AN ABSTRACT OF THE THESIS OF

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Title: Vegetation-Environmental Relationships on Two Clearcuts on the Western Slopes of the Oregon Cascades

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Douglas-fir and western hemlock growth and stocking were examined on two neighboring clear-cut watersheds in the Western Cascades of Oregon and related to the intensity of burning and logging disturbance, habitat type, soil type, aspect and the influence of percent cover of both invading _Ceanothus_ species and residual _Acer circinatum_.

The nitrogen content of the surface soil, both total and mineralizable nitrogen, and current and year old Douglas-fir foliar nitrogen contents as percent dry weight were determined. Total nitrogen content was determined by micro-kjeldahl techniques. Mineralizable nitrogen was obtained through anaerobic incubation at 40 C for seven days.

Douglas-fir establishment and growth were not limited on severely burned or compacted sites. A strong preference for unburned sites

was shown by western hemlock, however. Appreciable Douglas-fir stocking, basal diameters, basal areas and relative densities were supported by Rhma/Gash, Acci/Gash and Cola habitat types. Cola communities also contained the greatest western hemlock stocking and basal area values. Soil type influenced Douglas-fir but not western hemlock. Largest Douglas-fir basal diameters, basal areas and relative densities were found on lateritic soil types. Both Douglas-fir and western hemlock stocking were favored on northerly exposures, though the basal diameters of Douglas-fir were maximized on level and westerly aspects.

The percent cover of snowbrush (*Ceanothus velutinus*), redstem ceanothus (*C. sanguineus*), deerbrush (*C. integerrimus*) and vine maple (*Acer circinatum*) was also examined in relation to site factors. Cover values of all *Ceanothus* species were highest on disturbed and/or burned sites. For the most part, the three *Ceanothus* species had varying preferences in terms of habitat type, soil type and aspect expressed as degrees of cover.

Percent vine maple cover was only influenced by burning and habitat type, preferring sites undisturbed by burning and Rhma/Gash, Acci/Gash and Acci/Bene communities in which it was also an important component before logging.

Multiple regressions indicated that no site factor, shrub cover or nitrogen variable accounted for more than sixteen percent of the total explained variation in conifer growth or stocking. Site factors could explain the most variation.

Greater Douglas-fir basal diameters occurred on plots with snowbrush cover, while the presence of redstem ceanothus was associated with lower Douglas-fir basal diameters, basal areas and relative densities.

The presence of <u>Ceanothus</u> species was generally not associated with increased soil or foliar nitrogen content, though Douglas-fir year old needles showed slightly higher mean values on sites with redstem ceanothus. Plots containing vine maple, however, contained greater quantities of mineralizable nitrogen.

Nitrogen data indicates that though total soil nitrogen levels appear adequate for Douglas-fir nutrition, mineralizable and foliar nitrogen may be limiting at least during the growing season.

While partially ameliorated, results suggest that the effects from harvesting and slash burning have yet to subside, though factors including habitat type, soil type and aspect are becoming increasingly important in determining the distribution of shrub cover as well as the growth and establishment of Douglas-fir and western hemlock.

Vegetation-Environmental Relationships on Two Clearcuts on the Western Slopes of the Oregon Cascades

by

Dawn M. Egeland

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Associate Professor of Forest Ecology and Silviculture in charge of major

Signature redacted for privacy.

Head of department of Forest Science

Signature redacted for privacy.

Dean of Graduate School

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"Evidently for science there is neither truth nor reality but only the possibility of rationalization and the hope of reliability, and both of these can often be achieved in many ways. Apart from purpose and inspiration, little remains but economy to guide our choice." J. G. Skellam (1971)

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INTRODUCTION

Forest ecosystems consist of many complex and often delicate interrelationships between biotic and abiotic components. In the Pacific Northwest, conifer forests are noted for their great biomass accumulations, longevity and adaptions to the mild, wet winters and hot, dry summers of this maritime climate. Douglas-fir ranks as the most important species in the Tsuga heterophylla zone of the Western Cascades (Franklin and Dyrness, 1973), occurring mainly as a pioneer species following either clear-cutting or natural disturbance. Douglas-fir may be only considered a climax species on xeric sites where it may perpetuate itself. On mesic sites, western hemlock replaces Douglas-fir as the terminal type and perpetuates its role as the most important species in terms of climactic success. Although also fairly widespread, western hemlock is notably absent from more xeric sites (Dyrness et. al., 1976). Because of the longevity and persistance of Douglas-fir, often over six hundred and fifty years, it causes succession to slow down drastically (Waring et. al., 1981).

Coniferous forests are a major resource in Western Oregon with some seven and one-half million cubic meters harvested annually from national forests alone. Clear-cutting is the most common harvesting method and slash is generally disposed of by broadcast burning (Harr, 1976). Aside from removal of timber harvested, much nutrient rich litter in the form of foliage, stems and branches is added to the site during clear-cutting. In addition, accompanying microclimatic changes often stimulate micro-organisms, and therefore increase the rate of nutrient cycling. Higher rates of soil respiration result in the bicarbonate ion level being raised and the resulting acidity may increase the loss of cations by leaching (Fredriksen, 1971). Nitrate loss may occur when its release by decomposer activities exceeds its uptake by plants. Gessel and others (1973) found nitrogen to often be limiting to forest growth in the Pacific Northwest.

Aside from drastic alterations in nutrient cycling, clear-cutting and slash burning may result in changes of the microclimate, water relations, erosional potential, soil properties, species composition, tree regeneration and site productivity. As Brown (1976) points out, however, clear-cutting as a forest practice is neither uniformly good nor bad for soil and water resources and generalizations about the impact of harvesting must be made carefully and interpreted only in regards to the specific ecosystem under study.

Studies have been done throughout the Pacific Northwest as well as in other areas detailing the effects of clear-cutting on site and vegetational factors. Most, however, have only followed these effects for a few years after harvesting (Dyrness, 1973; Morris, 1958; Tarrant and Wright, 1955), or have compared different sites in various stages of succession following logging and burning (Issac, 1940). Because of the variety of sites involved, the inherent biological variation, the multitude of site and climatic factors present as well as the interrelationships among the above, generalizations are often lacking or misleading.

That logging and burning does influence vegetation and soil properties is recognized. Successional trends in the Western Cascades were found to be greatly influenced by varying degrees of disturbance from logging and burning, with residual species most common on undisturbed sites, a combination of residual and invading species on disturbed but unburned sites, and a predominance of invading species on burned areas (Dyrness, 1973). The development of vegetation following the Wickersham Dome fire in Alaska was also found to be closely related to the severity of the burn (Viereck and Dyrness, 1979). Franklin (1979) noted that, among other factors, the type and intensity of disturbance was important in the development of young forest stands.

Temporary increases in erosion and accelerated nutrient losses have often been noted to result from logging and burning. Issac and Hopkins (1937) observed changes in soil fertility, chemical properties, structure and moisture holding capacity following burning in the Douglas-fir region. In addition, organic matter was reduced, resulting in increased capacity of the soil to absorb heat. Tarrant (1956b) found that severe burning increased soil bulk density, and perhaps reduced soil nitrogen content as well. Bulk density was also increased on deeply disturbed or compacted soils following either hi-lead or tractor logging (Dyrness, 1965a). Miller and others (1976) working in the Coastal Douglas-fir region, stated that harvesting Douglas-fir forests and establishing new crops inherently causes nutrient losses which may reduce soil productivity. They also mentioned the possibility of fire-induced water repellancy of the soil, an effect first noted by DeBano (1966) in Chapparal systems.

A study by Tarrant and Wright (1955) reported significantly greater height growth of one year Douglas-fir seedlings on severely burned soils but also lower germination and fewer trees with mycorrhizal infections on these same soils. Poor regeneration and survival of Noble fir was attributed to slash burning or past fire history by Austin and Baisinger (1955), especially on already severe or borderline sites.

As is evidenced from just the small sample of studies cited, timber harvesting and slash burning influence many ecosystem properties. What is not always evident is that disturbance in the rule rather than the exception in many natural ecosystems. Ecosystem recovery is a normal part of community maintenance and repair (Marks and Bormann, 1972). In their study of nutrient and soil losses in overland flow, DeByle and Packer (1972) found revegetation of the area within four years had restored conditions to those before harvesting. Austin and Baisinger (1955) noted a seventy-five percent recovery of nitrogen loss in the top twelve inches of soil two years after burning in the Pacific Northwest. Youngberg and Wollum (1976) indicated that the presence of the nonleguminous nitrogen fixer, Ceanothus velutinus, would return the soil nitrogen content to preburn levels possibly in as little as seven years on sites they studied. Although hydrologic losses of nutrients may persist for varying periods after harvesting, Swank and Waide (1979) feel that these would not often be great enough to influence site productivity.

Revegetation plays an important role in recovery of the nutrient cycle following disturbance. Marks and Bormann (1972) found a roughly inverse relationship between the amount of erosional and nutritional loss and the rate of reestablishment of vegetation following a disturbance at Hubbard Brook. In Dyrness' study (1973) on the H. J. Andrews, residual tree species constantly increased their cover, though cover values were still found below predisturbance levels five years after clear-cutting and slash burning. Even in these early stages of succession, recognition of characteristics of prelogging habitat types was possible. Twenty to one hundred years is believed to be necessary for Douglas-fir forests to achieve a full natural recovery with partial recovery occurring in five years under intensive management (Waring, 1976, cited in Cairns, 1980).

In the Pacific Northwest, various species in the genus Ceanothus are among the most important colonizing plants following fire. Ceanothus species occur from California to British Columbia and from the Pacific Coast to the Rocky Mountains, although the center of distribution is most likely Oregon and Washington (Zavitkovski, 1966, cited in Zavitkovski and Newton, 1968). Of the fifty-one western species, about one-third are found in forest communities where they are often widespread and important components, especially in the early stages of succession and in more xeric forest zones (Franklin, 1982). Virtually absent from all but the most open old growth forests, Ceanothus species proliferate on disturbed and burned areas, where the heat from slash burning or wildfires stimulates germination of long dormant seeds. Ceanothus not only has the potential to fix nitrogen, it produces nutrient rich litter (Zavitkovski and Newton, 1968), serves as a nurse crop for conifers (Wollum, 1962; Scott, 1969; Gratkowski and Lauterbach, 1974), prevents erosion, and is a valuable browse species for wildlife (Binkley and Husted, 1983; Conard et. al., 1982).

Ceanothus species in general are shade intolerant pioneers which are very tolerant to stress. They are characteristic of droughty habitats with low soil nitrogen (Stewart, 1966; Zavitkovski and Newton, 1968). Though burning is not a prerequisite for germination, on the H. J. Andrews Experimental Forest, greatest cover of *C. velutinus* and *C. sanguineus* was found where hot burns had occurred (Halpern cited in Conard et. al., 1982). Zavitkovski and Newton (1968) noted southern exposures were more likely to have dense *C. velutinus* stands while northern aspects had a very low density, and attributed this to more complete burning on southern slopes.

Three of the more common species in the *Tsuga heterophylla* zone on the western slopes of the Cascades are *Ceanothus velutinus*, *C. sanguineus* and *C. integerrimus*. Most studies to date have been centered on *C. velutinus* which has been estimated to fix between 0 and 108 kg N/ha/yr (Zavitkovski and Newton, 1968; Binkley et. al., 1982; Youngberg and Wollum, 1976). A study by Binkley and Husted (1983) reported rates of nitrogen fixation by *C. sanguineus* at 70 to 90 kg N/ha/yr, comparable to that of *C. velutinus*. There is limited information on the rate of nitrogen fixation by *C. integerrimus*. Wollum and Youngberg (1965) found *C. integerrimus* to be nodulated and Delwiche and others (1965) estimated *C. integerrimus* nodules to fix

58.3 to 72.0 nmoles/hr/gr fresh weight of nitrogen. Franklin (1982) speculates that most likely all Ceanothus species have the potential to fix nitrogen on some sites for at least part of the time.

A large number of Ceanothus seedlings can occur on a clear-cut, usually germinating from seed. Seedling mortality from drought and intraspecific competition is generally high, however. Although growth rates vary by site, in general growth is slow for the first few years, followed by a rapid growth period until about ten years of age. Stands may start to decay in fifteen to twenty years, as they are shaded out by emerging forest canopy or subject to snow damage. On some sites in the Cascades it takes as long as twenty to forty years before deterioration sets in (Zavitkovski and Newton, 1968; Conard et. al., 1982).

Advocates of Ceanothus cite its beneficial effects in site amelioration, tree seedling establishment and nitrogen fixation. Hellmers and Kelleher (1959) grew tomatoes in pots which C. leucodermis was previously grown and found twice as much nitrogen was available to the tomato plants as in pots without prior Ceanothus. They concluded that C. leucodermis was a beneficial plant in the development of California mountain soils. Wollum and Youngberg (1964) found that when Monterey pine seedlings were grown in pots with C. velutinus roots, the yield and nitrogen content of the seedlings were comparable to the addition of 35 ppm of nitrogen.

A number of studies have compared soil and plant nitrogen content and/or tree growth at varying distances from Ceanothus stands. A greater number of fine roots and higher nitrogen content was found in Ponderosa pine seedlings growing under C. velutinus than in the open in Central Oregon (Wollum and Youngberg, 1964). Dyrness (1960, cited in Wollum, 1962) noted more favorable soil moisture and temperature regimes, as well as higher nitrogen content in the litter and A horizon under C. velutinus than in the open. Wollum (1962) also found conditions to be more favorable under C. velutinus. In the Western Cascades, Scott (1969) found better survival and growth of planted Douglas-fir seedlings, greater milacre stocking, more soil moisture in the top six inches, cooler soil surface temperacures, and a higher concentration of nitrogen in soils and in current year needles under C. velutinus stands than in open areas. Increased survival of western yellow pine in Montana under C. velutinus was attributed to a more favorable microclimate during the dry summer (Wahlenburg, 1930). Binkley and Husted (1983), in their examination of the nutrient content of Douglas-fir foliage and soil on sites with and without C. sanguineus, found fifty to seventy-five percent greater total soil nitrogen in plots at the edge of and within C. sanguineus stands than in open areas.

Balanced against the positive effects of Ceanothus species is their potential for competition with tree seedlings. As early as 1912, Foster (1912) realized that C. velutinus cover was often dense enough to seriously affect the success of regenerating forests. Scott (1969) observed less available water at the twenty-four inch soil depth under C. velutinus than in the open, suggesting that soil moisture may become limiting to Douglas-fir growing in Ceanothus stands. Gratkowski and Lauterbach (1974) found that C. velutinus competed with trees for light, nutrients and soil moisture and noted increased Douglas-fir height growth following release from C. velutinus. They estimated that release would reduce the time required to grow trees from two to twenty feet by almost eight years.

Zavitkovski and Newton (1968) point out that existing evidence suggests that C. velutinus' nitrogen fixing capacity decreases as soil fertility levels increase, making fixation important only on sites of moderate to low fertility. They also suggest that Ceanothus could be an important factor affecting successional trends, reasoning that as the length of dominance by Ceanothus species increases, so does the proportion of shade tolerant trees in the emerging canopy. Zavitkovski and others (1969) found that height growth of four coniferous tree species declined when planted in C. velutinus stands greater than ten years of age, which corresponds approximately to the time C. velutinus attains full site occupancy. They noted that the capacity of conifers to emerge and gain dominance decreased as they were planted under increasingly older C. velutinus. Of the four conifers studied, Douglas-fir appeared most able to achieve dominance over C. velutinus, however, it was felt that reduction in height growth could be caused by even moderate suppression.

It is generally believed that Ceanothus is an integral part of the coniferous forest ecosystem. Although young conifer growth probably would not be limited if Ceanothus were absent, it appears likely that its importance lies in long term maintenance of site productivity. During the early stages of succession following clear-cutting and slash burning, the nitrogen fixation by C. velutinus is thought to be able to compensate for nitrogen losses incurred by harvesting practices and this may be of particular importance to recovery, most notably on severely disturbed or marginal ecosystems (Binkley et. al., 1982). Many researchers feel the benefits outweigh the disadvantages (Youngberg and Wollum, 1976; Scott, 1969).

Early succession undoubtedly varies from one site to another, depending on environmental conditions; and this, in turn, affects both the rate at which nutrient cycling processes recover, and competitive interactions between commercial tree species and other vegetation. For these reasons, it is important to assess the environmental characteristics of a site prior to timber harvest. Vegetation, which may be thought of as the culmination of integrated environmental factors acting on a site, has long been used for this purpose. Dyrness and others (1976) noted that vegetation types within the Tsuga heterophylla zone in the Western Cascades could be delineated by temperature (elevation) and moisture availability, and Dyrness and Youngberg (1966) assumed that each habitat type reflected the effects of a slightly different microclimatic regime. Plant species composition may also reflect soil texture and nutrient status (eg., Peet and Louck, 1977). Soil properties such as texture, structure, depth to ground water table, organic matter content and fertility affect establishment of both planted seedlings and those developing from either natural or artificial seeding (Youngberg, 1955; Lowry and Youngberg, 1955).

Clear-cutting may remove the tree biomass from an entire area, but individual site effects are often varied. Slash burning is accompanied by differing degrees of burning intensities along with varying proportions of the area directly affected by the fire (Tarrant, 1956b; Worthington, 1959). Dyrness (1965b) found considerable variation in species composition and cover on individual plots on a single cutting unit following slash burning. Though partially due to site characteristics and prelogging plant communities, the intensity of disturbance played a major role in determining plant distribution during the early stages of succession. Dyrness felt, however, that as succession advanced the influence of logging and burning would diminish and other site factors, such as aspect and soil characteristics, would become more important in controlling plant cover and species composition.

This study is focused on the effects of disturbance from logging and slash burning, prelogging understory habitat type, aspect and soil type on the growth of planted Douglas-fir seedlings (Pseudotsuga menziesii (Mirb.) Franco) and naturally seeded Douglas-fir and western hemlock (Tsuga heterophylla (Raf.) Sarg.). No distinction was made between planted and naturally occurring stock. The data was collected from the same sites as Dyrness (1965a, 1973) but also expanded to include a larger neighboring clear-cut watershed. Emphasis is on interactions between Douglas-fir and Ceanothus species and vine maple (Acer circinatum Pursh), both prevalent shrub species in secondary succession of many ecosystems on the western slopes of the Oregon Cascades. Acer circinatum, present throughout the course of succession on various habitat types, is considered a residual species while *Ceanothus* species are invaders whose major influence appears to be in early successional stages. Three *Ceanothus* species occur on these watersheds and all were found to be nodulated. *Ceanothus* and *Acer circinatum* cover were also related to disturbance regime, soil type, aspect and prelogging habitat type to examine the effects these site factors might have on shrub cover.

This is primarily a descriptive study and not a controlled growth experiment. Unequal cell sizes prevail on all site factors since the effects of logging and slash burning as well as the distribution of the site factors themselves could not be controlled and were merely recorded as they occurred.

STUDY AREA

Study sites are located on the H. J. Andrews Experimental Forest which is on the western slopes of the Cascades approximately sixty-five kilometers east of Eugene, Oregon. All of the ninety-six hectare Watershed 1 was clear-cut beginning in the summer of 1962. Because of operational difficulties, the harvesting was not completed until 1966, followed by slash burning. Three small patch cuts, totaling twenty-five hectares, were made in late 1962 on the one hundred and one hectare Watershed 3. Cutting units ranged in size from five to eleven hectares with an additional eight percent of the area used for roads. Slash was broadcast burned in the fall of 1963.

Watershed topography is extremely dissected with elevations ranging from three hundred sixty to one thousand meters and average slopes of fifty to sixty percent. Climate is maritime, with hot, dry summers and mild, wet winters. Precipitation, falling mostly in the winter, averages greater than twenty-three hundred millimeters annually. Located within the Western Cascades Geologic Province, watershed geology is entirely volcanic, and includes andesites, basalts, tuffs and breccias deposited during the Oligocene and Miocene epochs. A heavy overburden of unconsolidated material often makes bedrock identification difficult. Though varied in texture and stoniness, the eight soil series included in this study demonstrate similarities due to the mixing of parent material from erosional and mass movement transfer processes. Because of the high volcanic ash content, bulk density of the surface horizons is extremely low, rarely greater than one g/cc even in the B horizon. A well developed A horizon is found on all soils, though some exhibit little evidence of further profile development. Mitchel (1979) attributes this lack of profile development in part to the high amounts of annual precipitation which discourages the formation of argillic B horizons resulting instead in amorphous clay formation and translocation to cracks in underlying rocks. Shallow soils predominate, mainly because of the steep terrain, however, they are frequently underlain by deep deposits of unconsolidated rock and soil. Soils were grouped for analysis into two associations, according to profile development (Dyrness et. al., 1976). McKenzie River, Budworm and Slipout soil series belong to the reddish-brown and yellowish-brown lateritic association. This association is generally located on residuum and colluvium deposits from tuffs and breccia bedrock on moderate slopes at low to medium elevations. These lateritic soils have a fairly well developed B horizon and surface horizon textures ranging from loam to clay loam.

Frissell, Stony Frissell, Limberlost, Stony Limberlost and Andesite Colluvium are classified as regosols. Found on comparable elevations to lateritic soils, this association usually occurs on steeper slopes. Weak profile development is demonstrated by lack of a B horizon. Frissell and Limberlost and their stony counterparts are derived from weathered or rotted breccia. Andesite Colluvium is located above vast deposits of andesite stones, with depths of sometimes over twenty-five feet. The regosols on these watersheds have a tendency to be stonier than the lateritic soils. Surface soil textures range from loam to gravelly loam. This is the most prevalent soil association on the two watersheds occupying more than eighty percent of the area. The lateritic and regosol associations would presently be classified as haplumbrepts and dystrochrepts, respectively (P. Sollins, personal communication).

