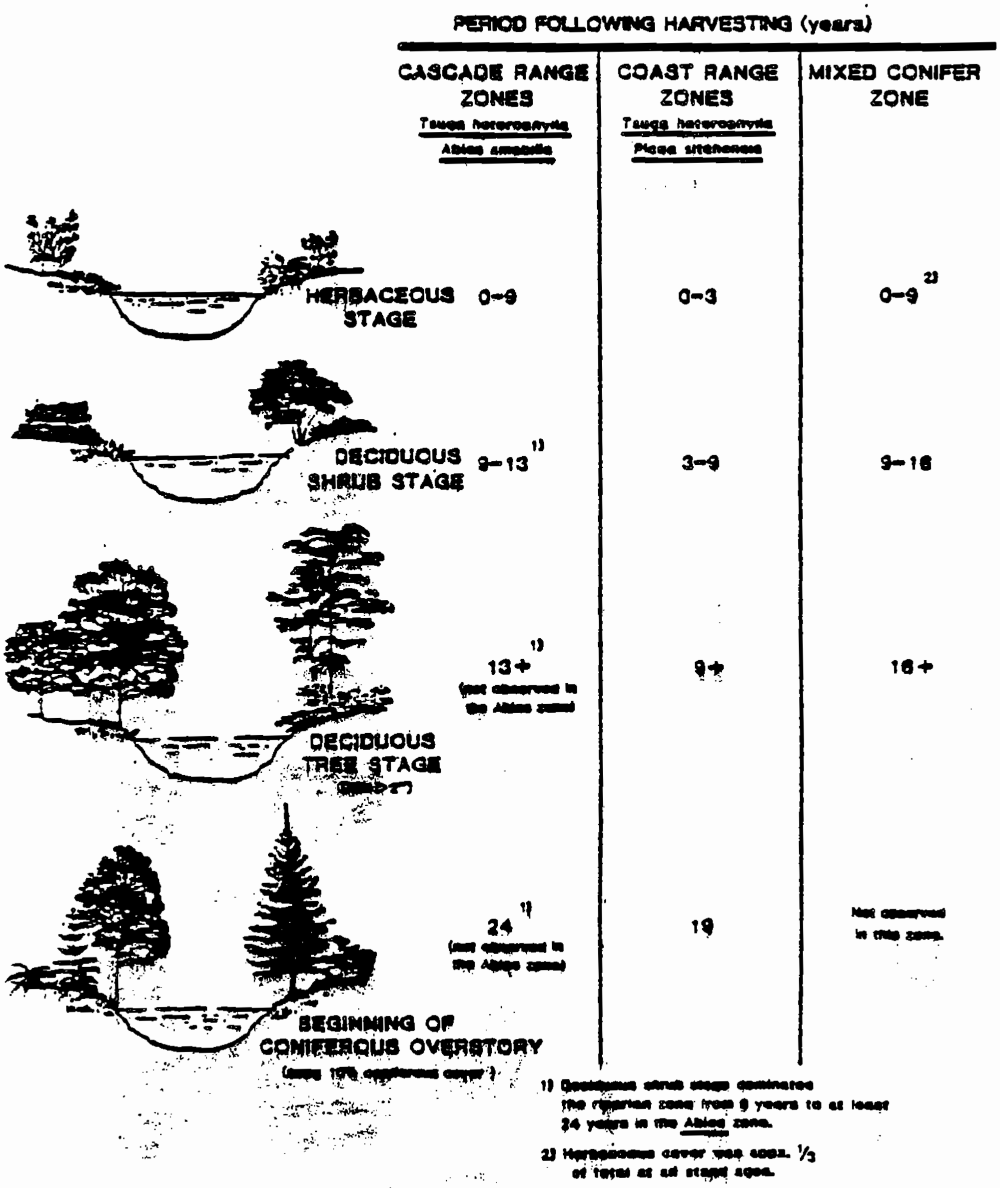


Figure 13. Generalized view of riparian vegetation development through four vegetative stages with expected time period of site occupancy for western Oregon.

sites. Coniferous vegetation was generally less than 20 percent in both the understory and overstory layers during a period of two decades following timber harvesting. Riparian zone vegetation at the harvested sites tended to be dominated by a single vegetation (e.g., deciduous or herbaceous) rather than the diverse pattern of vegetation observed at the forested control sites. The forested control sites generally had significant cover provided by coniferous, deciduous, and herbaceous vegetation which provides a rich and diverse food supply in terms of both timing and quantity to the stream ecosystem. It was also noted that a change from a deciduous dominated riparian zone to a coniferous dominated zone was generally not observed in the two and one-half decade period studied.