About ten percent of the study plots are located on talus slopes consisting of unconsolidated deposits of rock rubble, stones or boulders. Pockets of thin soil may be found but for the most part soil development is severely limited.

All soils have granular and porous structure in the surface horizon and have high infiltration rates. Several series, most notably Slipout, have imperfectly drained subsoils.

Six distinct habitat types (Rothacher et. al., 1967) occur on Watersheds 1 and 3. From xeric to mesic they are:

1. Corylus cornuta/Gaultheria shallon (Coco/Gash) - occurring only on Watershed 1, generally occupying shallow soils and south-facing slopes. Species present generally are indicative of very dry growing conditions.
2. Rhododendron macrophyllum/Gaultheria shallon (Rhma/Gash) - characterized by dense shrub cover. Most often found on ridgetops or other exposed sites where unfavorable conditions for timber growth usually exist.
3. Acer circinatum/Gaultheria shallon (Acci/Gash) - This habitat type has a relatively high shrub cover, predom-

inantly vine maple and salal.

4. Acer circinatum/Berberis nervosa (Acci/Bene) - A fairly productive timber site for both Douglas-fir and western hemlock. The shrub layer, mainly composed of vine maple with small amounts of other shrubs and herbs, is of moderate density.

5. Coptis laciniata (Cola) - A very productive habitat type with sparse shrub and herb cover in undisturbed forests.

6. Polystichum munitum (Pomu) - most mesic habitat type on these watersheds, it is generally situated in seepage areas and along drainages in steep north and east facing slopes. It is very productive and is characterized by lush herbaceous growth, especially of swordfern.

Though most plots were on north and west aspects, enough were found on other exposures to merit aspect as a variable in analysis. Because some aspects were poorly represented, they were grouped as level, north-northeast, east-southeast, west-northwest and south-southwest.

METHODS

Original plots were established by Dyrness in 1962 prior to logging on both Watersheds 1 and 3. Location of transects on Watershed 1 was determined from aerial photographs. These transects were placed at 800 foot intervals extending across the watershed perpendicular to the main stream channel. With the exception of the initial plot, where location from the edge of the cutting unit was randomly determined, 2 m^2 sample plots were established along the transects at 100 foot slope corrected intervals. Plots on Watershed 3 were laid out in a similar manner except that transects were closer together at 400 foot intervals and located only on areas to be logged. Wherever possible these transects were placed on contour. On each clear-cut area all transects have the same compass bearing. Several of the initial 195 plots have been eliminated.

Plots were arranged in a modified nested quadrat design. Within each, crown cover was visually estimated for all shrub species less than twenty feet in height. Grass and herbaceous cover estimates were made only in the lower left quarter of the main plot. Cover estimates were made before logging, following logging but prior to slash burning, and then on an annual basis until 1972 when data was collected at two year intervals.

After logging, plots were classified into one of the following logging disturbance categories (Dyrness, 1965a):

1. Undisturbed - litter still in place with no evidence of

compaction.

2. Slightly disturbed - a. litter removed and undisturbed mineral soil exposed, or
   b. mineral soil and litter intimately mixed with about fifty percent of each, or
   c. pure mineral soil deposited on top of litter and slash to a depth of two inches.
3. Deeply disturbed - surface soil removed and subsoil exposed with the surface soil seldom covered by litter or slash.
4. Compacted - obvious compaction due to passage of logs or mobile equipment.

Upon completion of slash burning, plots were reclassified as to the extent and intensity of burning (Dyrness and Youngberg, 1957):

1. Undisturbed - soil surface condition identical to that in undisturbed timber.
2. Disturbed-unburned - evidence of disturbance during logging but no visible effect of fire.
3. Lightly burned - surface litter is charred by fire but not removed.
4. Severely burned - litter completely removed and mineral soil left highly colored.

In 1979, 250 m^2 circular plots were established centered on Dyrness' initial ones. All trees within the larger plots were tagged and basal diameters recorded. Four 2 m^2 subplots, one in each quadrant, were established five meters from the original center stake (Figure 1). Data collected from Dyrness' original plus the four new quadrats include herbaceous, shrub and tree cover as well as parameters necessary to use in pre-existing biomass equations or to formulate new ones as needed.

Bulk density was obtained by using the irregular hole method. Samples were taken as close to the center quadrat as possible. After removing surface litter and large stones, the soil was leveled, a small hole dug approximately 5 to 7 cm deep and lined with saran wrap. The soil sample was placed in a paper bag and labeled. Sand was used to fill the hole, then transferred to a graduated cylinder to determine the volume. The soil sample was oven dried and bulk density accordingly calculated. Howard and Singer (1981) found the irregular hole method to be equal in precision to the paraffin clod method with added advantages of rapid measurements and being more suited to porous, granular soils as are found on the H. J. Andrews.

After bulk density was determined soils were stored and later analyzed for nitrogen. Total nitrogen was analyzed by the USDA Forest Service Central Lab, Corvallis, Oregon using a kjeldahl technique. Mineralizable nitrogen was determined by an anaerobic incubation technique developed by Waring and Bremner (1964) and modified by W. B. Silvester (personal communication): 6.25 ml of distilled, deionized water was added to 5 g of soil in an incubation jar, the jar covered with saran wrap and lid and incubated at 40 C for 7 days.

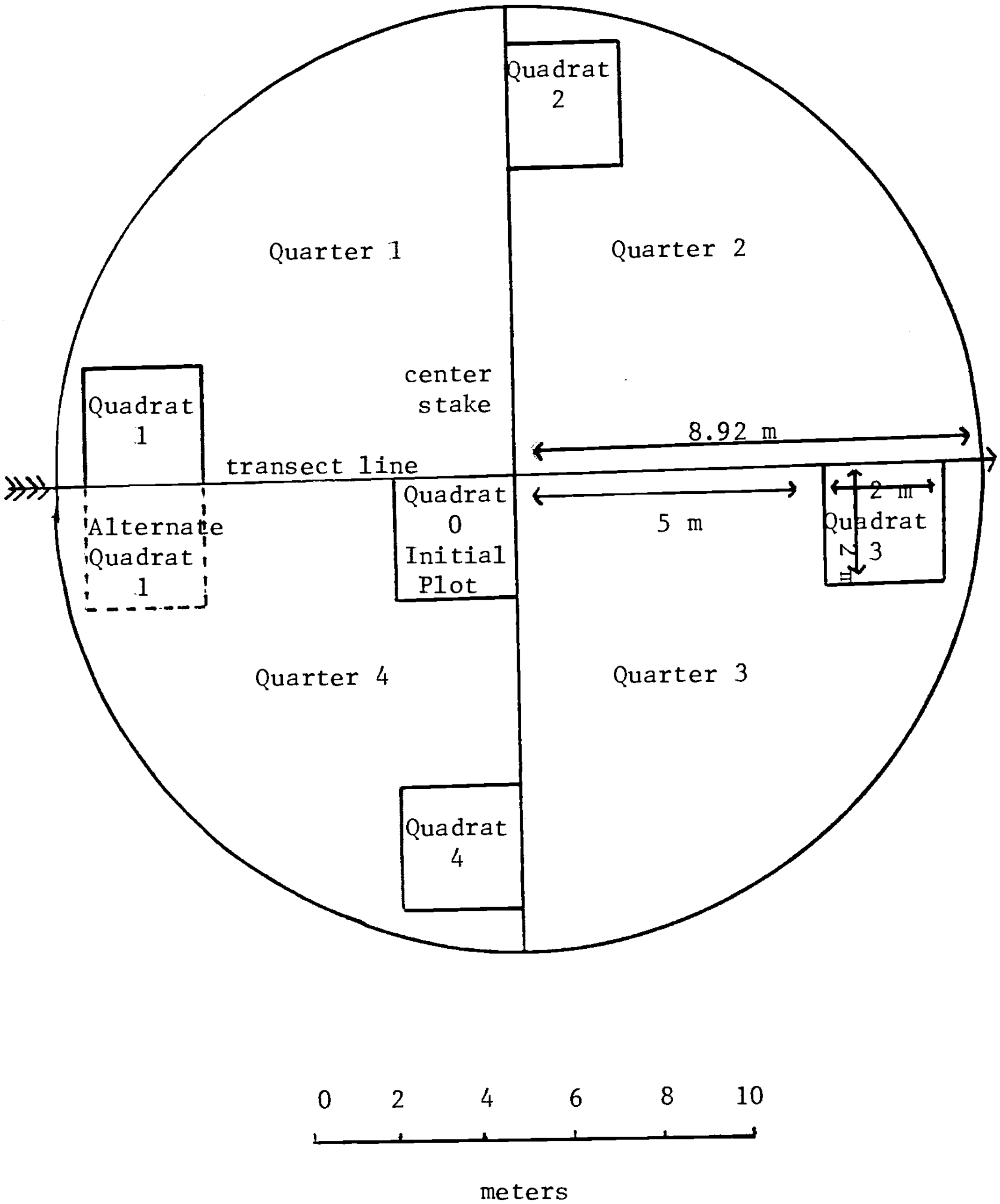

Figure 1. New study plots with respect to original ones.

At the end of 7 days, jars were removed from the incubator, 6.25 ml of 2N KCl was added and they were mechanically shaken for one hour. After allowing material to settle, approximately 45 minutes, 1 ml of the supernatant was placed in a 25 ml beaker with .9 ml of .1 NaOH, and ammonium content measured using an ammonia electrode (HNV ion selective electrode model, ISE-10-10-000). Initial ammonium content was determined using the same procedure except for incubation. Mineralizable nitrogen was calculated as the difference between the initial and final readings and assumed to be an estimate of ammonium production. Banwart and others (1972) using an Orion ammonia electrode, found it to provide a satisfactory determination of ammonium in soil extracts. Ammonium production measured by anaerobic incubation methods correlates with increased Douglas-fir diameter growth following fertilizer applications (Shumway and Atkinson, 1977). Although a 7-day incubation period was a relatively short one, Stanford and Smith (1972) noted that during short term incubations, the mineralizable nitrogen that is released is reflective of the relative nitrogen supplying capacities of soils.

Needle samples were collected from current and one year old Douglas-fir foliage in the mid crown. Though current year foliage is frequently a very sensitive indicator of a tree's nitrogen status, often correlating with soil nutrient availability, older foliage might provide a better assessment of foliar nutrient levels as it is believed to supply nutrients to growing points (Van Den Driessche, 1974; Waring and Youngberg, 1972). The needles were oven dried at

70 C and ground in a Wiley mill. Total nitrogen as percent dry weight was determined using a microkjeldahl method (Association of Official Agricultural Chemists, 1960). Because samples were collected from June to September, 1979, nitrogen analyses should be interpreted with caution as the nitrogen content of both needles and soil has been shown to vary, often substantially, throughout the year (Van Den Driessche, 1974; Smith et. al., 1981; Harmsen and Kolenbrander, 1965), and frequently in samples collected in a single area over a limited time period (Delwiche and Wijler, 1956; Zavitkovski and Newton, 1968).

Statistical analyses were performed using the SPSS computer software package (Nie et. al., 1975). A student's t-test was employed to determine significant differences in mean tree growth parameters and nitrogen contents on plots with and without Ceanothus species or A. circinatum cover. Analysis of variance was performed on Douglas-fir and western hemlock growth and stocking variables, shrub cover, bulk density and nitrogen contents to examine whether burning or logging disturbance, habitat type, aspect or soil type could account for differences observed. Analyses were also run using only logging disturbance as an independent variable to examine any effects which might be related to severe soil disturbance (i. e., deeply disturbed or compacted sites).

Although interaction effects most likely exist, because of unequal cell size they could not be directly examined using analysis of variance. Potential two-way relationships were depicted diagramatically through the use of isolines. Isolines are presented based on their informative nature.

Multiple regression analysis was used to discover the variation in tree growth and stocking that might be accounted for by site factors, shrub cover and soil and foliar nitrogen content. Allocated codes were assigned to site factors corresponding to the order in which they were previously listed (i.e., 1 = Undisturbed...4 = Severely burned). Data transformations such as logarithmic or quadratic did not contribute to any reductions in the unexplained variation of the dependent variables. Large standard deviations of several of the measured variables seem to indicate a large amount of heterogeneity in growing conditions. As previously mentioned, Dyrness (1965b) found a large degree of variability among plots on Watershed 3.

RESULTS

Environmental-Vegetation Relationships

A. Shrub Cover as Related to Site Factors

Results from analysis of variance of site factors on shrub species are listed in Table 1.

Snowbrush

Ceanothus velutinus Dougl. ex Hook. or snowbrush, the most prevalent of the tbree Ceanothus species, (found on 66 percent of the study plots) had cover values ranging from 0 to 77 percent with a mean cover of 15 percent per plot. Though it has been almost twenty years since these watersheds were clear-cut and burned, the effects of burning are still a significant factor affecting the amount of snowbrush cover. Plots that were disturbed and/or burned had nearly two to three times as much cover as those which were undisturbed, not surprising since seeds require heat in order to break dormancy (Zavitkovski and Newton, 1968). Degree of logging disturbance (independent of burning) did not affect snowbrush cover (Figure 2a.).

Soil association exerted a highly significant effect on the amount of snowbrush cover, largest values occurring on lateritic soils, with little to none on talus slopes. Maximum snowbrush cover occurred on relatively lightly disturbed plots on laterites, perhaps because of better moisture and/or nutrient relations on these soils (Figure 2b.).

Snowbrush cover was significantly influenced by habitat type. Except for the xeric Coco/Gash habitat type, where only low amounts

Table 1. Results of analysis of variance on shrub cover.

	BURNING DISTURBANCE				
	Undisturbed n=21	Disturbed-unburned n=61	Lightly burned n=92	Severely burned n=16	Significance of Anova
	% cover (SE)				
C. velutinus	6.76a* (3.31)	12.02ab (2.19)	19.34b (2.16)	12.97ab (3.25)	.05
C. sanguineus	2.65a (1.84)	9.29ab (2.12)	15.14b (1.82)	14.89b (5.59)	.01
C. integerrimus	0a	3.25a (1.32)	2.32a (0.89)	0a	NS
A. circinatum	17.67a (4.48)	9.55b (1.47)	9.36b (1.23)	7.73b (1.97)	.05

	LOGGING DISTURBANCE				
	Undisturbed n=101	Slightly disturbed n=62	Deeply disturbed n=23	Compacted n=4	Significance of Anova
	% cover (SE)				
C. velutinus	16.24a (1.96)	13.48a (2.37)	14.41a (3.52)	13.72a (8.27)	NS
C. sanguineus	15.07a (1.91)	8.48ab (1.65)	8.87ab (3.67)	0.51b (0.49)	.05
C. integerrimus	1.43a (0.68)	4.22a (1.47)	0.22a (0.22)	0a	NS
A. circinatum	10.56a (1.33)	10.16a (1.68)	9.55a (2.20)	5.51a (4.58)	NS

Table 1. cont.

	HABITAT TYPE							
	Coco/Gash n=12	Rhma/Gash n=30	Acci/Gash n=17	Acci/Bene n=44	Cola n=35	Pomu n=43	Unclass-fied n=9	Significance of Anova
	xeric					mesic		
	% cover (SE)							
C. velutinus	5.65a (4.25)	28.81b (4.31)	22.41bc (4.18)	18.22bc (4.18)	12.44ac (2.74)	6.64a (1.37)	3.01a (1.72)	.01
C. sanguineus	24.81a (5.32)	4.00b (1.49)	16.26a (5.51)	15.92a (2.78)	5.52bc (1.63)	15.27ac (3.06)	1.02b (0.97)	.01
C. integerrimus	6.08a (3.83)	0.01b (0.01)	2.68ab (1.69)	5.08ab (2.03)	0b	0.05b (0.05)	7.55a (4.55)	.01
A. circinatum	3.53a (1.43)	13.07bc (2.30)	13.28bc (2.68)	15.46c (2.37)	5.16a (1.10)	8.13abc (2.16)	7.59ab (3.11)	.01

	ASPECT					
	Level n=5	NNE n=71	ESE n=6	WNW n=56	SSW n=52	Significance of Anova
	% cover (SE)					
C. velutinus**	10.52 (6.68)	8.53 (1.35)	21.83 (5.85)	20.79 (2.82)	17.48 (3.16)	.01
C. sanguineus	0.53a (0.33)	8.27ab (1.76)	36.10c (10.01)	10.29ab (2.22)	16.74b (2.49)	.01
C. integerrimus	0a	0.03a (0.03)	0a	0.19a (0.19)	7.68b (2.04)	.01
A. circinatum	10.33a (6.39)	8.63a (1.63)	7.41a (3.04)	11.21a (1.69)	11.58a (1.73)	NS

Table 1. cont.

	SOIL ASSOCIATION			
	Lateritic n=16	Regosol n=157	Talus n=17	Significance of Anova
	% cover (SE)			
C. velutinus	27.37a (5.03)	15.16b (1.51)	2.60c (1.67)	.01
C. sanguineus	2.73a (1.29)	13.04b (1.43)	9.56ab (3.87)	.10
C. integerrimus	0a	2.08ab (0.63)	5.02b (3.50)	NS
A. circinatum	6.99a (2.41)	11.07a (1.07)	5.24a (2.01)	NS

* Means, in any row, which are followed by the same letter, are not significantly different at the .05 level.
** LSD procedure did not show means to be significantly different.

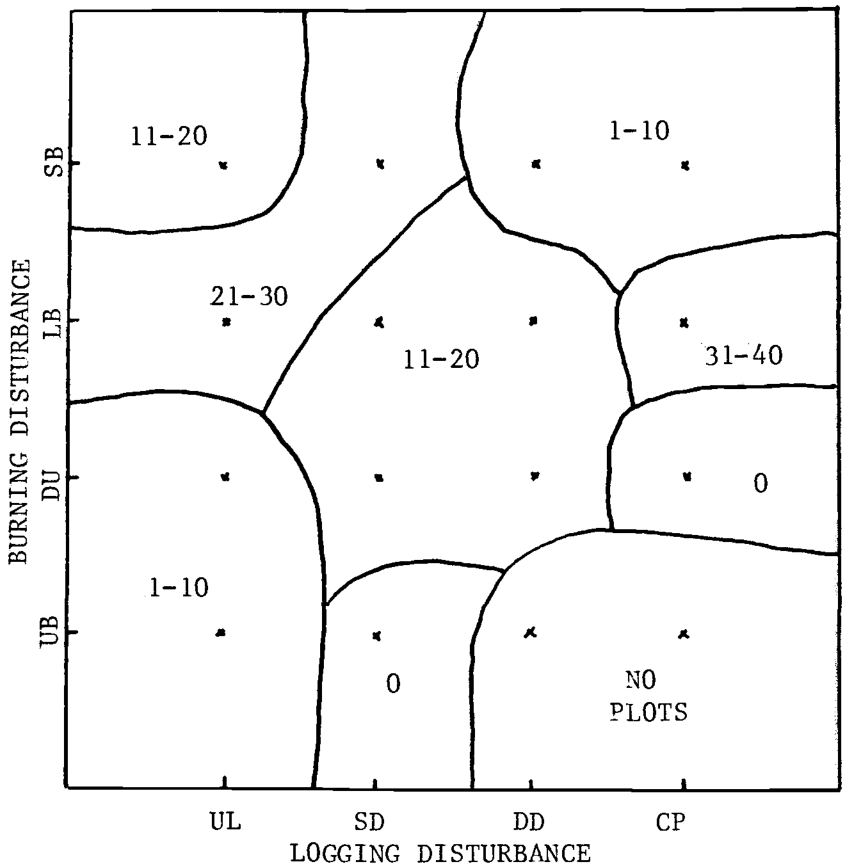

Figure 2a. The combined influence of burning and logging disturbance on percent C. velutinus cover.

Notations for these and other figures are as follows:

Burning disturbance:
1) Undisturbed - UB
2) Disturbed-unburned - DU
3) Lightly burned - LB
4) Severely burned - SB

Logging disturbance:
1) Undisturbed - UL
2) Slightly disturbed - SD
3) Deeply disturbed - DD
4) Compacted - CP

Habitat type:
1) Coco/Gash - C/G
2) Rhma/Gash - R/G
3) Acci/Gash - A/G
4) Acci/Bene - A/B
5) Cola - C
6) Pomu - P
7) Unclassified - UN

Soil association:
1) Lateritic - L
2) Regosol - R
3) Talus - T

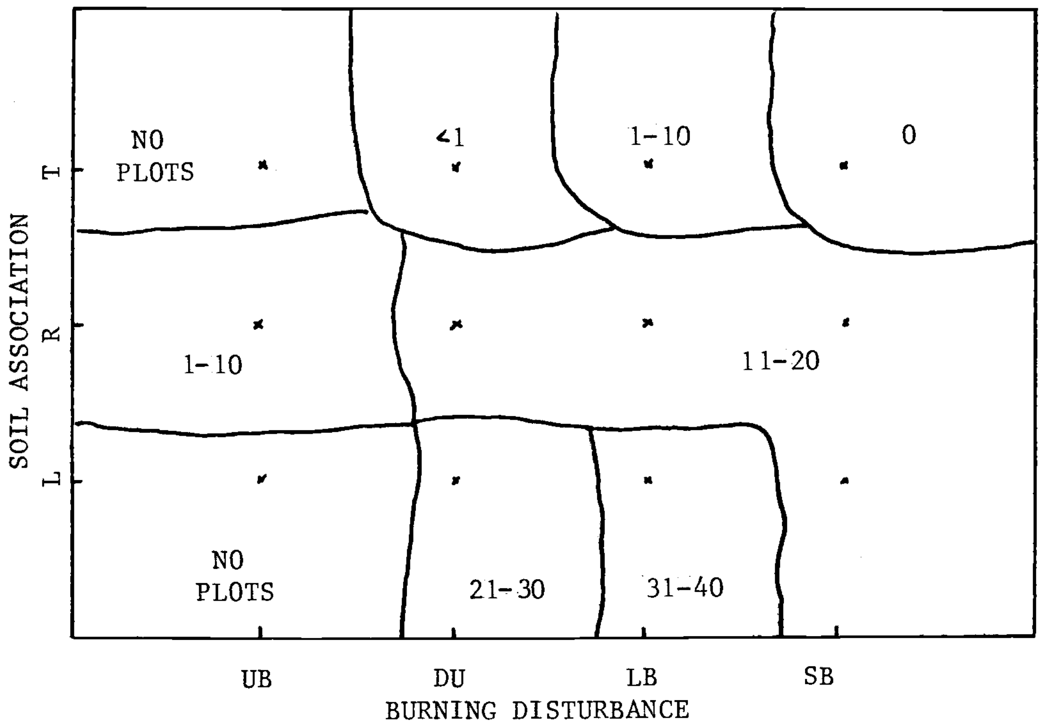

Figure 2b. The combined influence of soil association and burning on percent C. velutinus cover.

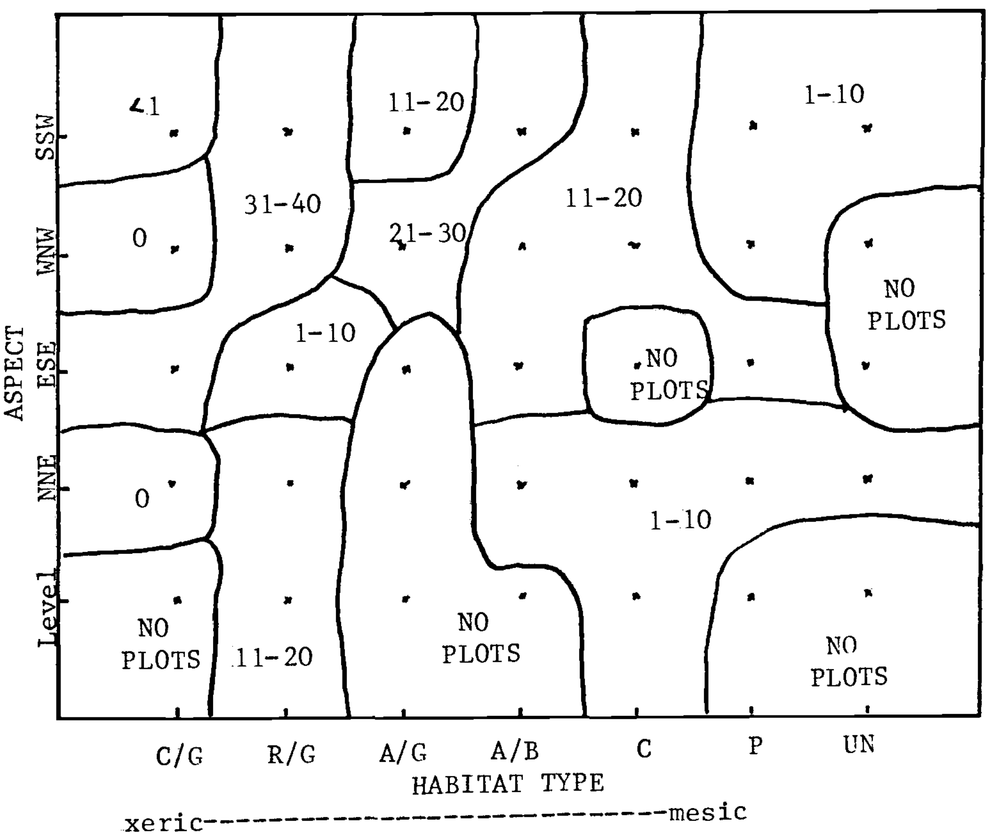

Figure 2c. The combined influence of aspect and habitat type on percent <u>C. velutinus</u> cover.

were found, cover values increase from moist to dry habitat types.

Aspect also significantly affected snowbrush cover. While the various aspects do not appear to particularly restrict snowbrush, certain exposures seem to be more conducive to its development. Almost twice as much cover occurred on eastern, southern and western aspects as on northern or level sites.

The joint effects of habitat type and aspect are portrayed in Figure 2c. Highest cover is in xeric communities on generally southerly slopes, although high cover also occurs on more mesic habitats as westerly slopes.

Redstem ceanothus

C. sanguineus Pursh or redstem ceanothus, is the second most prevalent Ceanothus species on these watersheds, occurring on 62 percent of the plots, with a mean cover value of 12 percent and maximum coverage of up to 82 percent on a single plot. Highest cover values occur on southerly exposures, regosols and talus slopes (Table 1). Consistent with its aspect preferences, redstem ceanothus reaches its greatest development in the most xeric habitat type, Coco/Gash. Whereas snowbrush was affected by burning but not by logging disturbance, redstem ceanothus was significantly affected by both. Redstem ceanothus cover is very low on undisturbed sites and moderate on disturbed-unburned areas. Highest cover occurred on lightly and severely burned sites, however the combination of severe burning and xeric conditions did not favor redstem (Figure 3a.). Logging disturbance appears to adversely affect redstem ceanothus co-

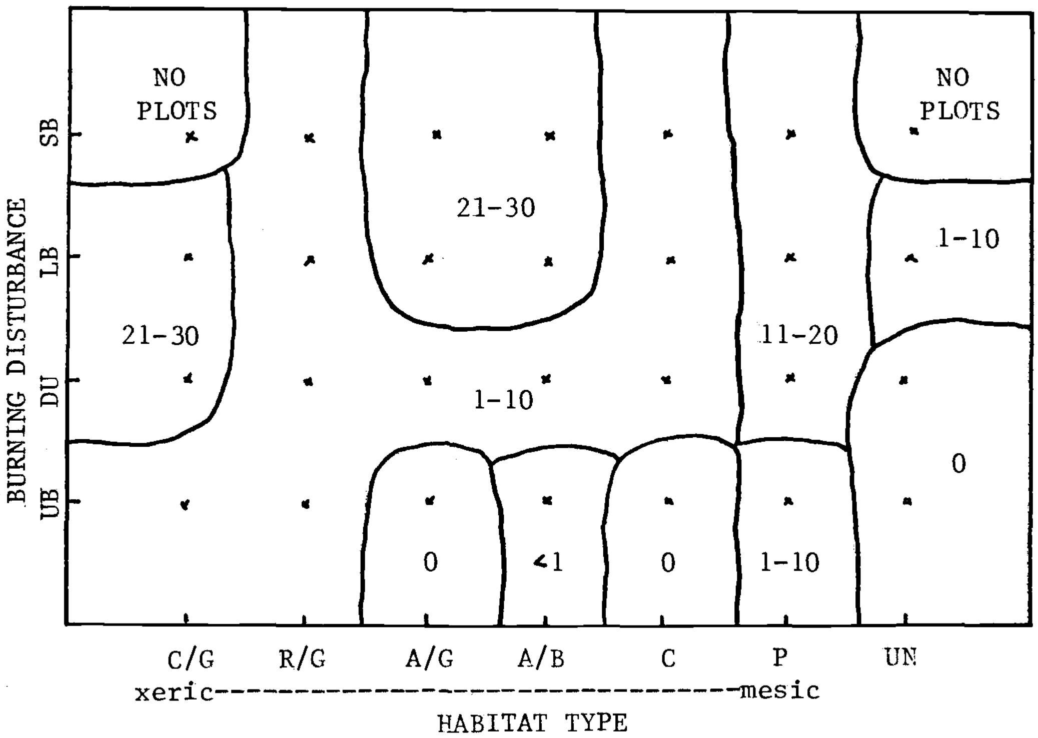

Figure 3a. The combined influence of burning and habitat type on percent C. sanguineus cover.

ver; as disturbance becomes more severe redstem coverage decreases. While burning apparently stimulates cover, logging disturbance, especially soil compaction, seems detrimental to redstem ceanothus' development (Figure 3b.).

Deerbrush

C. integerrimus H. & A., or deerbrush, is not very well represented on the study area, occurring on only 10 percent of the plots with an average cover of just 2 percent. Though maximum cover of up to 54 percent occurred on a single plot, this was unusual, and it is doubtful that deerbrush is a serious barrier to regeneration on these sites. As with the other Ceanothus species, deerbrush reaches its greatest development on southerly exposures, although it is distributed rather randomly across habitat types (Table 1). Neither logging disturbance nor burning influenced deerbrush establishment. Results may be partially obscurred because of the large number of plots where no cover was found and the high variability in cover on plots where it occurred. No cover was found on severely burned or compacted plots and very little to none on sites undisturbed by either burning or logging (Figure 4a.).

Although soil association did not significantly affect deerbrush cover, average cover values were highest on talus slopes. No deerbrush occurred on lateritic soils.

The limited distribution of deerbrush in this study area, unlike the other two Ceanothus species, allows for more specific relations between its occurrence and various site factors as evidenced by Figures 4b. and 4c. Deerbrush is most likely to occur on moderately

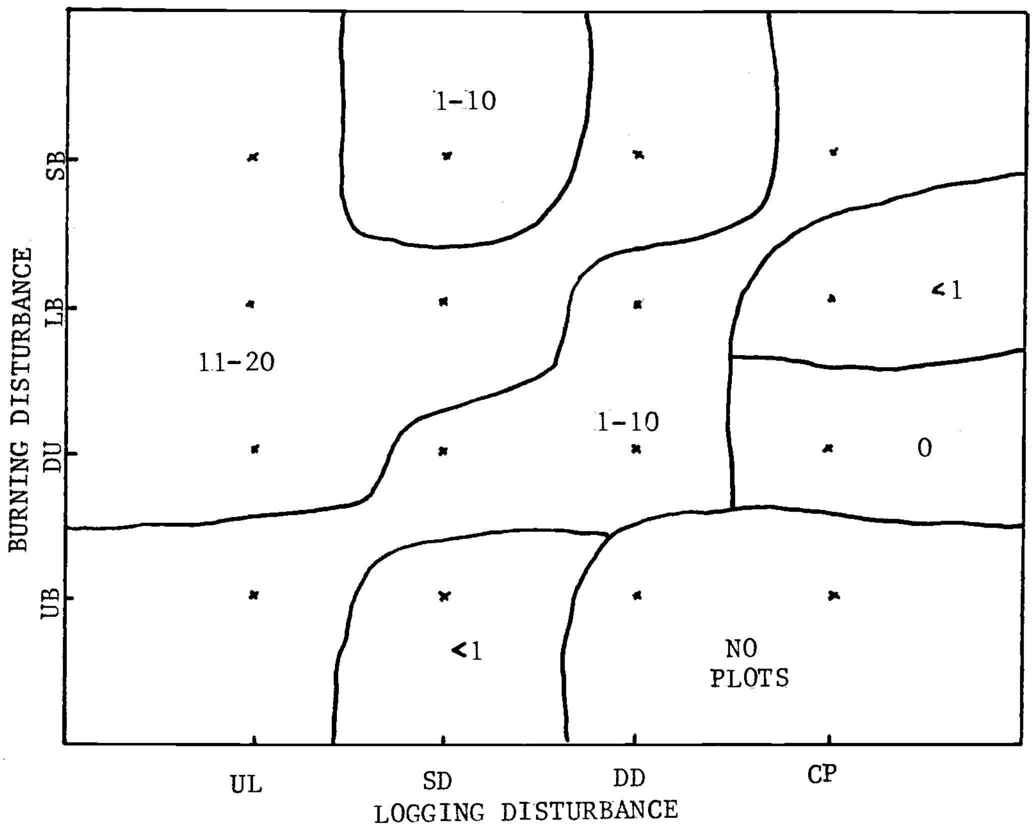

Figure 3b. The combined influence of burning and logging disturbance on percent C. sanguineus cover.

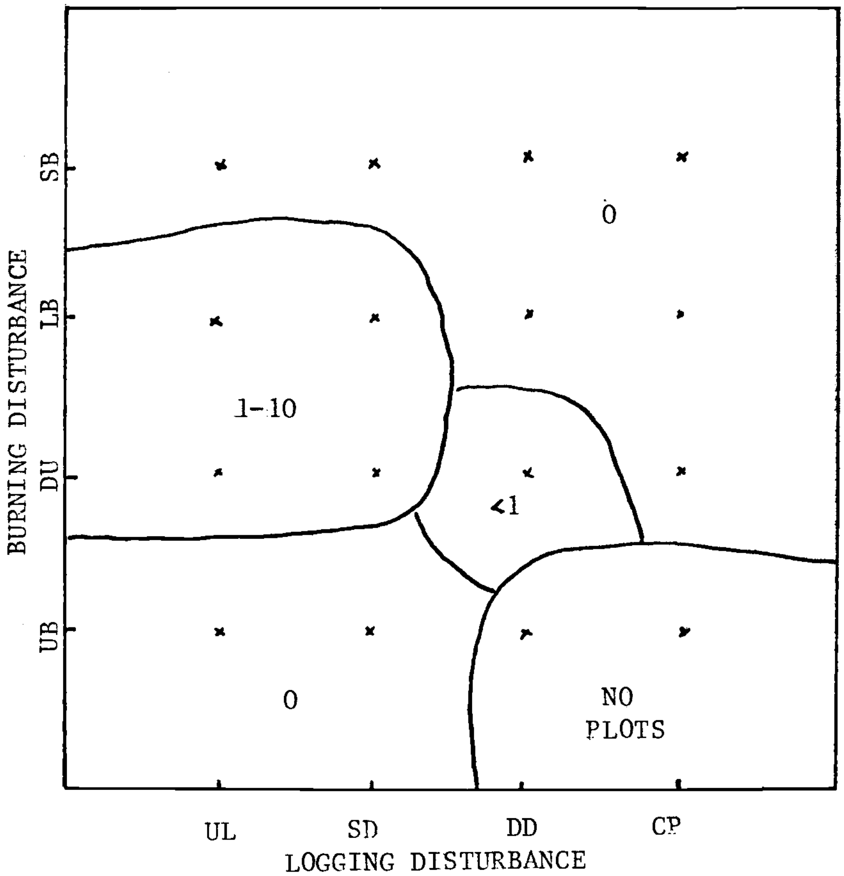

Figure 4a. The combined influence of burning and logging disturbance on percent C. integerrimus cover.

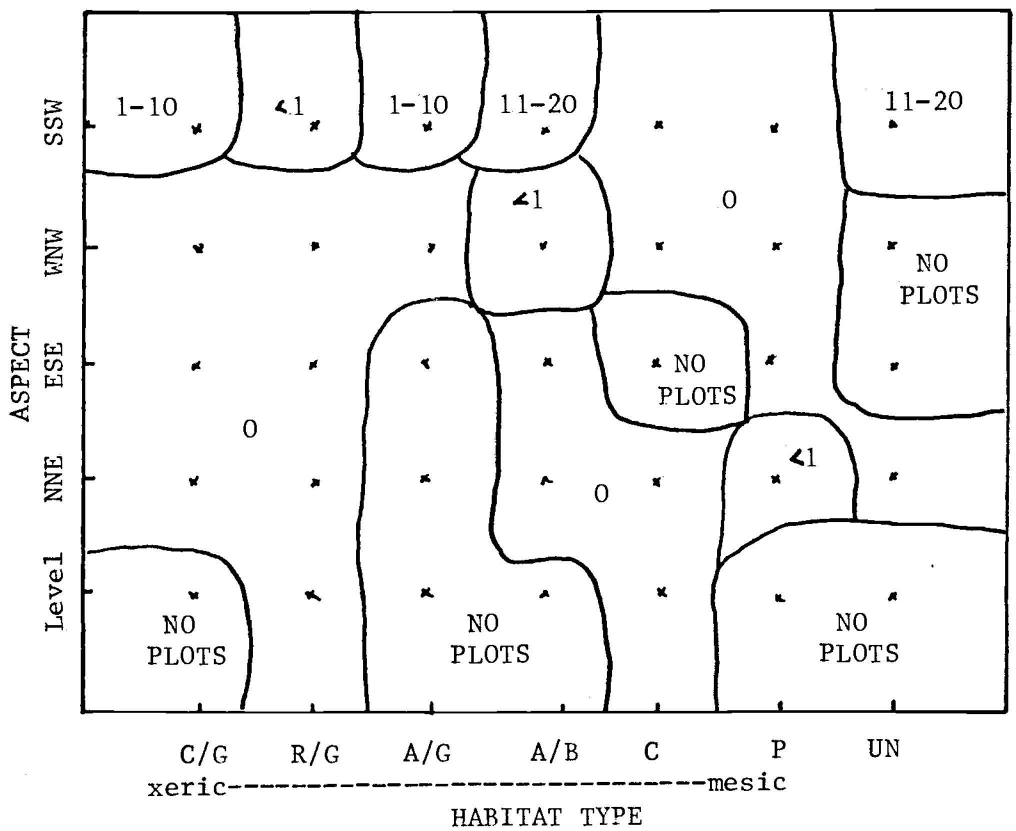

Figure 4b. The combined influence of aspect and habitat type on percent C. integerrimus cover.

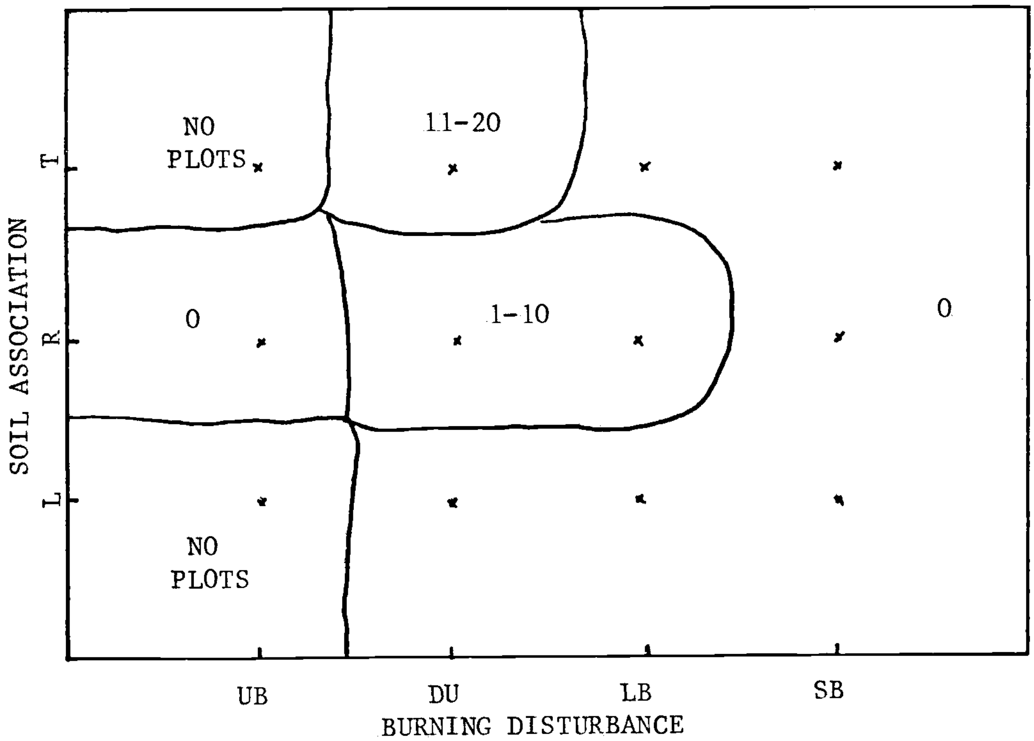

Figure 4c. The combined influence of soil association and burning on percent C. integerrimus cover.

moist to xeric communities with SSW exposures, on regosol soil types or talus slopes with burning disturbance classes of disturbed-unburned or lightly burned. Little to no cover existed on any other sites. Deerbrush appears to be the most site specific of the three Ceanothus species present.

Vine maple

Acer circinatum or vine maple, is a residual species, present on all habitat types studied and often occurring during all stages of succession. Mean cover value is only 10 percent, however vine maple is found on 81 percent of the plots with maximum cover values as high as 72 percent on a single plot.

With few exceptions, greatest vine maple cover is associated with unburned sites and minimal logging disturbance (Figure 5a.). Since vine maple is a residual species, its preference for undisturbed sites was not unexpected. It is interesting to note however, that even after almost twenty years site disturbance is still reflected in vine maple cover values. This might partially reflect slow migration--almost entirely due to layering. Slopes of more than 40 percent can bar upslope migration of this species (Anderson, 1969).

Although not significantly influenced by soil association or aspect, vine maple cover did vary among habitat types. Greatest coverage is associated with Acci/Gash, Acci/Bene and Rhma/Gash communities. Notably less cover was observed on more xeric and mesic habitat types, primarily due to the relatively low cover values found on disturbed plots in these communities (Figure 5b.).