Canopy density observed at the unmanaged sites averaged approximately 85 percent. This cover was attained at some sites in the Cascade and Coast range _Tsuga heterophylla_ zones and the Coast range _Picea sitchensis_ zone within 9 to 24 years. In the high elevation _Abies amabilis_ and the Mixed Conifer zones the maximum canopy density observed within 29 years of harvesting averaged approximately 65 percent.

Satisfactory relationships could be developed for trends in Angular Canopy Density (ACD) with time following harvesting, but high variablility between sites within vegetation zones requires that for other vegetative factors a larger sample size be taken or better stratification by defining intermediate vegetation zones be done. However, various patterns of succession could be followed with occassional extreme values appearing from zone to zone. These outliers may be due to the severity of slash treatments or logging disturbance. ACD values were found to correlate well with stand age and an equation was developed to describe these data for each zone. The time period to reach 50 percent ACD was calculated for each zone. The _Tsuga heterophylla_ Coast zone was the most rapid, the _Abies amabilis_ zone the slowest, and the _Picea_ _sitchensis_, _Tsuga_ _heterophylla_ Cascade, and Mixed Conifer zones having intermediate recovery periods in this order.

Large organic debris loading in the unmanaged forested sites averaged 13.4 pieces per 100 feet (30.5 m) while the harvested sites had an average of 10.4 pieces per 100 feet. A few of the harvested streams had unusually high loadings (e.g., 27 pieces/100 ft) while 77 percent of the streams contained less than the forested streams.

BIBLIOGRAPHY

Bailey, R. G. 1976. Ecoregions of the United States. Dept. of Agriculture. United States Forest Service. Intermountain Region, Ogden, Utah.

Baldwin, E. M. 1976. Geology of Oregon. Kendall/Hunt Publ. Co., Dubuque, Iowa. 147 pp.

Brazier, J. R. 1973. Controlling water temperatures with buffer strips. M.S. thesis, Oregon State University, Corvallis, Oregon. 65 pp.

Brown, G. W. 1969. Predicting temperatures of small streams. For. Res. Lab, School of Forestry, Oregon State Univ., Corvallis, Oregon. Water Resoures Research Vol. 5, No.1, 68-75.

________. 1970. Predicting the effect of clearcutting on stream temperature. Journal of Soil and Water Conservation, 25:11-13.

________, D. Carlson, G. Carter, D. H. Heckeroth, M. Miller, B. Thomas. 1977. Meeting water quality objectives through the Oregon Forest Practices Act. Oregon Dept. of Forestry. 146 pp.

________, and J. T. Krygier. 1970. Effects of clearcutting on stream temperature. Water Resources Research, 6(4):1133-1140.

________, G. W. Swank, J. Rothacher. 1971. Water temperature in the Steamboat drainage. U.S.D.A., For. Serv., Pac. Northwest For. and Range Exp. Sta., Res. paper PNW-119.

Bowmann, Q. O. 1975. Stream corridor management. S. Santiam Water Control District. Salem, Oregon.

Cain, S. A., and G. M. Castro. 1959. Manual of vegetation analysis. Harper and Bros., Publ. Co., New York, N.Y.

Campbell, A. G., and J. F. Franklin. 1979. Riparian vegetation in Oregon's western Cascade mountains: Composition, Biomass and Autumn Phenology. Coniferous Forest Biome. Bulln. No. 14.

Christner, J. 1981. Changes in peak streamflows from managed areas of the Willamette National Forest. Report, U.S.F.S. Willamette National Forest, 8 pp.