While soil association did not significantly affect vine maple

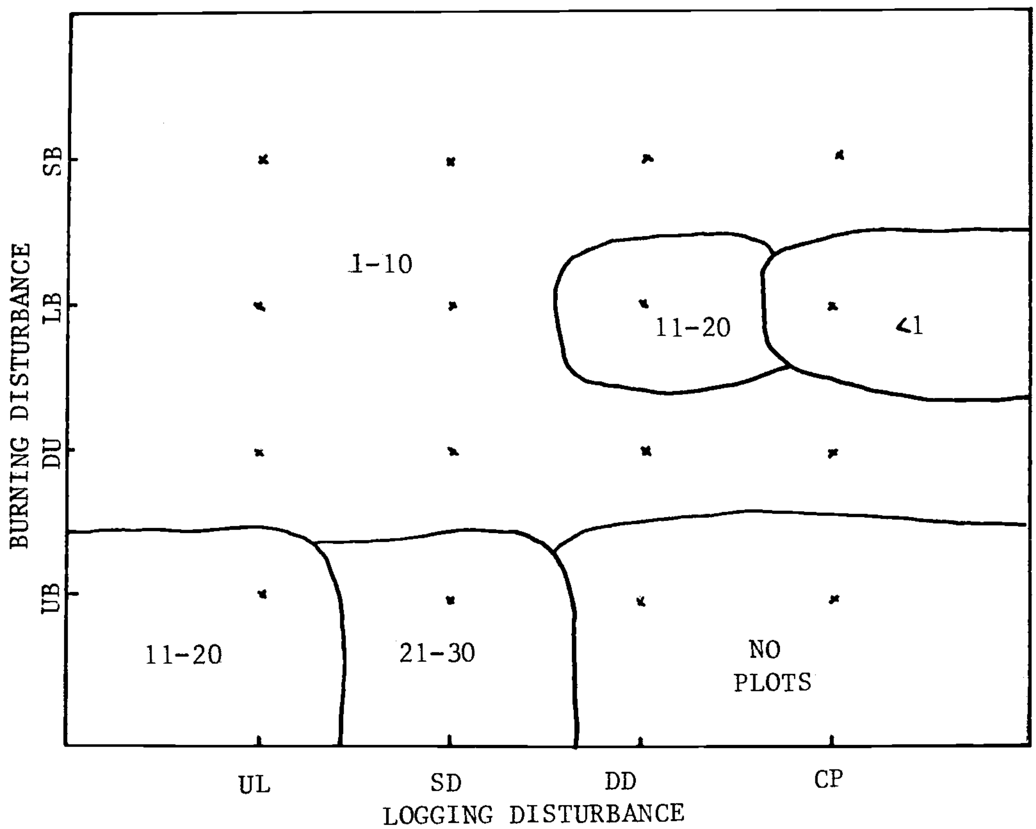

Figure 5a. The combined influence of burning and logging disturbance on percent A. circinatum cover.

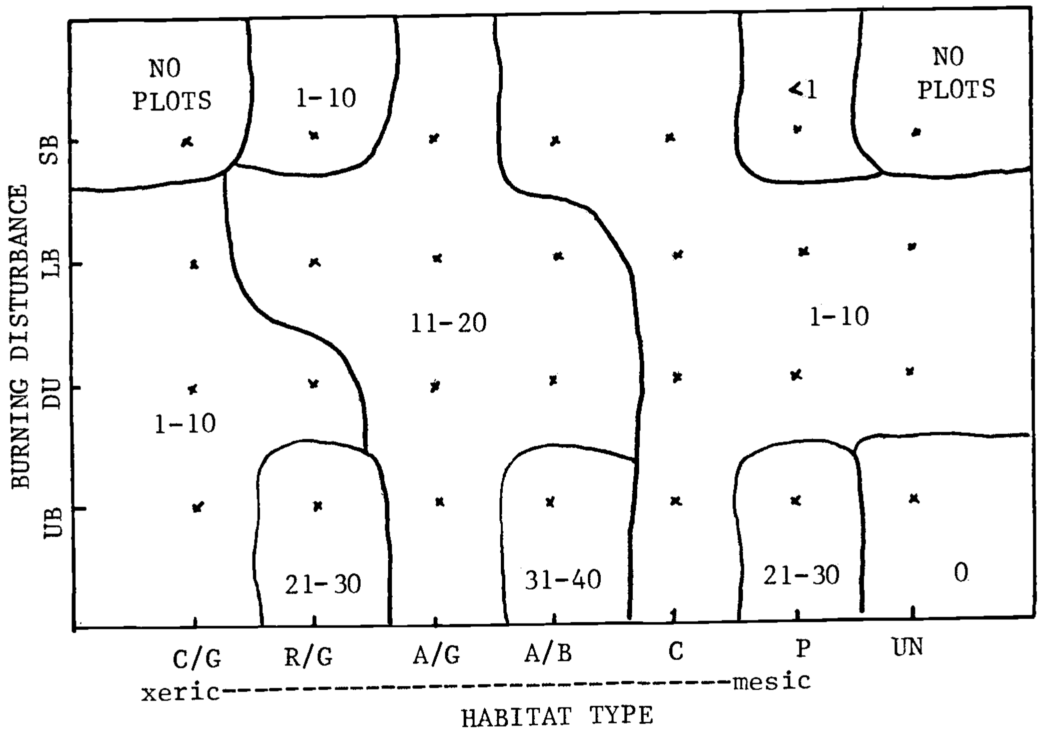

Figure 5b. The combined influence of burning and habitat type on percent A. circinatum cover.

cover, greatest average cover occurred on regosols. The overriding influence of habitat type was such that even on regosols, cover values greater than 10 percent were limited to the three communities which vine maple has dominated since prior to disturbance (Figure 5c.).

B. Conifer Growth and Stocking as Related to Site Factors

Results of analysis of variance on Douglas-fir and western hemlock growth measurements are presented in Table 2. Because the growth parameters measured appeared to differ in their response to site factors and with few exceptions did not show very high intercorrelations, they were examined separately.

Douglas-fir

1. Average Basal Diameter

The average basal diameter of Douglas-fir was not significantly influenced by burning. In contrast, logging disturbance significantly affected average basal diameter. As the intensity of logging disturbance increased, the average basal diameter also increased. Curiously, greatest mean basal diameters are associated with compacted sites although compaction is generally thought to be detrimental to conifer development. It is possible that less competition was encountered on these sites during initial seedling establishment allowing for increased growth. Also, while Dyrness (1973) noted logging disturbance on the original study plots, the intensity might not be uniform throughout the new larger plots on which tree measurements were made. When logging disturbance is coupled with burning (Figure 6a.), diameter growth appears enhanced as evidenced by greatest mean basal diameters occurring on plots exposed to both burning and

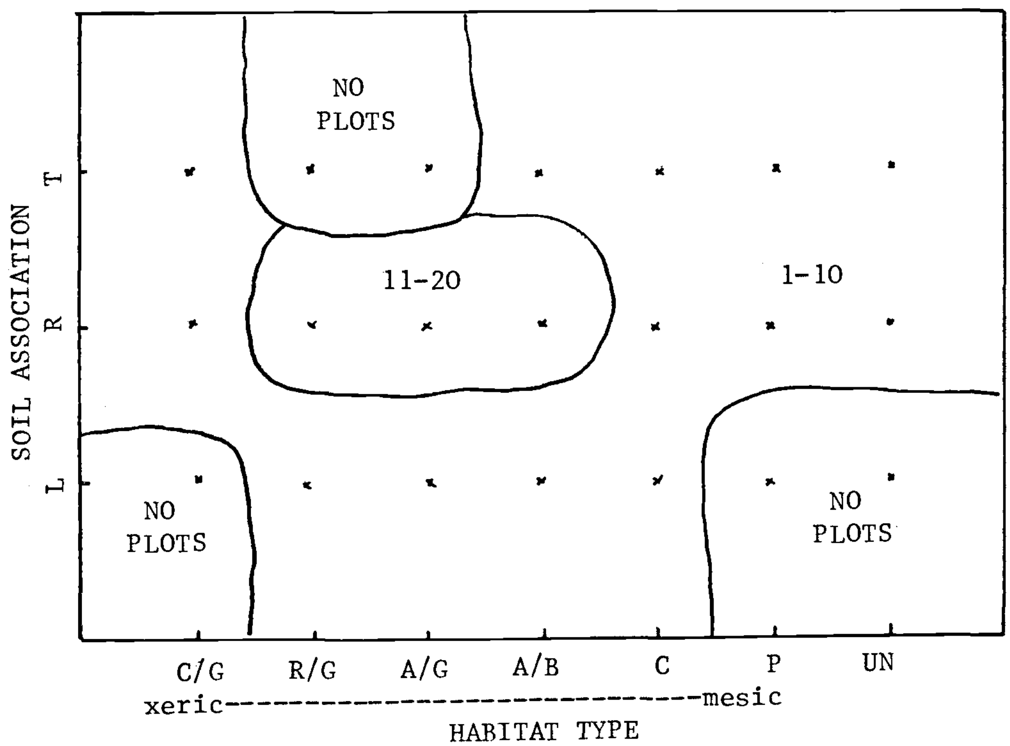

Figure 5c. The combined influence of soil association and habitat type on percent A. circinatum cover.

Table 2. Results of analysis of variance on conifer growth and stocking.

	BURNING DISTURBANCE				
	Undisturbed n=21	Disturbed-unburned n=61	Lightly burned n=92	Severely burned n=16	Significance of Anova
	x̄ (SE)				
Douglas-fir					
Average basal diameter (cm)	5.32a* (0.40)	5.15a (0.33)	5.31a (0.26)	6.02a (0.65)	NS
Trees/ha	1587a (321)	799b (118)	811b (99)	1155ab (263)	.01
Basal area (m^2/ha)	3.6a (2.80)	2.8ab (0.40)	2.0b (0.24)	3.6ab (0.40)	.05
Relative density (%)	8.07a (1.51)	5.21b (0.78)	4.39b (0.45)	6.82ab (1.03)	.05
Western hemlock					
Trees/ha	849a (279)	191b (96)	55b (21)	120b (82)	.01
Basal area (m^2/ha)	1.60a (0.40)	0.32b (0.16)	0.08b (0.04)	0.12b (0.08)	.01

Table 2. cont.

	LOGGING DISTURBANCE				
	Undisturbed n=101	Slightly disturbed n=62	Deeply disturbed n=23	Compacted n=4	Significance of Anova
	---------- $\bar{x}$ (SE) ----------				
Douglas-fir					
Average basal diameter (cm)	4.99a (0.21)	5.11ab (0.32)	6.88bc (0.59)	7.96c (1.34)	.01
Trees/ha	1022a (115)	690a (112)	847a (132)	1410a (840)	NS
Basal area (m^2/ha)	2.4ab (0.40)	2.0a (0.28)	4.4bc (0.80)	5.6c (2.40)	.01
Relative density (%)	5.31a (0.53)	4.09a (0.58)	7.22ab (1.21)	11.07b (5.30)	.05
Western hemlock					
Trees/ha	246a (84)	160a (54)	50a (15)	110a (97)	NS
Basal area (m2/ha)	0.40a (0.12)	0.32a (0.12)	0.04a (0.04)	0.20a (0.20)	NS

Table 2. cont.

	HABITAT TYPE							
	Coco/Gash n=12	Rhma/Gash n=30	Acci/Gash n=17	Acci/Bene n=44	Cola n=35	Pomu n=43	Unclassified n=9	Significance of Anova
	xeric					mesic		
	$\bar{x}$ (SE)							
Douglas-fir								
Average basal diameter (cm)	4.03a (0.62)	6.42bc (0.45)	7.63b (0.69)	4.63ad (0.30)	6.00cd (0.32)	4.34a (0.29)	4.44a (1.06)	.01
Trees/ha	623a (353)	932a (148)	809a (178)	628a (121)	1178a (208)	1202a (187)	604a (290)	.10
Basal area (m^2/ha)	0.80a (0.24)	3.60b (0.40)	3.60b (0.40)	1.60ac (0.40)	3.60b (0.40)	0.05abc (0.32)	2.40bc (0.80)	.01
Relative density (%)	1.85a (0.64)	6.52bc (0.93)	6.65bc (1.11)	3.65ac (0.77)	7.60b (1.14)	4.79abc (0.68)	4.08ac (1.98)	.01
Western hemlock								
Trees/ha	0a	85ab (41)	19a (12)	214ab (133)	480b (174)	154ab (63)	75ab (32)	NS
Basal area (m^2/ha)	0a	0.16ab (0.08)	0.02a (0.00)	0.48ab (0.24)	0.72b (0.24)	0.24ab (0.01)	0.12ab (0.04)	NS

Table 2. cont.

	SOIL ASSOCIATION			
	Lateritic n=16	Regosol n=157	Talus n=17	Significance of Anova
	$\bar{x}$ (SE)			
Douglas-fir				
Average basal diameter (cm)	7.27a (0.38)	5.41b (0.18)	2.72c (0.54)	.01
Trees/ha	687a (87)	992a (83)	494a (316)	NS
Basal area (m^2/ha)	3.20a (0.40)	2.80a (0.40)	0.80b (0.40)	.05
Relative density (%)	6.38a (0.83)	5.55a (0.44)	1.55b (0.92)	.01
Western hemlock				
Trees/ha	35a (24)	222a (58)	59a (47)	NS
Basal area (m^2/ha)	0.02a (0.00)	0.40a (0.08)	0.08a (0.04)	NS

Table 2. cont.

	ASPECT					
	Level n=5	NNE n=71	ESE n=6	WNW n=56	SSW n=52	Significance of Anova
	$\bar{x}$ (SE)					
Douglas-fir						
Average basal diameter (cm)	7.88a (0.49)	4.65b (0.18)	4.90b (0.76)	6.28ab (0.40)	5.01b (0.35)	.01
Trees/ha	744a (176)	1547b (157)	640a (174)	496a (46)	577a (106)	.01
Basal area (m^2/ha)	3.6a (0.80)	3.6ab (0.40)	1.2b (0.28)	2.4ab (1.20)	1.6ab (0.28)	.01
Relative density (%)	7.26a (1.53)	7.15a (0.73)	2.78b (0.62)	4.81ab (0.70)	3.29ab (0.52)	.01
Western hemlock						
Trees/ha**	88 (57)	398 (101)	13 (13)	129 (93)	9 (8)	.05
Basal area** (m^2/ha)	0.080 (0.040)	0.800 (0.160)	0.016 (0.004)	0.200 (0.120)	0.016 (0.004)	.01

* Means, in any one row, which are followed by the same letter, are not significantly different at the .05 level.

** LSD procedure did not show means to be significantly different.

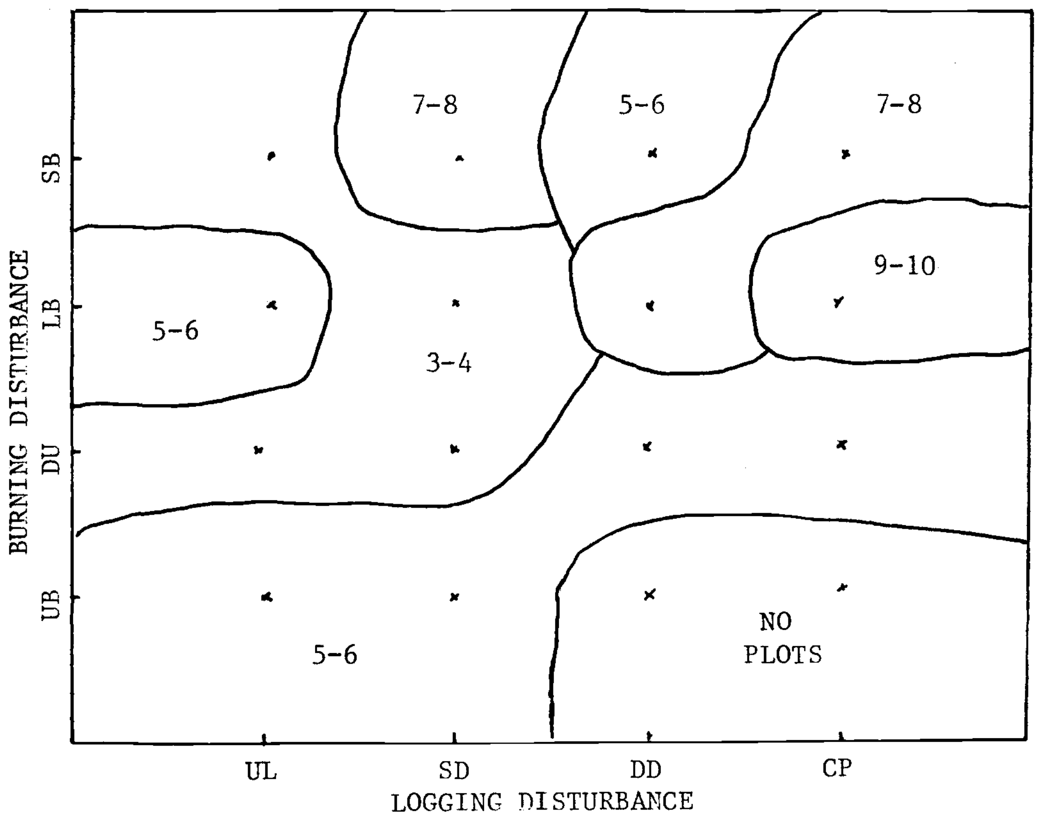

Figure 6a. The combined influence of burning and logging disturbance on the average basal diameter of Douglas-fir (cm).

severe logging disturbance.

Average basal diameters varied significantly with habitat type. Largest average basal diameters were found on relatively dry Rhma/Gash and Acci/Gash and on moist Cola habitat types, with the lowest basal diameters on both xeric Coco/Gash and mesic Pomu communities.

Basal diameters also varied according to soil association and aspect, with the largest mean basal diameters occurring on lateritic soils. Level and WNW aspects contained the greatest mean basal diameters. NNE and ESE exposures had the lowest average basal diameters, although plots on lateritic soils exhibited considerable diameters even on northern aspects (Figure 6b.).

2. Number of Trees

In contrast to average basal diameter, Douglas-fir stocking was significantly influenced by burning but not by logging disturbance. It was interesting to note, however, that compacted plots which were undisturbed by burning averaged the most trees (Figure 7a.).

The effects of burning, though significant, do not demonstrate any linear trend. Greatest numbers of trees are found on undisturbed sites though severely burned plots contain almost one-third more trees than disturbed-unburned or lightly burned plots. Clearly Douglas-fir can survive and become established on severely burned plots on these study sites.

Stocking was only slightly influenced by habitat type with plots averaging the most trees occurring in mesic Cola and Pomu communities. In almost all communities plots undisturbed by burning contain relatively high numbers of trees (Figure 7b.). The primary im-

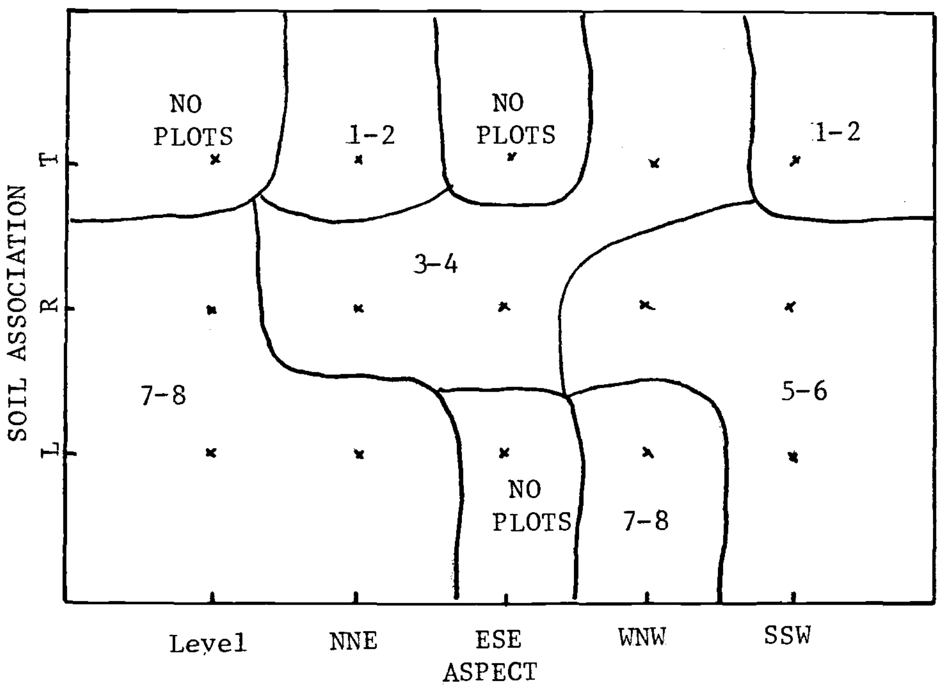

Figure 6b. The combined influence of soil association and aspect on the average basal diameter of Douglas-fir (cm).

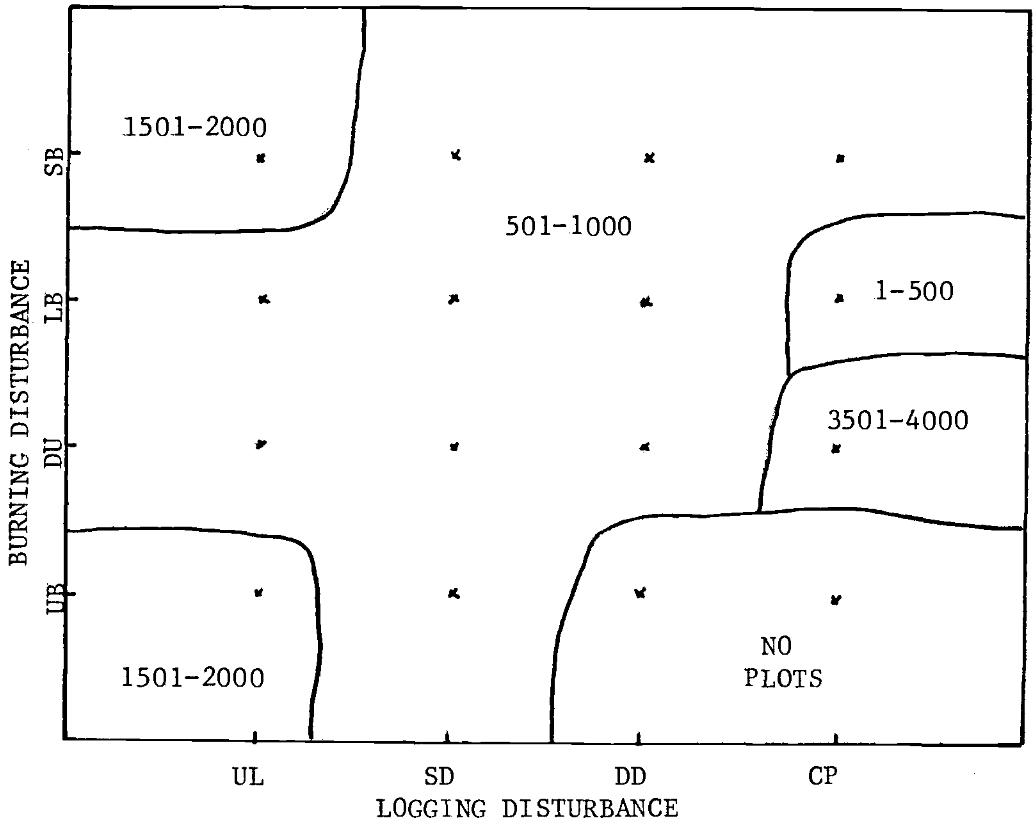

Figure 7a. The combined influence of burning and logging disturbance on the number of Douglas-fir trees (trees/ha).

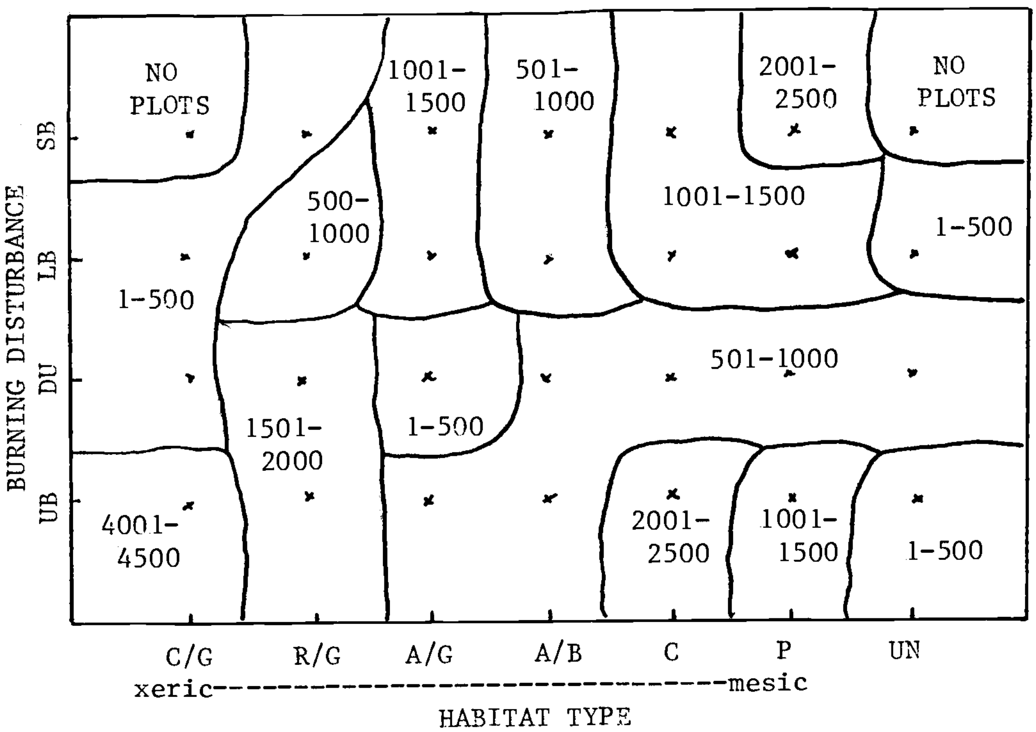

Figure 7b. The combined influence of burning and habitat type on the number of Douglas-fir trees (trees/ha).

pact of burning is on the driest habitat types; even though almost twenty years have passed since disturbance, conditions in burned areas in xeric habitat types remain limiting to seedling establishment and/or survival.

Aspect was an important determinant of Douglas-fir stocking. NNE exposures had the greatest number of trees. These aspects also had the lowest average basal diameters. All other aspects exhibited values slightly to well below the mean number of trees (920 trees/ha) on these watersheds.

The relationship between aspect and soil association is depicted in Figure 7c. Though soil association was non-significant, it appears that at least moderately developed soils are necessary for Douglas-fir survival on southerly exposures; only those talus slopes which were on NNE aspects had significant stocking.

3. Basal Area

Douglas-fir basal area, an integration of size and density, varied significantly with all site factors. At full stocking, high basal areas, whether due to few trees with very large diameters or many trees with small diameters, are assumed to indicate potentially productive sites.

Sites which were either deeply disturbed or compacted during logging supported about twice the basal area as undisturbed or slightly disturbed areas. However, a dual pattern emerged with regard to burning with greatest basal areas occurring on both severely burned plots and those undisturbed by burning. Lightly burned plots supported the lowest basal areas except where deeply disturbed by log-

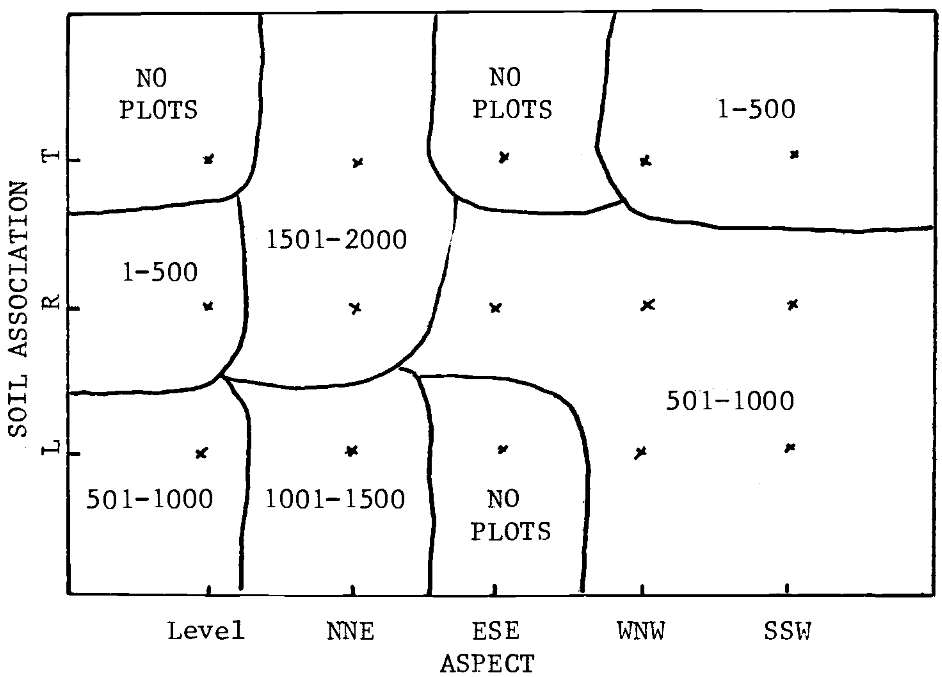

Figure 7c. The combined influence of soil association and aspect on the number of Douglas-fir trees (trees/ha).

ging (Figure 8a.).

Mesic Cola communities, generally recognized as being very productive in terms of timber growth, contained large Douglas-fir basal areas as did more xeric Rhma/Gash and Acci/Gash habitat types. On undisturbed sites moderate to high basal areas occurred on almost all communities (Figure 8b.). On severely burned plots high basal areas are associated with increasingly mesic habitat types suggesting that the effects of burning may be at least partially ameliorated under more mesic conditions.

Basal areas were two to three times greater on northerly than southerly exposures and talus slopes supported appreciable Douglas-fir basal areas only when on northerly aspects (Figure 8c.). Basal area did not differ between laterites and regosols.

4. Relative Density

Douglas-fir relative density was calculated from the following equation from Reincke (1933): (-1.605 x log(average basal diameter)) + 5.42 = log(number of trees/ha). The number of Douglas-fir trees calculated by this equation, using the average basal diameter measurements, represents full stocking levels to be expected on study sites. Observed number of trees per hectare is then divided by that calculated, providing an estimate of relative density or percent full occupancy on these sites. According to this equation, all plots on the study area were understocked, with relative densities averaging only 5.27 percent, and never reaching values greater than 26 percent.

As with basal area, all site factors exerted significant influ-

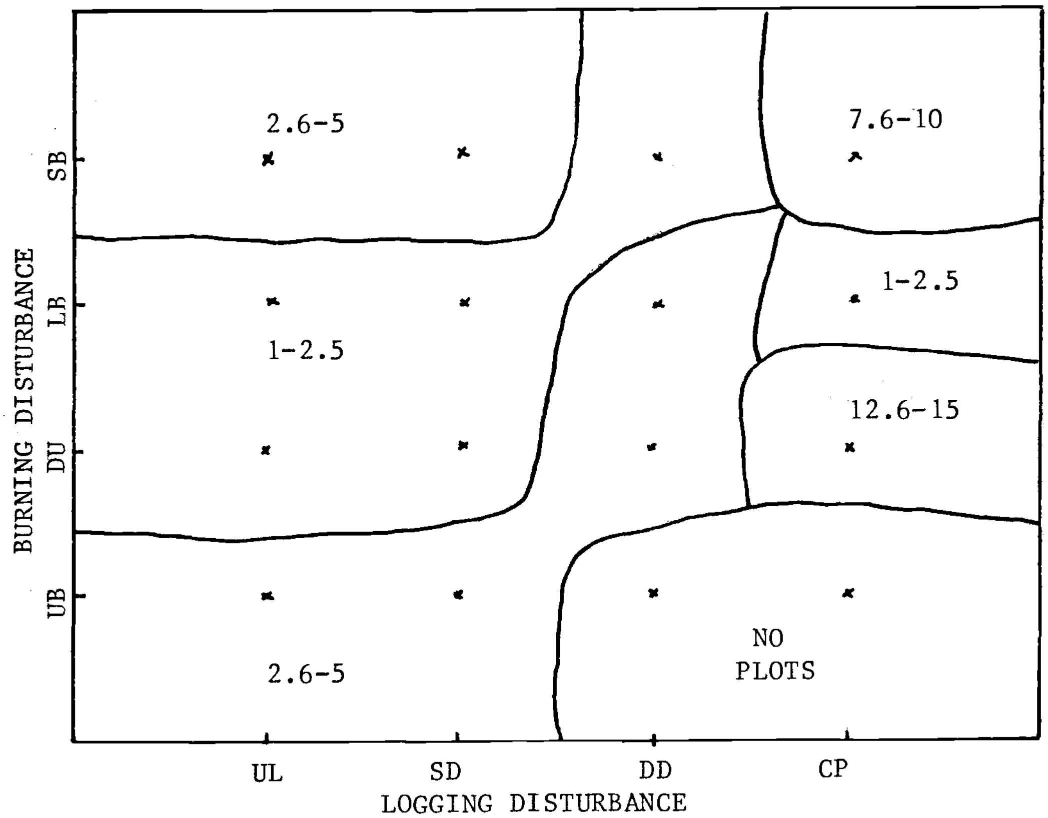

Figure 8a. The combined influence of burning and logging disturbance on the basal area of Douglas-fir (m^2/ha).

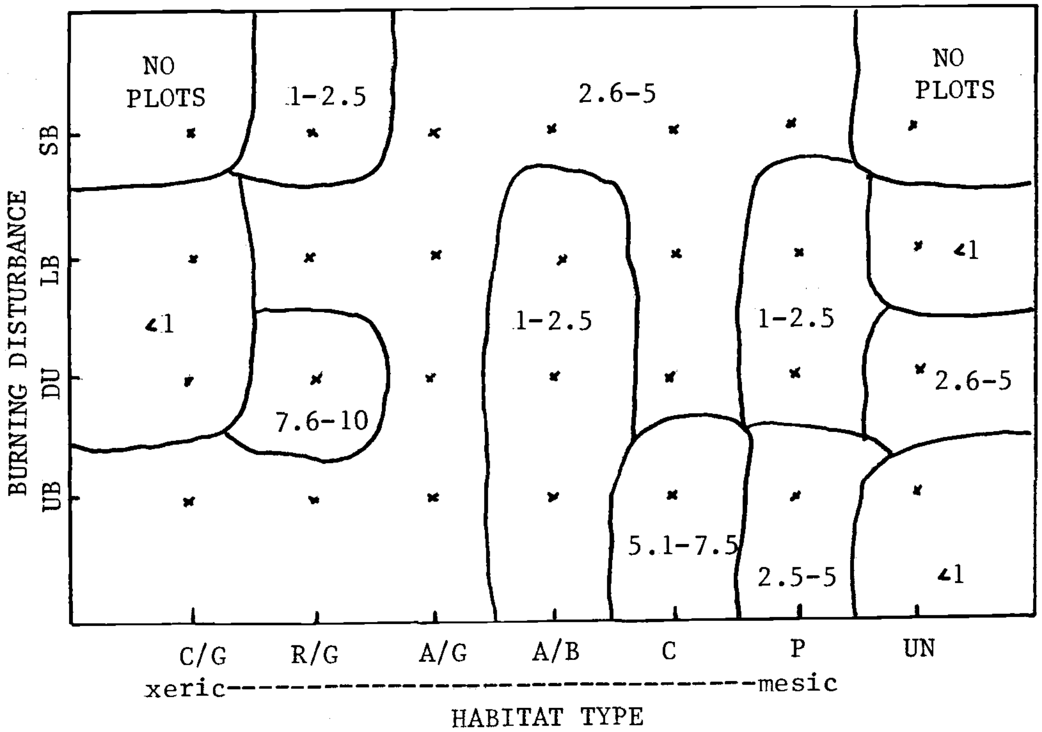

Figure 8b. The combined influence of burning and habitat type on the basal area of Douglas-fir (m^2/ha).

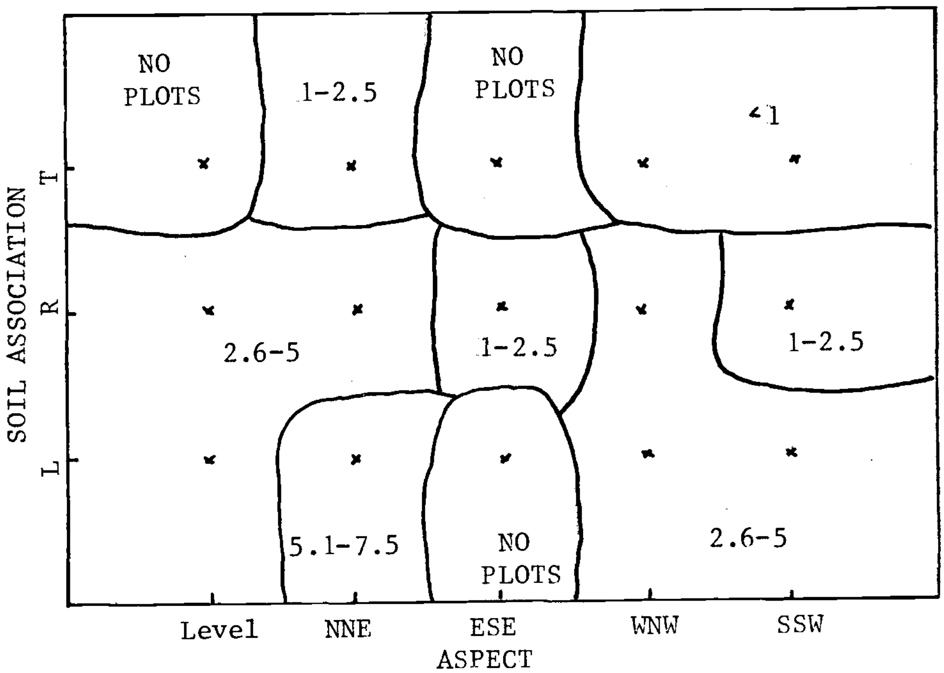

Figure 8c. The combined influence of soil association and aspect on the basal area of Douglas-fir (m^2/ha).

ences on the relative density of Douglas-fir.

Highest relative densities were located in the logging disturbance classes of deeply disturbed and compacted, perhaps due to less competition or greater exposure of mineral soil on these severely disturbed sites. The pattern was different with regard to burning; greatest relative density values occurred on unburned sites, however, second highest values occurred on severely burned sites, suggesting again that Douglas-fir appears tolerant of a variety of post-logging conditions. Plots that were disturbed-unburned or lightly burned did not support appreciable Douglas-fir relative densities unless deeply disturbed or compacted by logging (Figure 9a.).

Communities containing the most basal area, Cola, Rhma/Gash and Acci/Gash, also had the largest relative densities. Lowest values (less than 2 percent) occurred in the xeric Coco/Gash habitat type. Sites undisturbed by burning supported relatively high relative densities in almost all communities, however as the intensity of burning increases, higher relative densities occur on moderate to mesic habitat types (Figure 9b.). Cola communities seem quite favorable for Douglas-fir establishment and growth on all burning classes, while good survival and development on xeric Coco/Gash communities appears limited to undisturbed sites.

Highest relative densities occurred on lateritic soils and regosols. Mean relative densities on talus slopes were only 1.5 percent, however talus slopes occurring on northerly aspects were reasonably well stocked (Figure 9c.). Regardless of soil types, NNE and level exposures had highest relative density values, though even on these

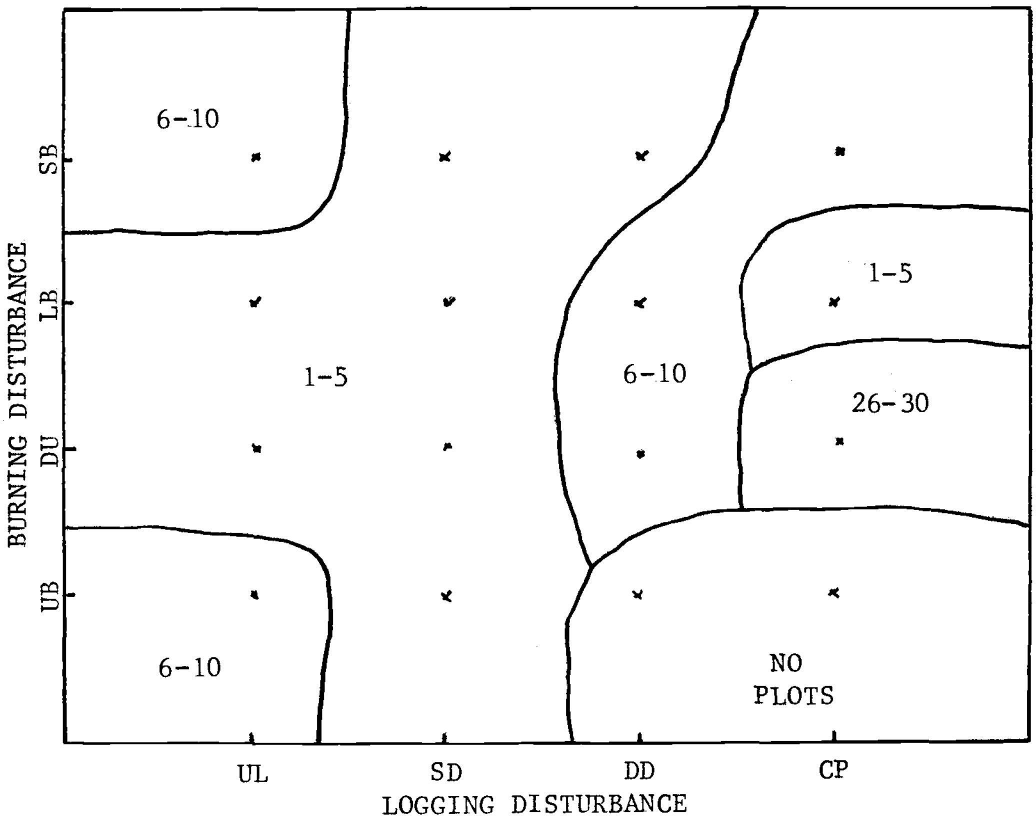

Figure 9a. The combined influence of burning and logging disturbance on Douglas-fir relative density (%).

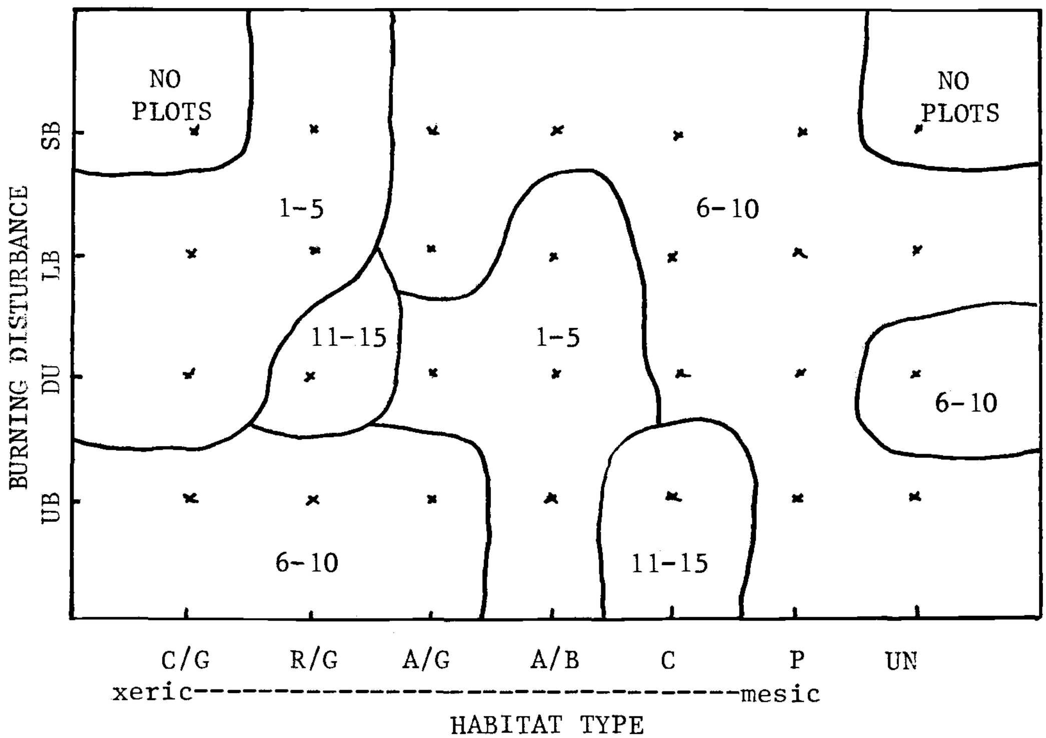

Figure 9b. The combined influence of burning and habitat type on Douglas-fir relative density (%).