Froehlich, H. A. 1975. Angular canopy densiometer. Report on file, Dept. Forest Engineering, Oregon State Univ., Corvallis, Oregon.

________. 1982. Precipiation map of Southwestern Oregon. Dept. Forest Engineering, Oregon State Univ., Corvallis, Oregon (In preparation).

Garrison, G. A. and J. M. Skovlin. 1976. Northwest plant names and symbols for ecosystem inventory and analysis. U.S.D.A. For. Serv. Gen. Tech. Report PNW-46. Pac. Northwest For. and Range Exp. Sta., Portland, Oregon.

Gholz, H. L., C. C. Grier, A. G. Campbell, and A. T. Brown. 1979. Equations for estimating biomass and leaf area of plants in the Pacific Northwest. For. Res. Lab, Oregon State Univ., Res. paper 41.

Hall, J. D., and R. L. Lantz. 1969. The effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams. In: T. G. Northcote (ed.), Symposium on salmon and trout in streams. H. R. MacMillan Lectures in Fisheries, Univ. of Brit. Columbia, Vancouver, B.C.

Hall, F. C. 1979. Codes for Pacific Northwest ecoclass classification. U.S.D.A. For. Serv. Pac. Northwest Region. R6 Ecol 79-002. 62 pp.

Hanson, D. M. 1976. The ecological life zones of Oregon: A test of the Holdridge model. Proc. Ore. Acad. Sci.,11.

Harr, R. D. 1976. Hydrology of small forest streams in western Oregon. U.S.D.A. For. Serv. Gen. Tech. Report PNW-55, Pac. Northwest For. and Range Exp. Sta., Portland, Oregon.

Hawk, G. M., J. F. Franklin, W. A. McKee, and R. B. Brown. 1978. H.J. Andrews Experimental Forest reference stand system: Established and use history. Coniferous Forest Biome, Bulln. No. 12.

Henderson, J. A. 1970. Biomass and composition fo the understory vegetation in some <u>Alnus rubra</u> stands in western Oregon. M.S. thesis, Oregon State Univ., Corvallis, Oregon.

Hobbs, D. and T. M. Halbach. 1981. Streamside management zone inventory. Water quality planning office of Water Programs. Wash. State Dept. of Ecology, Olympia, Wash. Rep. No. DOE 81-82.

Cline, S., and F. Swanson. 1979. Annual report on Coniferous Forest Biome Research. Copy on file, Forest Science Department, Oregon State Univ., Corvallis, Oregon.

________. 1982. Development of riparian and hillslope vegetation after clearcutting, western Oregon. Draft Report. Forest Sciences Lab, Corvallis, Oregon.

Cooper, W. S. 1953. Vegetation of the Northwest American province. Proceedings eigth Pacific Science Congress. 8(4):133-138.

Daubenmire, R. 1969. Ecologic plant geography of the Pacific Northwest. Madrono. 20(3):111-128.

Dyrness, C. T. 1965. The effect of logging and slash burning on understory vegetation in the H.J. Andrews Experimental Forest. U.S.D.A., For. Serv. Res. Note PNW-31. Pacific Northwest For. and Range Exp. Sta., Portland, Oregon.

Edmonds, R. L. 1974. An initial synthesis of results in the Coniferous Forest Biome, 1970-1973. Bulln. No. 7.

Fisher, S. G., and G. E. Likens. 1972. Stream ecosystem: Organic energy budget. Bioscience 22:33-35.

Franklin, J. F. 1980. Ecological site classification activities in Oregon and Washington. The Forestry Chronicle. 56(2):68-70.

________. 1982. Changing patterns of riparian vegetation. Seminar, Water Resources Research Institute, Oregon State Univ., Corvallis, Oregon.

________, and C. T. Dyrness. 1973. Natural vegetation of Oregon and Washington. U.S.D.A. For. Serv., Pacific Northwest For. and Range Exp. Sta., Gen. Tech. Report PNW-8, Portland, Oregon.

________,and R. H. Waring. 1980. Distinctive features of the Northwest coniferous forest: Development, structures, and function. U.S.D.A. For. Serv., Corvallis, Oregon (In preparation).