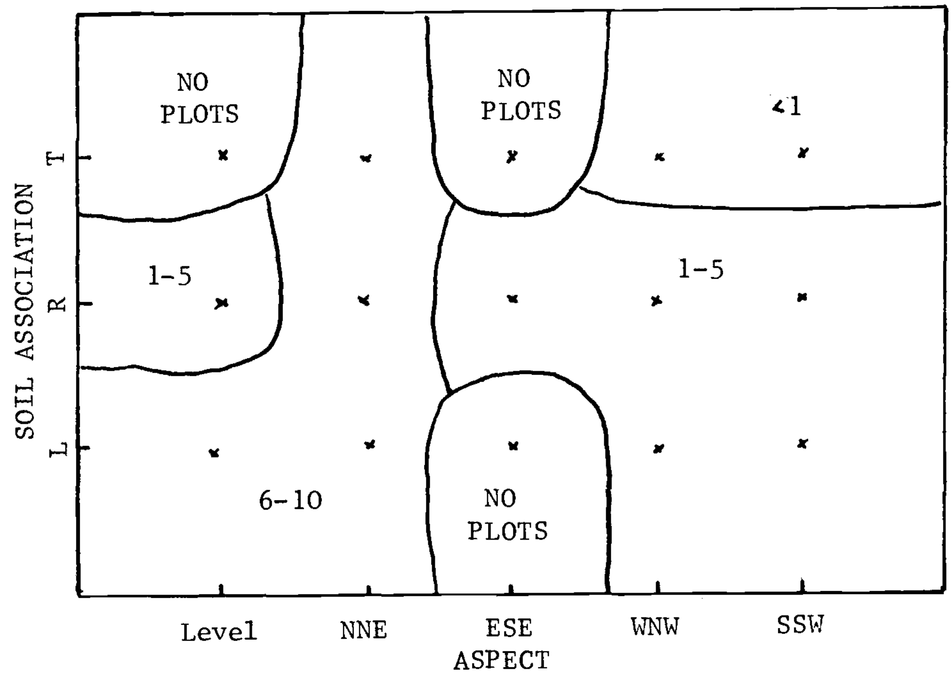

Figure 9c. The combined influence of soil association and aspect on Douglas-fir relative density (%).

apparently favored aspects values averaging only 7 percent of full occupancy were observed. Lowest relative densities were associated with ESE and SSW aspects, indicating again the apparently adverse conditions which seem to prevail on southern exposures.

Western Hemlock

1. Basal Area and Stocking

Both the number of trees and basal area behaved in a virtually identical manner and therefore results from both analyses are discussed concurrently.

The number and basal area of western hemlock (Table 2) were significantly influenced by burning. A strong preference was shown for undisturbed sites, with very few trees and correspondingly low basal areas found on both disturbed-unburned and burned areas. Some of these trees most likely were advanced regeneration occurring in the original understory. Logging disturbance was not a significant factor although few to no trees were found on most sites disturbed by logging especially in conjunction with burning (Figure 10a.).

Aspect significantly affected western hemlock stocking and basal area. NNE aspects appeared to be exceptionally favored by western hemlock, with some establishment even on burned areas (Figure 10b.), while conditions associated with ESE or SSW exposures seem barely sufficient for establishment.

Though soil association and habitat type were not significant influences, the relation between the number of western hemlock trees and these two site factors is interesting (Figure 10c.). Western hemlock establishes most successfully in mesic Cola communities

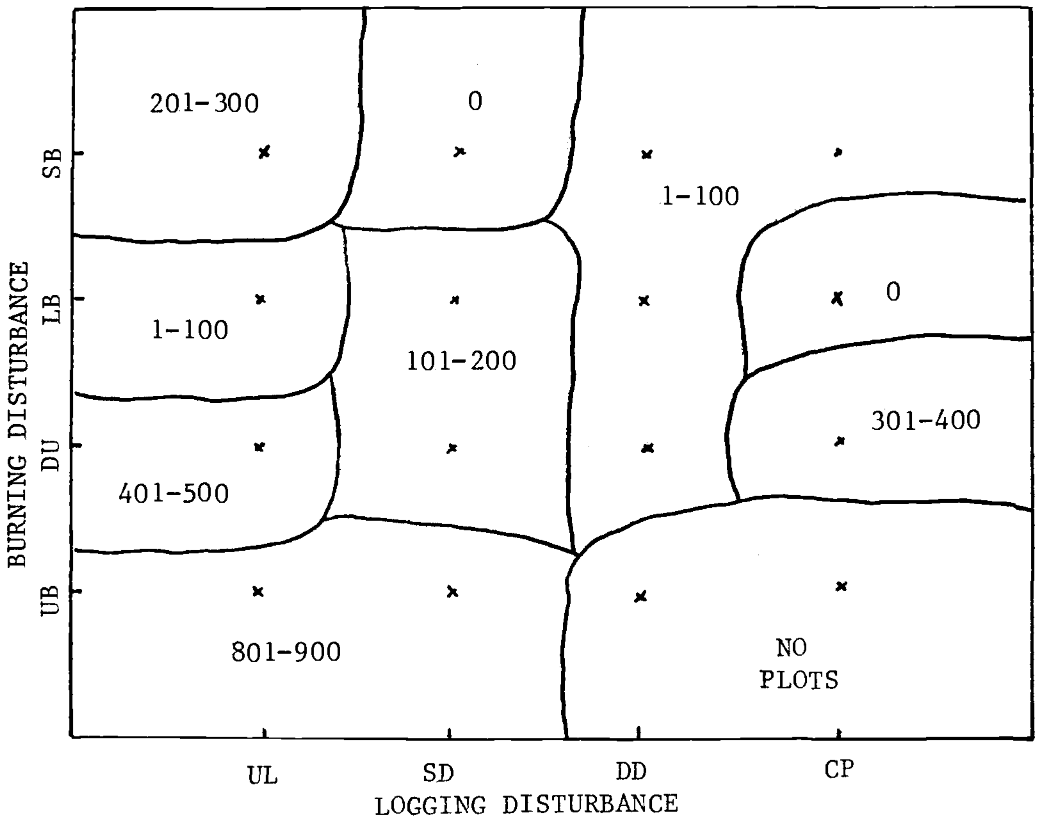

Figure 10a. The combined influence of burning and logging disturbance on the number of western hemlock (trees/ha).

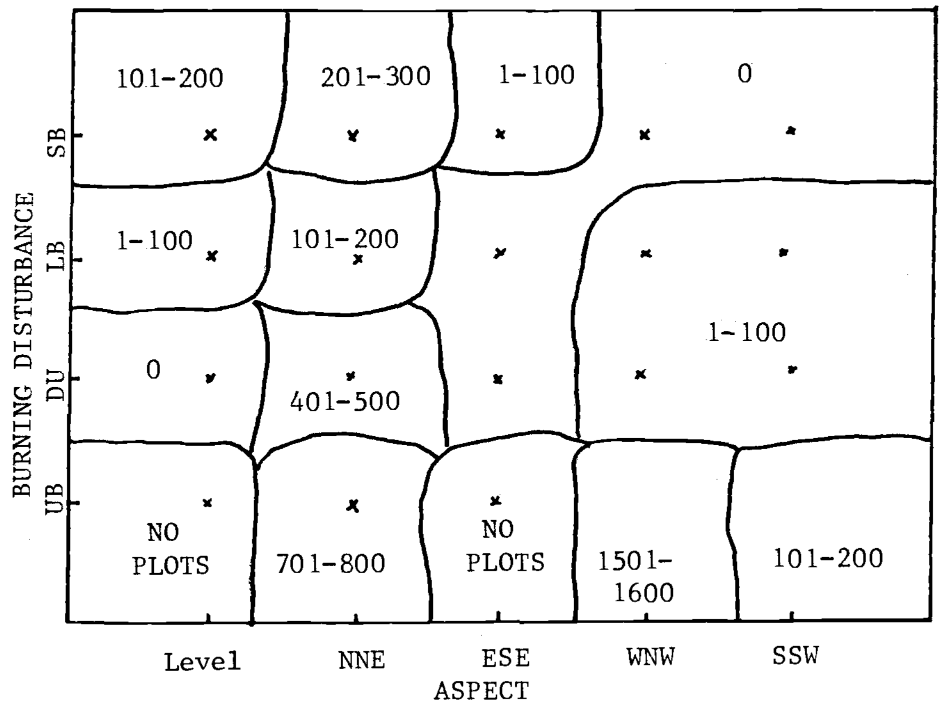

Figure 10b. The combined influence of burning and aspect on the number of western hemlock trees (trees/ha).

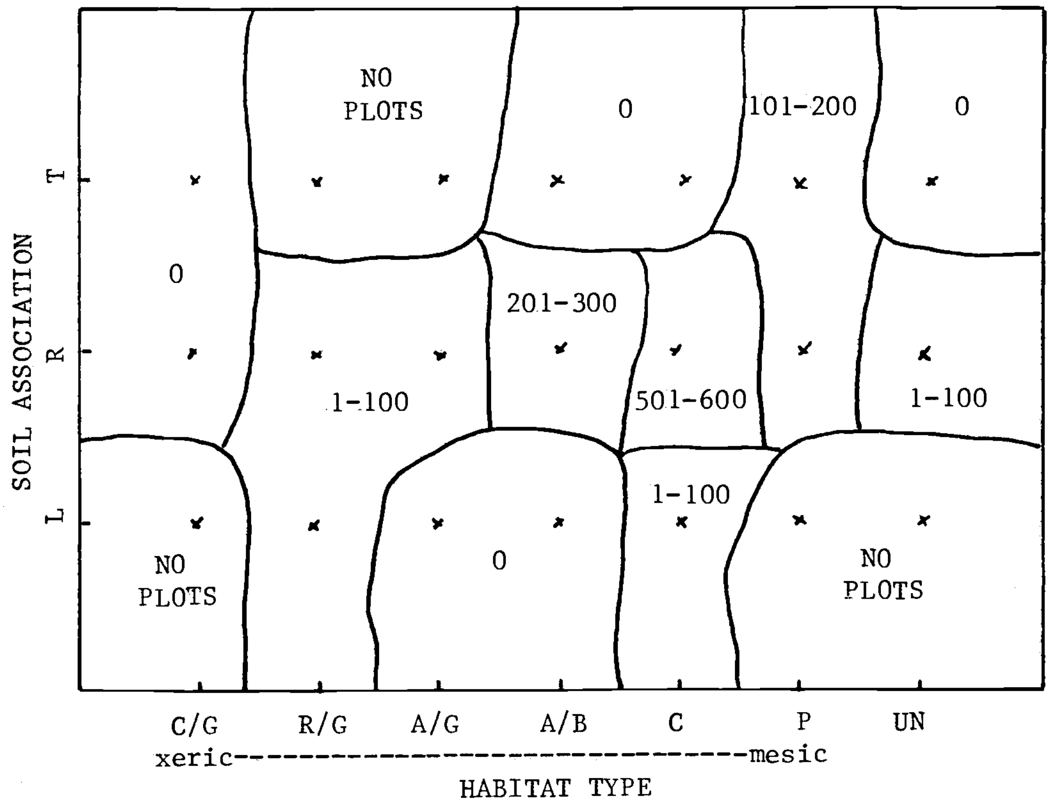

Figure 10c. The combined influence of soil association and habitat type on the number of western hemlock (trees/ha).

which are on regosols. No western hemlock occurred in the xeric Coco/Gash habitat type. Western hemlock seems much more limited by site factors than Douglas-fir, a factor which probably contributes to the lengthy seral stage occupied by Douglas-fir in some areas.

C. Bulk Density and Nitrogen Content as Related to Site Factors

Bulk Density

Bulk density was significantly affected only by soil association with greatest values occurring on talus slopes (Table 3). The bulk densities of laterites and regosols did not significantly differ. Previous studies (Tarrant, 1956b; Dyrness, 1965a) have often found increases in bulk density associated with compaction or severe burning, however, in this study thirteen to sixteen years following logging and slash burning, no differences were evident due to either logging or burning. This could be partly attributed to site amelioration or recovery since the initial disturbance, however the effects of low sample size on both compacted and severely burned sites may have influenced the results.

Total Soil Nitrogen (%)

Soil association was also the only site factor influencing total soil nitrogen (Table 3). Regosols had lower nitrogen contents than either lateritic or talus soils, which had identical values.

Neither burning nor logging disturbance, habitat type nor aspect significantly affected soil nitrogen. It was interesting however, that highest means occurred on WNW and level aspects which were associated with greatest Douglas-fir diameters and basal areas.

Table 3. Results of analysis of variance on bulk density and soil and foliar nitrogen content.

	BURNING DISTURBANCE				
	Undisturbed n=21	Disturbed-unburned n=61	Lightly burned n=92	Severely burned n=16	Significance of Anova
	---------- $\bar{x}$ (SE) ----------				
Bulk density (g/cc)	0.81a* (0.05)	0.77a (0.03)	0.81a (0.03)	0.86a (0.09)	NS
Total-N in soil (%)	0.23a (0.03)	0.23a (0.01)	0.24a (0.01)	0.27a (0.03)	NS
Mineralizable-N in soil (ug/g)	43.59a (5.95)	38.26a (4.17)	40.12a (3.62)	40.47a (8.96)	NS
Current DF foliar-N (%)	1.05a (0.04)	1.16a (0.03)	1.19a (0.03)	1.12a (0.08)	NS
Year old DF foliar-N (%)	1.03ab (0.04)	1.12a (0.03)	1.11a (0.03)	0.97b (0.07)	NS

	LOGGING DISTURBANCE				
	Undisturbed n=101	Slightly disturbed n=62	Deeply disturbed n=23	Compacted n=4	Significance of Anova
	---------- $\bar{x}$ (SE) ----------				
Bulk density (g/cc)	0.81a (0.03)	0.80a (0.03)	0.78a (0.05)	0.66a (0.12)	NS
Total-N in soil (%)	0.25a (0.01)	0.24a (0.01)	0.19a (0.02)	0.26a (0.06)	NS
Mineralizable-N in soil (ug/g)	39.09a (3.29)	39.98a (4.12)	39.55a (7.38)	64.48a (20.33)	NS
Current DF foliar-N (%)	1.17a (0.03)	1.12a (0.03)	1.19a (0.06)	1.12a (0.05)	NS
Year old DF foliar-N (%)	1.11a (0.03)	1.05a (0.03)	1.08a (0.04)	0.99a (0.04)	NS

Table 3. cont.

	HABITAT TYPE							
	Coco/Gash n=12	Rhma/Gash n=30	Acci/Gash n=17	Acci/Bene n=44	Cola n=35	Pomu n=43	Unclassified n=9	Significance of Anova
	xeric					mesic		
	$\bar{x}$ (SE)							
Bulk density (g/cc)	0.89a (0.07)	0.73a (0.05)	0.74a (0.04)	0.80a (0.05)	0.79a (0.05)	0.86a (0.04)	0.74a (0.06)	NS
Total-N in soil (%)	0.24a (0.04)	0.23a (0.02)	0.22a (0.02)	0.26a (0.02)	0.26a (0.03)	0.21a (0.02)	0.20a (0.04)	NS
Mineralizable-N in soil (ug/g)	25.19a (7.02)	41.86ab (7.19)	48.15b (8.16)	45.86ab (6.35)	40.03ab (4.67)	34.24ab (3.64)	35.48ab (8.94)	NS
Current DF foliar-N (%)	1.19a (0.07)	1.12ab (0.04)	1.13ab (0.06)	1.21a (0.04)	1.10ab (0.03)	1.22a (0.04)	0.98b (0.13)	.10
Year old DF foliar-N (%)	1.17a (0.07)	1.03a (0.03)	1.09a (0.04)	1.13a (0.04)	1.04a (0.03)	1.12a (0.04)	1.19a (0.07)	NS

	ASPECT					
	Level n=5	NNE n=71	ESE n=6	WNW n=56	SSW n=52	Significance of Anova
	$\bar{x}$ (SE)					
Bulk density (g/cc)	0.79a (0.18)	0.84a (0.03)	0.73a (0.12)	0.75a (0.04)	0.81a (0.04)	NS
Total-N in soil (%)	0.33a (0.06)	0.22a (0.01)	0.24a (0.05)	0.27a (0.02)	0.22a (0.01)	NS
Mineralizable-N in soil (ug/g)	57.43a (19.83)	41.38ab (3.54)	34.18ab (12.05)	46.58ab (5.26)	29.79b (3.84)	.10
Current DF foliar-N (%)	0.99a (0.07)	1.14a (0.02)	1.22b (0.09)	1.20ab (0.04)	1.15ab (0.04)	NS
Year old DF foliar-N (%)	0.90a (0.06)	1.06ab (0.02)	1.20b (0.14)	1.12b (0.04)	1.11b (0.04)	NS

Table 3. cont.

	SOIL ASSOCIATION			
	Lateritic n=16	Regosol n=157	Talus n=17	Significance of Anova
	------------------- $\bar{x}$ (SE) -------------------			
Bulk density (g/cc)	0.72a (0.08)	0.79a (0.02)	0.98b (0.07)	.05
Total-N in soil (%)	0.31a (0.05)	0.22b (0.01)	0.31a (0.04)	.01
Mineralizable-N in soil (ug/g)	46.88a (10.02)	38.67a (2.64)	45.04a (6.56)	NS
Current DF foliar-N (%)	1.07a (0.06)	1.16a (0.02)	1.22a (0.10)	NS
Year old DF foliar-N (%)	1.06a (0.04)	1.08a (0.02)	1.19a (0.08)	NS

* Means, in any one row, which are followed by the same letter, are not significantly different at the .05 level.

Mineralizable Nitrogen (ug/g) in Soil

Although mean mineralizable nitrogen varied considerably among plot-types, only aspect had a significant influence (.10 level). Lack of significance was due in part to high variability within plot-type. As with total soil nitrogen, highest values occurred on WNW and level aspects. These exposures appear especially favorable for soil nitrogen accumulation. ESE and SSW aspects had the lowest mineralizable nitrogen values and also the lowest Douglas-fir basal areas and relative densities. Though disturbance from logging or burning did not significantly affect the amounts of mineralizable nitrogen, means on compacted plots were almost one-third higher than on any other burning or logging disturbance regime.

Current Year Douglas-fir Needle Nitrogen

Percent total nitrogen in current year Douglas-fir needles was only slightly influenced (.10 level) by habitat types. In general, lowest current year foliar nitrogen values were found in communities containing the largest Douglas-fir average basal diameters, basal areas and relative densities, while highest current year foliar nitrogen values occurred on habitat types with the lowest values for average basal diameters, basal areas and relative densities. Perhaps this indicates the beginnings of nitrogen stress in Douglas-fir.

Burning, logging disturbance, soil association and aspect did not affect current year foliar nitrogen.

One Year Old Douglas-fir Needle Nitrogen

No site variable measured had significant effects on the nitrogen content of one year old foliage, though current and year old foliar nitrogen levels appeared to exhibit similar patterns. Nitrogen values for year old foliage were consistently lower than current foliar values. Past studies have also observed nitrogen content to decrease with increasing age of foliage (Turner, 1977). Internal factors such as redistribution may exert greater control over year old foliar nitrogen content than any of the site factors measured.

Influence of Shrub Cover, Site Factors and Nitrogen Content on Conifer Growth and Stocking

Multiple regression analysis, using site factors, shrub cover and foliar and soil nitrogen content as independent variables accounted for 17 to 82 percent of the variation in conifer growth and stocking. Regression equations obtained with "best" sets of variables are presented in Table 4. Independent variables left in the equation were chosen based on their significance and contribution to adjusted r^2 values.

Forty percent of the variation in average Douglas-fir basal diameters was explained by soil association (accounting for almost 16 percent), mineralizable nitrogen, logging disturbance, aspect, deerbrush cover, redstem ceanothus cover and total soil nitrogen. As individual variables, only soil association, mineralizable nitrogen and logging disturbance explained more than five percent of the variation.

Of the twenty-two percent explained variation in the number of Douglas-fir trees, more than two-thirds was accounted for by aspect (15.6 percent). Current foliar nitrogen content and vine maple cover

Table 4. Multiple regression analysis showing relations between conifer growth and stocking and site factors, shrub cover and nitrogen content.

X	B	V	Significance of regression coefficients
Douglas-fir Average Basal Diameter			
constant=7.33 adj. r^2=.40			
Soil association	-2.33	15.9	.000
Mineralizable-N	.02	8.0	.000
Logging disturbance	.69	6.5	.000
Aspect	.50	2.8	.000
Deerbrush cover	-.07	3.5	.000
Redstem ceanothus cover	-.03	3.6	.001
Total soil-N	-2.24	1.4	.037
Significance=.000			
Number of Douglas-fir			
constant=90.33 adj. r^2=.22			
Aspect	-7.58	15.6	.000
Current foliar-N	-17.64	3.4	.005
Vine maple cover	-.39	2.8	.003
Bulk density	-12.40	1.3	.054
Logging disturbance	-4.07	1.4	.064
Significance=.000			
Douglas-fir Basal Area			
constant=.108 adj. r^2=.58			
Number of Douglas-fir	.0017	42.7	<.001
Redstem ceanothus cover	-.0005	5.2	.008
Logging disturbance	.017	3.6	.000
Current foliar-N	-.043	2.9	.001
Soil association	-.024	2.0	.003
Mineralizable-N	.0003	1.1	.003
Total soil-N	-.07	1.6	.007
Significance=.000			
Douglas-fir Relative Density			
constant=-.83 adj. r^2=.82			
Number of Douglas-fir	.15	57.9	<.001
Douglas-fir average basal diameter	1.00	22.5	<.001
Current foliar-N	-1.95	1.0	.003
Redstem ceanothus cover	-.02	0.4	.026
Snowbrush cover	-.02	0.4	.035
Significance=.000			

Table 4. cont.