Fredriksen, R. L. 1970. Erosion and sedimentation following road construction and timber harvesting on unstable soils in three western Oregon watersheds. U.S.D.A. For. Serv. Pac. Northwest Forest and Range Exp. Sta., Res. paper PNW-104, Portland, Oregon.

Holdridge, L. R. 1947. Determination of world plant formations from simple climatic data. Science. 105:367-368.

Horton, R. E. 1945. Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology. Bulln. Geol. Soc. Am., Vol. 56, 275-370.

Kirkwood, J. E. 1902. The vegetation of Northwest Oregon. Torreya. 2(9):127-134.

Keller, E. A. and F. J. Swanson. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes, Vol. 4, 361-380.

Koski, K. V. 1966. The survival of coho salmon (Oncorhynchus kisutch) from egg deposition to emergence in three Oregon coastal streams. M. S. thesis, Oregon State Univ., Corvallis, Oregon. 84 pp.

Kuchler, A. W. 1964. Potential natural of the conterminous United States. Amer. Geographic Soc. Special Publ. No. 36.

Larson, R. W. 1958. Use of transects to measure low vegetation cover. IN: Techniques and methods of measuring understory vegetation, a Symposium. U.S.D.A. For. Serv. Southern For. Exp. Station.

Lemmon, P. E. 1956. A spherical densiometer for estimating forage overstory density. Forest Sci. 2:314-320.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial processes in geomorphology. W. H. Freeman, San Francisco, Calif., 522 pp.

Levno, A., and J. Rothacher. 1967. Increases in maximum stream temperatures after logging in old-growth Douglas-fir watersheds. U.S.D.A. For. Serv. Res. Note PNW-65, Pac. Northwest For. and Range Exp. Sta., Portland, Oregon.

________. 1969. Increases in maximum stream temperatures after slash burning in a small experimental watershed. U.S.D.A. For. Serv. Res. Note PNW-110, Pac. Northwest For. and Range Exp. Sta., Portland, Oregon.

Likens, G. E., and F. H. Bormann. 1974. Linkages between terrestrial and aquatic ecosystems. Bioscience. 24(8): 447-455.

Lislie, T. E. 1981. Erosion and sediment transport in Pacific rim steeplands. I.A.H.S. Publ. No. 132, p. 189-203.

Long, J. N., and J. Turner. 1975. Aboveground biomass of understory and overstory in an age sequence of four Douglas-fir stands. Coniferous Forest Biome Contribution No. 74, p. 179-187.

Marks, P. L., and F. H. Bormann. 1972. Revegetation following forest cutting: Mechanisms for return to steady-state nutrient cycling. Science. 176:914-915.

Meehan, W. R. 1969. Some effects of clearcutting on salmon habitat of two southeast Alaska streams. U.S.D.A. For. Serv. Res. Paper PNW-82, Pacific Northwest For. and Range Exp. Sta., Portland, Oregon.

________, F. J. Swanson, and J. R. Sedell. 1977. Influences of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply. IN: Symposium on the Importance, Preservation, and Management of the Riparian Habitat. U.S.D.A. For. Serv. Gen. Tech. Report RM-43, p. 137-145, Tucson, Arizona.

Megahan, W. F., and R. A. Nowlin. 1976. Sediment storage in channels draining small forested watersheds in the mountains of central Idaho. Proc. of the Third Fed. Inter-agency Sedimentation Conf., Denver, Colo., March 1976:4-15-4-126.

Miller, R. E., and M. D. Murray. 1981. The effects of Red Alder on growth of Douglas-fir. U.S.D.A. For. Serv. Gen. Tech. Report PNW-70, Pac. For. and Range Exp. Sta., Portland, Or.

Moring, J. R. 1975. The Alsea watershed study: Effects of logging on aquatic resources of three headwater streams of the Alsea river, Oregon. Oregon Dept. Fish and Wildlife. Fisheries Res. Paper No. 9, 39 pp.

Muckleston, K. 1982. Perspectives on the Riparian Zone. Seminar, Water Resources Research Institute, Oregon State Univ., Corvallis, Oregon.

Neter J., and W. Wasserman. 1974. Applied linear statistical models. Richard D. Irwin, Inc. Homewood, Illonois. 842 pp.

Newbold, J. D., J .W. Elwood, and R. V. O'Neil. 1979. Nutrient spiralling in streams: The concept and field measurement. Envrn. Sci. Div., Oak Ridge, Tennessee. (Nature, In press).

Newton, J. 1981. A stream on the mend. Oregon Wildlife. Vol. 36, No. 2, Feb. 1981, 15 pp.

Oregon, State of, Dept. of Forestry. 1980. Field guide to Oregon Forest Practice Rules. Seventh revision, Effective Jan. 10, 1980, 59 pp.

Packer, P. E. 1967. Forest treatment effects of water quality. IN: Forest Hydrology, Sopper, W. E., and H. W. Lull, eds., Pergamon Press, New York, N.Y., p. 687-699.

Pfankuch, D. J. 1975. Stream reach inventory and channel stability evaluation. U.S.D.A. Forest Serv., Northern Region, R1-75-002.

Phillips, E. A. 1959. Methods of vegetation study. Henry Holt and Co., Inc., Library of Congress Catalog No.:59-8736.

Platts, W. S. 1979. Relationships among stream order, fish populations, and aquatic geomorphology in an Idaho river drainage. Fisheries. 4(2):5-9.

________, and W. F. Megahan. 1975. Time trends in riverbed sediment composition in salmon and steelhead spawning areas: South Fork Salmon River, Idaho. Trans. of the 40th N. Amer. Wildlife and Nat. Res. Conf., Wash. D.C., p. 229-239.

Ringler, N. H., and J. D. Hall. 1975. Effects of logging on water temperature and dissolved oxygen in spawning beds. Trans. Amer. Fish. Soc. 104:117-121.

Riser, D. W., and T. C. Bjornn. 1979. Influence of forest and rangeland management on anadromous fish habitat in western North America: Habitat requirements of anadromous salmoids. U.S.D.A. For. Serv. Gen. Tech. Report PNW-96, Pac. For. and Range Exp. Sta., Portland, Oregon.

Sedell, J. R., F. H. Everest, F. J. Swanson. 1981. Fish habitat and streamside management: Past and present. U.S.D.A. For. Serv., Pac. Northwest For. and Range Exp. Sta., Porland, Or. (In preparation).

Sedell, J. R., F. J. Triska, J. D. Hall, N. H. Anderson, and J. H. Lyford. 1974. Sources and fates of organic inputs in coniferous forest streams. IN: Integrated Research in the Coniferous Forest Biome. Bulln. No. 5.

Sheridan, W. L., and W. J. McNeil. 1968. Some effects of logging on two salmon streams in Alaska. J. Forestry. 66:128-133.

Shirazi, M. A. 1979. An emphasis on spawning habitat for salmonids. Corvallis Envir. Res. Lab Office of Res. and Development, U.S. Envirn. Protect. Agency, Corvallis, Oregon. EPA-600/3-79-109. 37 pp.

Soil Conservation Service. 1964. Normal annual precipitation map for the State of Oregon. Soil Consv. Srv., U. S. Dept. of Agric., in cooperation with U. S. Weather Bureau. 7-64.

Sollins, P., and F. M. McCorrison. 1981. Nitrogen and carbon solution chemistry of an old-growth coniferous forest watershed before and after cutting. Water Resources Research. 17(5):1409-1418.

Steinblums, I. J. 1978. Streamside buffer strips: Survival, effectiveness, and design. M.S. thesis, Oregon State Univ., Corvallis, Oregon. 181 pp.

Strahler, A. N. 1964. Quantitative geomorphology of drainage basins and channel networks. IN: V. T. Chow (ed.) Handbook of applied hydrology- a compendium of water resource technology. McGraw-Hill Book Co., New York, N.Y. 868 pp.

Strickler, G. S. 1959. Use of the densiometer to estimate density of forest canopy on permanent sample plots. U.S.D.A. For. Serv. Res. Note 180, Portland, Oregon. 5 pp.