X	B	V	Significance of regression coefficients
Douglas-fir Relative Density			
constant=19.06 adj. r^2=.27			
Current foliar-N	-5.84	10.6	.000
Aspect	-.72	7.2	.012
Redstem ceanothus cover	-.05	3.6	.005
Deerbrush cover	-.12	2.7	.007
Vine maple cover	-.08	2.5	.004
Bulk density	-3.42	2.7	.009
Significance=.000			
Number of Western Hemlock			
constant=52.67 adj. r^2=.17			
Burning disturbance	-5.17	8.3	.000
Year old foliar-N	-12.13	3.4	.007
Aspect	-1.80	2.5	.047
Logging disturbance	-3.20	1.6	.029
Snowbrush cover	-.14	1.7	.022
Bulk density	-9.68	2.0	.024
Significance=.000			
Western Hemlock Basal Area			
constant=.07 adj. r^2=.21			
Burning disturbance	-.01	14.5	.000
Aspect	-.003	3.7	.034
Year old foliar-N	-.01	1.9	.019
Snowbrush cover	-.0002	1.7	.037
Logging disturbance	-.004	1.6	.050
Significance=.000			

General form of multiple regression $Y = A + B_1X_1 + B_2X_2 + \ldots B_nX_n$
A = constant, $B_1, B_2, \ldots B_n$ = regression coefficients,
Y = dependent variable, $X_1, X_2, \ldots X_n$ = independent variables
V = variation accounted for by the independent variable (%)

explained about three percent each, while bulk density and logging disturbance accounted for less than two percent individually.

Douglas-fir stocking accounted for more than two-thirds of the fifty-eight percent explained variation in Douglas-fir basal area, which was not unanticipated since basal area is the product of the number of trees and their basal diameters. Redstem ceanothus cover accounted for slightly more than five percent of the total explained variation. Other factors of apparently minor importance which had significant regression coefficients include logging disturbance, current foliar nitrogen, soil association, mineralizable nitrogen and total soil nitrogen content, none of which explained more than 3.6 percent of the variation in Douglas-fir basal area.

When the number of Douglas-fir trees and their average basal diameters were included in the multiple regression equation with relative density as a dependent variable, they accounted for seventy-eight of the eighty-two percent explained variation. Because of this they were excluded from a separate analysis in order to examine additional factors which might be important. This analysis indicated that almost eleven percent of the twenty-seven percent explained variation could be attributed to current Douglas-fir foliar nitrogen content with seven percent of the variation explained by aspect. Minor components having significant regression coefficients but accounting for less than four percent of the variation in Douglas-fir relative density include redstem ceanothus cover, deerbrush cover, vine maple cover and bulk density.

Only seventeen percent of the variation in the number of western hemlock trees could be explained by multiple regression. Burning disturbance accounted for almost one-half (8 percent) of the explained variation. Year old foliar nitrogen content, aspect, logging disturbance, snowbrush cover and bulk density explained three percent or less each.

Burning disturbance was also an important factor in explaining the variation in the basal area of western hemlock accounting for more than fourteen of the twenty-one percent total explained variation. Both the number of western hemlock and their basal area were negatively associated with burning. Almost four percent of the variation was attributed to aspect. Other variables in the equation accounting for less than two percent of the total explained variation are year old foliar nitrogen content, snowbrush cover and logging disturbance.

The Effects of Ceanothus Species and Vine Maple on Conifer Growth and Stocking

Because precise relations among shrub species, conifer growth and stocking and nitrogen were not clearly defined using multiple regression, t-tests were performed to determine the existence of more specific influences. The effects of competitive influences from *Ceanothus* species and vine maple are depicted in Table 5.

Douglas-fir average basal diameters were significantly larger on plots with than on plots without snowbrush, while just the opposite relation held with redstem ceanothus. Deerbrush and vine maple did not significantly influence Douglas-fir average basal diameters, though slightly higher average values were noted on plots

Table 5. Effect of shrub cover on Douglas-fir and western hemlock growth and stocking.

	Snowbrush		
	Plots without cover n=64	Plots with cover n=126	Significance
Douglas-fir	---------- $\bar{x}$	(SE)------------	
Average basal diameter[1]	4.46 (0.28)	5.76 (0.22)	**
Trees/ha	1030 (158)	867 (80)	NS
Basal area[2]	2.40 (0.40)	2.68 (0.24)	NS
Relative density[3]	5.13 (0.82)	5.33 (0.42)	NS
Western Hemlock			
Trees/ha	434 (135)	69 (16)	**
Basal area[2]	0.84 (0.20)	0.08 (0.04)	**

	Redstem ceanothus		
	Plots without cover n=72	Plots with cover n=118	Significance
Douglas-fir	---------- $\bar{x}$	(SE)------------	
Average basal diameter	5.87 (0.33)	4.98 (0.19)	*
Trees/ha	1011 (129)	868 (93)	NS
Basal area	3.76 (0.40)	1.92 (0.20)	**
Relative density	7.12 (0.76)	4.13 (0.39)	**
Western Hemlock			
Trees/ha	326 (93)	110 (52)	*
Basal area	0.60 (0.16)	0.16 (0.08)	*

	Deerbrush		
	Plots without cover n=170	Plots with cover n=20	Significance
Douglas-fir	---------- $\bar{x}$	(SE)------------	
Average basal diameter	5.39 (0.18)	4.74 (0.70)	NS
Trees/ha	980 (82)	428 (120)	**
Basal area	2.76 (0.24)	1.36 (0.36)	**
Relative density	5.59 (0.42)	2.49 (0.66)	**
Western Hemlock			
Trees/ha	No western hemlock trees were present on		
Basal area	plots with deerbrush cover.		

Table 5. cont.

	Vine maple Plots without cover n=35	Plots with cover n=155	Significance
Douglas-fir	---------- $\bar{x}$ (SE)	------------	
Average basal diameter	4.98 (0.48)	5.40 (0.19)	NS
Trees/ha	1105 (210)	881 (79)	NS
Basal area	2.72 (0.48)	2.56 (0.44)	NS
Relative density	5.58 (0.92)	5.19 (0.43)	NS
Western Hemlock			
Trees/ha	55 (28)	223 (58)	**
Basal area	0.20 (0.16)	0.36 (0.08)	NS

*,** significant at 5% and 1% level, respectively.
1 - measured in cm, 2 - m^2/ha, 3 - percent

containing vine maple than those without.

Fewer Douglas-fir occurred on sites with deerbrush, which were generally located on southern exposures or talus slopes. Most likely the larger number of trees occurring on sites without deerbrush cover indicate that conditions favoring Douglas-fir are different from those favoring deerbrush rather than suggestive of any competitive influence. The number of Douglas-fir trees was not affected by snowbrush, redstem ceanothus or vine maple cover.

Plots containing redstem ceanothus or deerbrush cover had lower Douglas-fir basal area and relative density than plots where cover was absent. In the case of deerbrush this is probably site related; since redstem ceanothus, however is quite prevalent throughout the study area, lower basal area and relative density values might be more reflective of a competitive interaction. Neither snowbrush nor vine maple influenced Douglas-fir basal area or relative density. It appears that though snowbrush is most important in terms of cover, redstem ceanothus exerts a greater influence on Douglas-fir growth.

More western hemlock trees and greater basal areas occurred on plots devoid of snowbrush and redstem ceanothus cover. Whether this was because of competitive impacts of these shrubs or site conditions cannot be determined from this analysis.

No western hemlock were found on plots containing deerbrush cover. Again, it is highly probable that this was because the environmental conditions on these sites are unfavorable and not because of competitive effects. Almost four times as many western hemlock occurred on plots with than on plots without vine maple. Both are residual species, appearing to prefer undisturbed sites and regosol soil types.

The Effects of Ceanothus Species and Vine Maple on Soil and Douglas-fir Foliar Nitrogen

Though average values of total soil nitrogen, mineralizable nitrogen and current foliar nitrogen levels of Douglas-fir were slightly higher on plots containing snowbrush, no differences were significant (Table 6). Similarly, there were no significant differences in total soil nitrogen, mineralizable nitrogen or current foliar nitrogen between plots with and without redstem ceanothus cover, however, Douglas-fir on plots with redstem had higher year old foliar nitrogen content.

Significantly lower soil nitrogen values (total and mineralizable) occurred on plots containing deerbrush. This does not necessarily imply a cause and effect relation however. Only twenty plots had deerbrush cover, often in only minute quantities. This limited sample size plus deerbrush's apparent affinity for southern exposures and more xeric habitat types, both exhibiting relatively low soil nitrogen values, is probably the most plausible explanation for the occurrence of low nitrogen levels associated with sites where deerbrush is present.

Greater amounts of mineralizable nitrogen occurred on plots with vine maple cover, perhaps because the relatively high nutrient contents of vine maple foliage stimulated decomposing organisms. However, where vine maple was present, Douglas-fir had lower current foliar nitrogen content.

Table 6. Effect of shrub cover on soil and foliar nitrogen content.

	Snowbrush		
	Plots without cover n=64	Plots with cover n=126	Significance
Soil	———— $\bar{x}$ (SE) ————		
Total soil nitrogen (%)	0.23 (0.02)	0.24 (0.01)	NS
Mineralizable-N (ug/g)	36.68 (3.30)	41.58 (3.22)	NS
Douglas-fir			
Current foliar-N (%)	1.12 (0.03)	1.17 (0.02)	NS
Year old foliar-N (%)	1.09 (0.03)	1.09 (0.02)	NS

	Redstem ceanothus		
	Plots without cover n=72	Plots with cover n=118	Significance
Soil	———— $\bar{x}$ (SE) ————		
Total soil nitrogen (%)	0.24 (0.02)	0.24 (0.01)	NS
Mineralizable-N (ug/g)	41.12 (3.49)	39.21 (3.25)	NS
Douglas-fir			
Current foliar-N (%)	1.12 (0.03)	1.18 (0.02)	NS
Year old foliar-N (%)	1.05 (0.02)	1.11 (0.03)	.10

	Deerbrush		
	Plots without cover n=170	Plots with cover n=20	Significance
Soil	———— $\bar{x}$ (SE) ————		
Total soil nitrogen (%)	0.25 (0.01)	0.18 (0.01)	**
Mineralizable-N (ug/g)	41.67 (2.63)	25.12 (3.66)	**
Douglas-fir			
Current foliar-N (%)	1.16 (0.20)	1.10 (0.07)	NS
Year old foliar-N (%)	1.09 (0.02)	1.10 (0.06)	NS

	Vine maple		
	Plots without cover n=35	Plots with cover n=155	Significance
Soil	———— $\bar{x}$ (SE) ————		
Total soil nitrogen (%)	0.23 (0.03)	0.24 (0.01)	NS
Mineralizable-N (ug/g)	29.78 (4.25)	42.22 (2.76)	*
Douglas-fir			
Current foliar-N (%)	1.22 (0.04)	1.14 (0.02)	.10
Year old foliar-N (%)	1.08 (0.04)	1.09 (0.02)	NS

*,** significant at 5% and 1% level, respectively.

DISCUSSION

Response of Shrub and Tree Species to Site Factors

Results from both analysis of variance and multiple regression suggest site factors are important determinants of both conifer growth and stocking and shrub cover. While many of the site factors individually (analysis of variance) exerted a significant influence, in general no more than one or two of the five site variables included in each multiple regression equation accounted for a relatively large portion of the total explained variation in conifer growth or stocking. Although inferences from multiple regression analysis concerning the potential relationships between conifer growth and stocking and the various independent variables may be made, they should be interpreted with caution. Problems inherent in the data include the presence of zeroes, the use of dummy variables and the likelihood of multicollinearity among several of the variables, all of which may effect the results. The presence of zero values associated with shrub cover or the existence of tree species on a particular plot can denote the absence of a species because of unfavorable growing conditions, mortality, competition or chance, however, there is no way of discerning from the data alone the reason for a zero value. The employment of allocated codes for the five site factors implies equal distances between the various graduated classifications which does not necessarily hold true in an ecological sense. This does however lend itself to detection of positive or negative associations between conifer growth and stocking and site factors which may be more fully explored in future studies.

Multicollinearity is most notably exhibited upon examination of Pearson correlation coefficients which showed twenty-two significant paired associations among the fourteen site factors, nitrogen and shrub cover variables used in the multiple regression equations. High correlations among the independent variables tend to make the estimated regression coefficients imprecise but this is generally not a problem when only inferences about a specific data set are being made (Neter and Wasserman, 1974).

Following slash burning, Dyrness found eleven percent of the plots to be undisturbed, thirty-two percent disturbed-unburned, forty-eight percent lightly burned and nine percent severely burned. These values are comparable to those found by Tarrant (1954) and Dyrness and Youngberg (1957) for corresponding burning disturbance classes. Although thirteen to sixteen years have passed since Watersheds 1 and 3 were clear-cut and burned, effects due to harvesting are still evident. Residuals such as vine maple and western hemlock were not very tolerant to slash burning, while invading Ceanothus species were more prevalent on sites which were burned. On Watershed 3 snowbrush cover has increased dramatically since disturbance, reaching a maximum coverage of 23.7 percent in 1972 followed by an abrupt decline (Figure 11.). Vine maple has almost returned to predisturbance levels. When broken down by burning disturbance classes (Figure 12.), snowbrush is still seen to flourish on disturbed and burned sites although its dominance on these sites is beginning to decrease, while vine maple has only attained one-half to two-thirds of its original coverage on these sites.

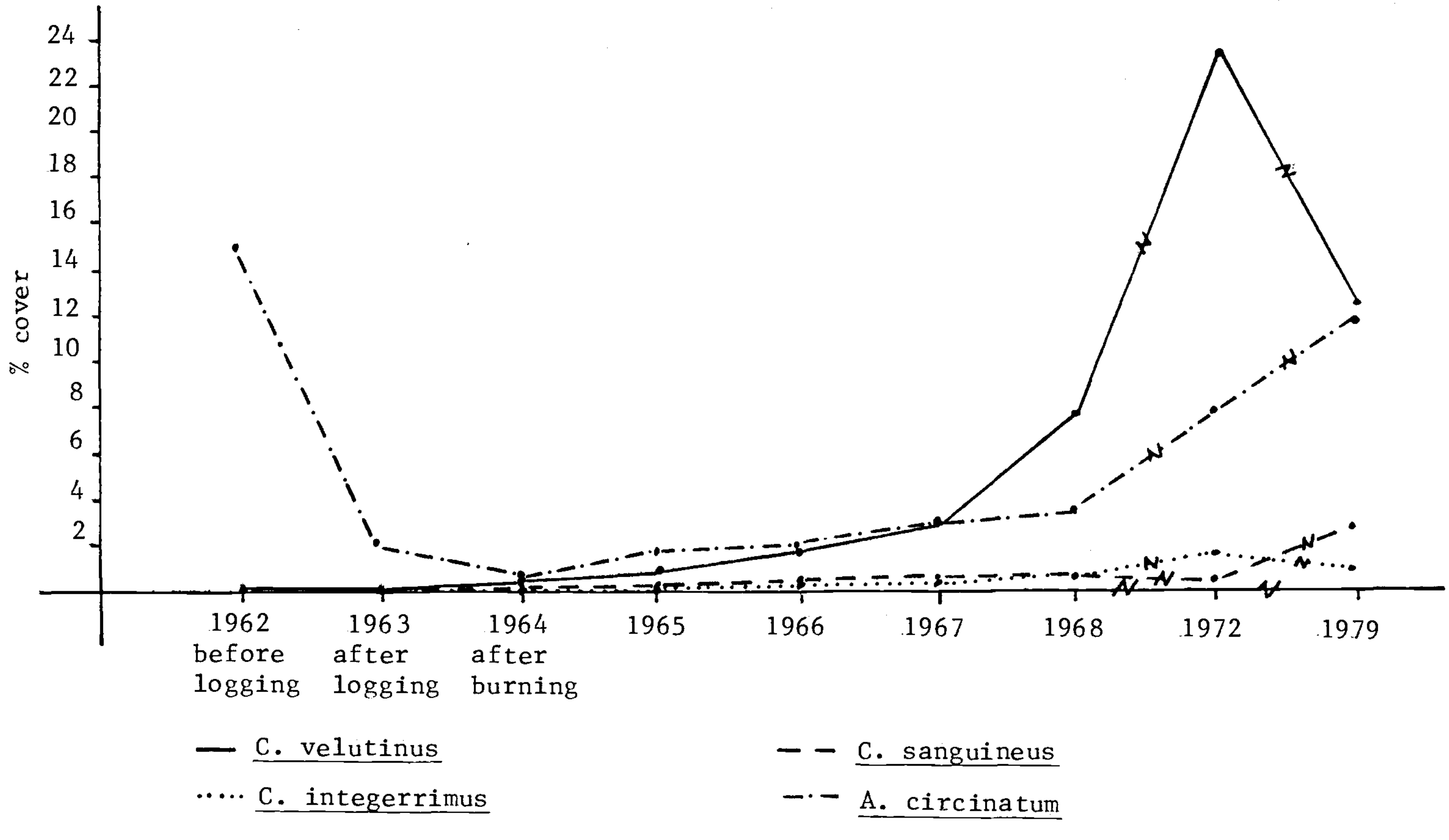

Figure 11. Development of Ceanothus spp. and A. circinatum cover on Watershed 3.

* All values except 1972 and 1979 from Dyrness (1973)

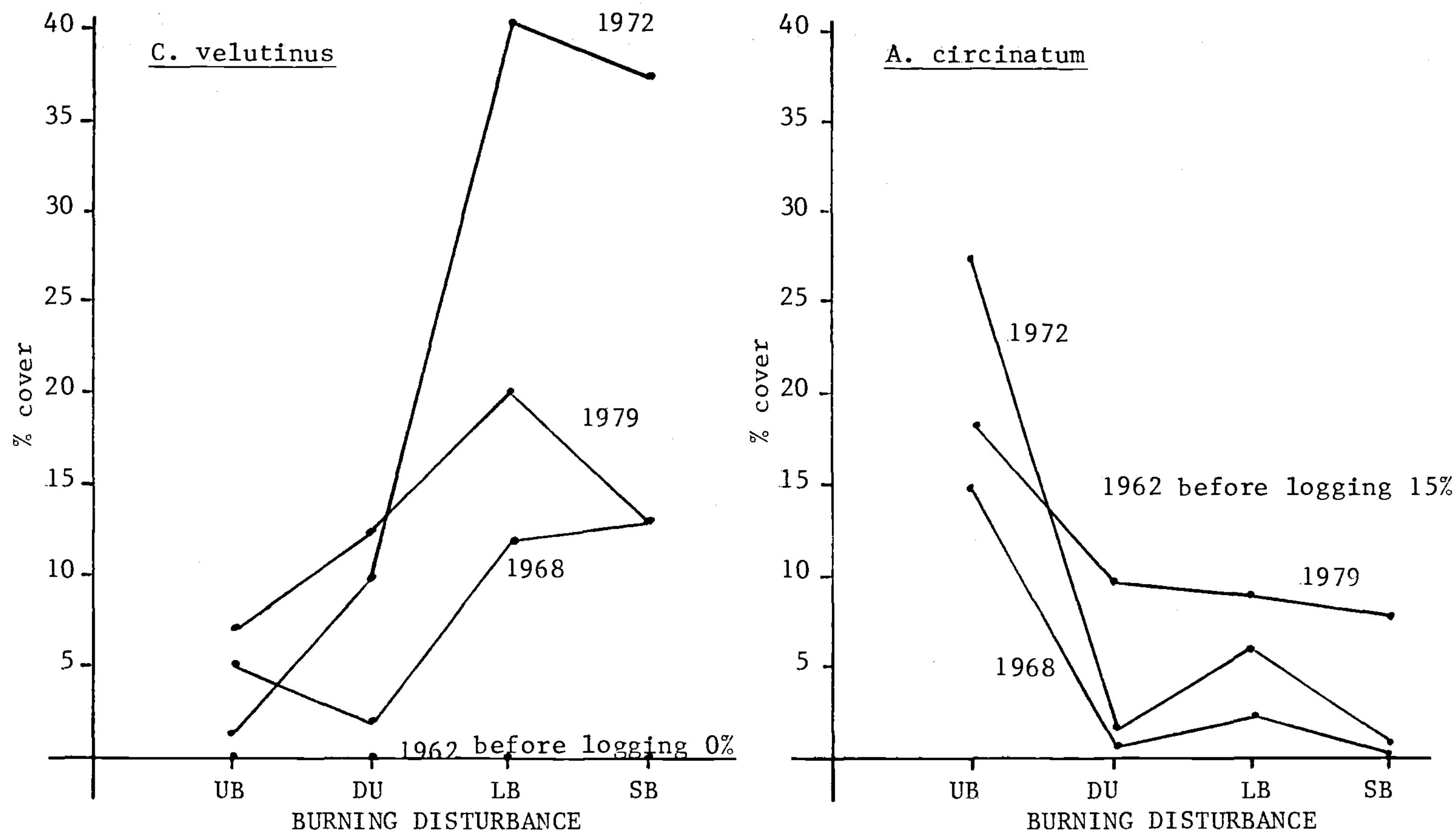

Figure 12. Changes in percent cover of invading C. velutinus and residual A. circinatum by burning disturbance classes on Watershed 3.