Stewart, K. S. and D. G. Skeesick. 1981. Stream rehabilitation needs associated with timber harvest units and roads. U.S.D.A. Willamette National Forest, August 1981. 43 pp.

Swanson, F. J., and G. W. Lienkaemper. 1978. Physical consequences of large organic debris in Pacific Northwest streams. U.S.D.A. For. Serv., Pac. Northwest For. and Range Exp. Sta., Portland, Oregon.

U.S.D.A. Textural Classification. 1971. IN: Engineering properties of soils and their measurement. McGraw-Hill Publ. New York, N.Y.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journ. of Fish. and Aquatic Sci. 37(1):13-137.

Waters, T. F. 1969. Invertebrate drift: Ecology and significance to stream fishes. IN: T. G. Northcote (ed.), Symposium on Salmon and Trout in Streams. H. R. McMillan Lectures in Fisheries. Univ. of B.C., Vancouver, B.C.

Zavitkouski, J., and R. D. Stevens. 1972. Primary productivity of red alder ecosystems. Ecology. 53(2):235-242.

APPENDICES

APPENDIX A

F-TEST FOR SLOPE EQUALS ZERO ($B_1=0$) HYPOTHESIS

The F-test was utilized to test the hypothesis that the dependent variable (Y) is related to the independent variable (X) which is equivalent to the test of the regression slope (B_1) is equal to zero. This test was conducted using the procedure outlined by Neter and Wasserman (1974). The test is as follows:

Hypothesis:

H_o: $B_1 = 0$

H_1: $B_1 \neq 0$

Test statistic:

$$F^* = \frac{MSR}{MSE} \qquad \text{where: } MSR = \Sigma(Y-Y)^2 /1$$

$$MSE = \Sigma(Y-Y)^2 /n-2$$

Decision rule:

If $F^* \leq F(1-\alpha;1,n-2)$, conclude H_o.

If $F^* > F(1-\alpha;1,n-2)$, conclude H_1.

This test was performed for each Angular Canopy Density verses Stand age equation from each of the five vegetational zones. The results of the tests are summarized in the following table:

Vegetational zone	F*	$F(1-\alpha,1,n-2)$	α-level
T.heterophylla (Cascades)	21.188	18.60	0.005
A.amabilis	6.045	4.06	0.100
T.heterophylla (Coast)	103.241	47.20	0.001
P.sitchensis	6.241	4.54	0.100
Mixed Conifer	4.662	4.54	0.100

APPENDIX B

SPECIES CODE LIST

The following species codes were used as outlined by Garrison and Skovlin (1976):

SPECIES CODE	SPECIES
ABAM	*Abies amabilis* (Dougl.)
ABGR	*Abies grandis* (Dougl.)
ACCI	*Acer circinatum* (L.)
ACMA	*Acer macrophyllum* (Pursh)
ALRU	*Alnus rubra* (Bong.)
ALSI	*Alnus sinuata* (Regel)
ALTE	*Alnus tenuifolia* (Nutt.)
CESA	*Ceanothus sanguineus* (Pursh)
COCOC	*Corylus cornuta* var. *californica*
COST	*Cornus stolonifera* (Michx.)
DIGIT	*Digitalis* spp. (L.)
EPAN	*Epilobium angustifolium* (L.)
ERECH	*Erechtites prenanthoides* (A.Rich.)
OPHO	*Oplopanax horridum* (J.E. Sm.)
PEFR	*Petasites frigidus* (L.)
PIPO	*Pinus ponderosa* (Dougl.)
PISI	*Picea sitchensis* (Bong.)
POLYS	*Polystichum* spp. (Roth)
POTR2	*Populus trichocarpa*
PSMEM	*Psuedotsuga menziesii* var. *menziesii*
RISA	*Ribes sanguineum* (Pursh)
RUPA	*Rubus parviflorus* (Nutt.)
RUSP	*Rubus spectabilis* (Pursh)
SALIX	*Salix* spp. (L.)
TSHE	*Tsuga heterophylla* (Raf.)
VAOV	*Vaccinium ovalifolium* (Smith)
VAPA	*Vaccinium parvafolium* (Smith)