* 1962 and 1968 values from Dyrness (1973)

Douglas-fir had a mixed response to burning. Greatest numbers of trees with correspondingly largest basal areas and highest relative densities were associated with undisturbed sites, though greatest average basal diameters and second highest values for stocking, basal area and relative density occurred on severely burned sites. This dichotomy could be attributed to several factors. The importance of interrelationships with other site factors and vegetation probably plays a key role in determining both species distribution and growth. For example, almost one-half of the severely burned plots were located on NNE aspects, which contained the greatest number of Douglas-fir trees, while only one of the sixteen severely burned plots occurred on talus slopes, which were associated with the lowest Douglas-fir growth and stocking values. Even though severe burning has been found to at least temporarily alter various soil properties, often in a detrimental way (Tarrant, 1956a, 1956b; Morris, 1958; Dyrness and Youngberg, 1957), the favorable moisture regime of northern exposures, along with more developed lateritic and regosol soil types and perhaps coupled with the temporary increase in soluble nutrients following slash burning (Grier and Cole, 1971) may off-set the initial influence of severe burning. Recalling the joint effects of burning and habitat type on the number of Douglas-fir, their basal area and relative density (Figures 7b, 8b, 9b.), plots that were severely burned could support high values when located in moderate to mesic communities suggesting the effects of burning may also be partially ameliorated under more mesic conditions.

Lack of competition in the initial stages of stand development may also contribute to the relative success of Douglas-fir on severely burned sites. Although considerable snowbrush and redstem ceanothus cover occurred on these sites in 1979, cover on the severely burned plots of Watershed 3 was initially low following slash burning and consistently lagged behind the other burning disturbance classes (Dyrness, 1973). Even five seasons after slash burning, few shrub and tree species occurred on these sites. Tarrant and Wright (1955) found that in the first two years of growth naturally occurring Douglas-fir seedlings were not hindered by slash burning, and Morris (1958) observed no significant differences in conifer stocking between burned and unburned sites.

Similarly, high values for the number, basal area and relative density of Douglas-fir on sites undisturbed by burning may be at least partially due to site, rather than lack of disturbance. All of the twenty-one plots undisturbed by burning occurred on regosols, and more than two-thirds of these were located on NNE exposures.

In contrast to Douglas-fir, western hemlock is adversely affected by burning, even on favorable sites. Wierman and Oliver (1979) reported evidence of suppression of western hemlock by Douglas-fir in naturally seeded stands at about twenty years. While competition cannot be discounted on the few more populated sites, low Douglas-fir relative densities suggest that it is not a prevailing factor accounting for the small numbers of western hemlock trees on all but undisturbed sites. Positive correlations between Douglas-fir and western hemlock growth and stocking indicate the general absence of interspecific competition.

Drought and associated high moisture is a common occurrence on the study area with only about ten percent of annual precipitation occurring during the growing season. Brix (1979) observed poorer western hemlock survival when compared to Douglas-fir under drought conditions following field planting. Western hemlock in general is known to frequent the moderate to mesic end of the moisture gradient. While mesic habitat types exist on these watersheds, increased soil and air temperatures and associated high evaporative demand, once partially ameliorated by the overstory canopy, may have restricted greater establishment by western hemlock. Seedlings which may have been present in the original stand could also have been eliminated or reduced by solarization or burning. The possibility of a poor seed source, whether due to unfavorable seed years, ineffective dissemination or consumption by animals cannot be completely discounted either.

Poor western hemlock growth has also been associated with phosphorus deficiences by Heilman and Ekuan (1980a). Low phosphorus values were found to be inherent on many of the highly acid soils in the Pacific Northwest since most of the phosphorus was tied up in relatively insoluble iron and aluminum compounds (Tarrant et. al., 1951). Problems with phosphorus deficiencies following slash burning were noted in Daniel and others (1979) and by Heilman and Ekuan (1980b) and Smith (1970) who attributed the decreased solubility of phosphorus in soil following burning to its precipitation with aluminum and iron. That nutrient deficiencies may persist for extended times following logging and slash burning was evidenced by Perry and

and others (1984) who found that ten years after harvesting, pot-grown Douglas-fir seedling growth to be limited by chelated iron in soil from sites which were broadcast-burned.

Prelogging habitat type and aspect appear to be slightly more influential than soil type in determining conifer growth and establishment as well as the distribution of shrub cover in this stage of succession. Greatest Ceanothus cover was generally associated with moderate to xeric communities and on southerly and westerly aspects, agreeing with observations of Zavitkovski and Newton (1968). The distribution of vine maple closely resembled that reported for Watershed 3 five years after slash burning (Dyrness, 1973); highest cover is still found on Acci/Bene communities and low values on Cola habitat types. The proportion of vine maple cover on Rhma/Gash and Acci/Gash communities increased with time and lowest cover now occurs in Coco/Gash communities.

The greatest western hemlock development occurred in mesic Cola communities, corresponding to Dyrness' (1973) earlier findings. Others have found western hemlock to prefer NNE exposures (Issac, 1940; Minore and Dubrasich, 1981). Western hemlock was almost totally excluded from all sites except those on NNE exposures, mesic habitat types and areas unaffected by burning. Franklin and Dyrness (1973) reported that significant invasion by hemlock did not occur on some sites for fifty to one hundred years following disturbance. Apparently conditions on Watersheds 1 and 3 are such to severely limit western hemlock establishment following clear-cutting and slash burning at least during these early stages of succession.

Five years following slash burning, the greatest percent Douglas-fir cover was associated with Cola communities (Dyrness, 1973). While Douglas-fir still seems favored on this habitat type, it did almost equally well on the more xeric Rhma/Gash and Acci/Gash communities. Douglas-fir has been noted to have comparable importance values in both ends of the moisture gradient in the <u>Tsuga heterophylla</u> zone (Dyrness et. al., 1976). In the <u>Abies amabilis</u> zone, Sullivan (1978) found distinct differences between habitat types in stocking potential after clear-cutting. Low growth parameters exhibited by Douglas-fir in Pomu and Acci/Bene communities are apparently due to site factors other than moisture.

WNW and level exposures favored Douglas-fir diameter growth, while NNE aspects were most suited for survival and establishment. Lowry and Youngberg (1955) also found excellant Douglas-fir survival following burning on northerly exposures. Even at generally low relative densities, intraspecific competition has been noted by Perry (unpublished) which might account for the lowest Douglas-fir mean basal diameters on the most densely stocked NNE exposures.

Though there were differences in shrub cover values and conifer growth and stocking among the various soil associations, in many cases they were nonsignificant, suggesting that soil characteristics may not be important until later in succession. In general, more developed regosols and laterites were preferred by both shrub and tree species. Only deerbrush had highest cover values associated with talus slopes, though redstem ceanothus also occurred on these areas.

Douglas-fir Stocking

The origin of the Douglas-fir planting stock is not known but it was not necessarily from the immediate area. It has long been recognized that large genetic variation in morphological and physiological characteristics can exist among populations or even within individuals within populations, including differences in drought tolerance, frost resistance, nutrient relations and growth characteristics (Perry, 1978). This suggests the possibility that the planting stock was not matched to the site, which might in part be responsible for the low relative densities. Campbell (1979) found surprisingly large genetic differentiation in Douglas-fir seedling growth traits though seed collection was limited to the H. J. Andrews, suggesting that even if a localized seed source was used, there could be a mismatch with the particular habitat it was planted in.

Initial planting densities were probably somewhere around 1500 to 2000 trees per hectare (personal communication, David A. Perry). Density on the combined watersheds in 1979 averaged only 920 trees per hectare. While this value is comparable to Binkley and Husted's (1983) of 900 Douglas-fir saplings per hectare, and within the range suggested by Miller and others (1976) to fulfill most management objectives, relative density figures indicate it is strikingly low relative to the size of the trees. The mean relative density on combined Watersheds 1 and 3 is only slightly more than five percent, ie. only about five percent as many trees are present as would be necessary to achieve full site occupancy according to the diameter size classes present on the watersheds. The non-significance of the correlation coefficient between average basal diameter and Douglas-fir stocking (-.03) suggests that very little intraspecific competition is occurring. Mortality can more likely be attributed to adverse site conditions, interspecific competition or poorly adapted planting stock. Only ten plots had more than 3600 trees per hectare. All of these were on regosol soil types and most were on northern aspects and in mesic habitat types. They were also on the edge of the clear-cut adjacent to old growth stands. These site factors appear conducive not only to survival of planted seedlings but natural regeneration as well, as evidenced by numerous saplings younger than the age of the clear-cuts.

Relation Between Shrub Species and Nitrogen Content

With few exceptions, site factors were not important influences of either soil or Douglas-fir foliar nitrogen content. Total soil nitrogen was significantly affected by soil association with regosols containing the least total nitrogen. Reasons for these low values were not readily apparent but might in part be due to differing parent materials, other site factors which might affect decomposition, uptake and storage by vegetation as well as sampling dates. Though not significant, plots on regosol soil types also contained the lowest mineralizable nitrogen values as well as the greatest number of Douglas-fir and western hemlock trees. Aspect exerted a slight influence on mineralizable nitrogen with level and WNW exposures apparently favoring soil nitrogen accumulation perhaps reflecting the quality and quantity of litter available, favorable conditions for decomposition or inherent site fertility. As was found by McNabb and others (1978) in a separate study on the H. J. Andrews, no significant differences in mineralizable nitrogen occurred among the various habitat types. Douglas-fir current year foliar nitrogen however, varied slightly among the various communities. Figure 13. shows a tendency for an inverse relation between Douglas-fir mean basal diameter and its corresponding current foliar nitrogen content perhaps indicating nitrogen stress during the growing season.

For the most part, neither soil nor Douglas-fir foliar nitrogen content were directly related to any of the three Ceanothus species present on Watersheds 1 and 3. Year old Douglas-fir foliage showed a slightly higher nitrogen content on plots with redstem cover but the significance only existed at the ten percent level. While there were significant differences in soil nitrogen levels between sites with and without deerbrush cover, these lower values are likely due to more severe site conditions rather than the presence of deerbrush.

Problems inherent in the sampling procedures might have obscured nitrogen relationships. Studies finding significant increases in foliar or soil nitrogen associated with Ceanothus have usually compared samples from within, at the edge of and outside Ceanothus stands (Scott, 1969; Binkley and Husted, 1983). In this study, soil and needle samples were taken as close to Dyrness' original plots as possible but the position of the samples relative to Ceanothus was not noted. Also samples were collected throughout the growing season and as previously mentioned, both soil and needle nitrogen may vary

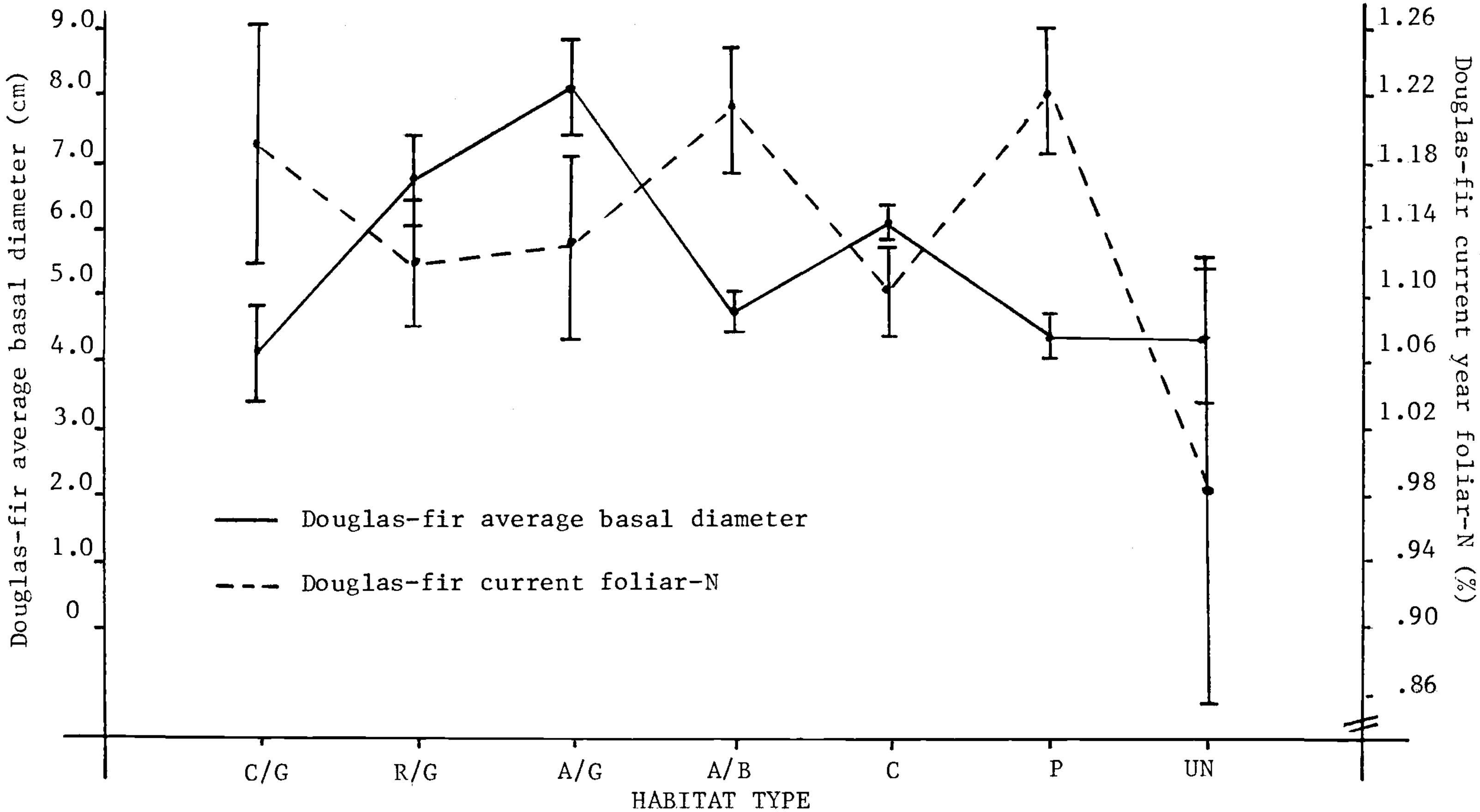

Figure 13. Relation between Douglas-fir average basal diameter and current year foliar-N among the communities on Watersheds 1 and 3. (Mean ± std. error)

throughout the year.

It is also possible that even if sampling procedures had been modified, Ceanothus would still not be seen to significantly influence nitrogen levels. Old growth Douglas-fir present on these sites before logging ranged in age from one hundred to five hundred years, the older age classes being more common. Wollum and others (1968) found nodulation of snowbrush to be inversely proportional to its period of absence from the stand, with poor nodulation where conifer stands were older than one hundred years. Assuming satisfactory nodulation, nitrogen fixation can be limited by temperature extremes or deficiencies in minor essential elements such as cobalt, iron or especially molybdenum, as well as high soil nitrogen levels (Wollum, 1962; Stewart, 1966). Nitrogen can also be stored in Ceanothus biomass, with greater quantities made available by mortality and decomposition of shrub tissue. Total soil nitrogen on Watersheds 1 and 3 averaged .24 percent which is more than double the .1 percent considered by Gessel and others (1960, cited in Scott, 1969) sufficient to avert nitrogen deficiencies in Douglas-fir. Zavitkovski and Newton (1968) indicated that while nitrogen fixation rates by snowbrush can be consequential on infertile soils, they seem unlikely to occur on sites of moderate to better fertility. Binkley and others (1982), however, found substantial nitrogen fixation to occur even on highly fertile sites.

The functional lifespan of snowbrush in the Cascades is thought to be between twenty and forty years (Franklin, 1982). That of redstem ceanothus and deerbrush is most likely comparable. These stands may be already becoming decadent due to snow damage, unseasonable killing frosts (personal communication, Kermit Cromack, Jr.) and reduced light levels from overtopping vegetation. Watershed 3 snowbrush cover has decreased by more than fifty percent from 1972 to 1979. Youngberg and others (1979) found that the nitrogen fixation rates of snowbrush can decrease substantially after the first decade.

Relation Between Conifer Species and Nitrogen Content

Previous studies have indicated that correlations do exist between foliar nitrogen content as percent dry weight and tree growth as well as soil nitrogen levels. Mitchell and Chandler (1939) found that eastern deciduous tree growth was related to both leaf nitrogen concentration and soil nitrogen content in accordance with the law of diminishing returns. Fertilization increased foliar nitrogen, height, and volume growth of Douglas-fir (Heilman and Gessel, 1963). In nutrient deficient soils, a positive relation exists between soil nutrient levels, nutrient concentration in foliage, and growth of Scots pine, Sitka spruce and Japanese larch (Leyton and Armson, 1955; Leyton, 1954, cited in Leyton and Armson, 1955; Leyton, 1956; Leyton, 1957). Everard (1973) noted that mean height of Sitka spruce at six years correlated with foliar nitrogen content and both Scott (1969) and Brix (1971) found that nitrogen concentration of conifers increased with levels of soil fertility, whether due to fertilization or symbiotic nitrogen fixation.

Total soil nitrogen was not highly correlated with any of the conifer growth and stocking measurements in this study. Because only a small proportion of total soil nitrogen is available to plants, measures such as mineralizable nitrogen or plant nitrogen content more accurately reflect site nitrogen status (e.g. Powers, 1980). Mineralizable nitrogen positively correlated with the average basal diameter, basal area and relative density of Douglas-fir, and with the number of western hemlock trees, suggesting that levels of available nitrogen are more important to tree establishment and growth than total amounts present in the soil. This is consistent with Shumway and Atkinson (1977), who reasoned that if a good growth response by Douglas-fir could occur over a wide range of total soil nitrogen levels, then only a portion of total nitrogen is available for plant growth and this portion can vary by site.

Leyton (1956) suggested that the presence of a significant positive correlation coefficient between growth parameters and nutrients was evidence for a deficiency in that nutrient. While total nitrogen in the soils appears adequate for Douglas-fir nutrition, the amount of available nitrogen might be limiting. Mineralizable nitrogen averaged 40 ug/g on the watersheds, lower than the soil nitrogen availability index of 66 - 116 ug/g found by Binkley and others (1982) to be present on a neighboring young clear-cut in the H. J. Andrews. Shumway and Atkinson (1977) observed no significant growth response of Douglas-fir when mineralizable nitrogen was greater than 44 ug/g. The relatively low values found here might in part be attributed to using the top 5 to 7 cm of soil. Keeney and Bremner (1966) found mineralizable nitrogen to be underestimated when surface soil was used, due to the possibility of undecomposed organic material rising to the surface of the soil suspension during incubation resulting in both aerobic and anaerobic conditions within the incubation jar.

Nitrogen values for current and year old Douglas-fir foliage averaged 1.16 and 1.09 percent respectively. According to Gessel and others (1960, cited in Scott, 1969) a Douglas-fir needle nitrogen content of .6 percent dry weight is associated with severe deficiency, at 1.1 - 1.2 percent, deficiency symptoms are no longer visible, and optimum growth is reached at about 1.6 percent nitrogen. Though these values fall within the range found by Waring and Youngberg (1972) in the Siskiyou Mountains of southwestern Oregon, who assumed a critical level of at least 1.2 percent to be necessary for sustaining maximum growth of Douglas-fir during periods of maximum development, they are well below the critical levels of 1.6 to 1.7 percent estimated by Gessel and others (1960, cited in Scott, 1969) and Van Den Driessche (1969, cited in Waring and Youngberg, 1972). The negative correlations found between tree growth and stocking and foliar nitrogen suggest that, even at these relatively low stocking levels, Douglas-fir are competing among themselves for nitrogen. Competition for available nitrogen can occur between conifers, other vegetation and heterotrophs as well.

Apparent Niches of Ceanothus Species and Vine Maple

The three *Ceanothus* species could be differentiated based on the effects of site factors and their relations to conifer growth. Snowbrush had the highest cover values of the three species. Although fairly widespread, it prefers burned sites. Maximum coverage occurred on Rhma/Gash communities, though fairly high amounts were also present on moderately moist Acci/Gash and Acci/Bene habitat types. In general, on these watersheds, snowbrush does not achieve substantial development in communities representing moisture extremes, as evidenced by lowest cover on xeric Coco/Gash communities and relatively low cover on mesic Cola and Pomu habitat types. Maximum snowbrush cover occurred on lateritic soil types. Aspect limited snowbrush only on northern and level exposures. The presence of this species was not observed to directly affect either foliar or soil nitrogen content on these watersheds at this stage of community development. Though sometimes thought to be an effective competitor with Douglas-fir, it was not seen to be so here, if anything, it appears to enhance average basal diameter growth. The apparently negative effect snowbrush has on western hemlock is more likely due to the two species having different site requirements for optimum development rather than competition.

Redstem ceanothus had slightly less coverage than snowbrush, and its distribution appeared more dependent on burning. Compaction inhibited redstem cover, while apparently not affecting snowbrush. Highest redstem ceanothus cover was associated with xeric Coco/Gash communities, though considerable cover was found to exist in more moderate and mesic communities. Rhma/Gash and Cola habitat types exhibited lowest cover. Maximum establishment occurred on regosols though, unlike snowbrush, development was not limited on talus slopes. Strikingly low amounts of cover were found on lateritic soils where snowbrush apparently flourishes. Whether this could be attributed to snowbrush competition, some inherent adaption of redstem to less developed soils, or coincidence is hard to say. ESE aspects were favored with less than half as much cover occurring on other exposures. Like snowbrush, lowest values were associated with NNE and level aspects.

Redstem ceanothus affected neither soil nitrogen levels nor current Douglas-fir foliar nitrogen levels, though slightly higher year old foliar nitrogen content occurred on plots containing redstem ceanothus. While not affecting the number of Douglas-fir, significantly lower basal diameters, basal areas and relative densities were found on plots containing redstem, suggesting that it may be a competitor on these sites. Its effects on western hemlock are attributed to the same factors as those of snowbrush.

Very low levels of deerbrush were present on these sites. Whether its limited occurrence was due to unfavorable site conditions or to factors such as poor seed source or grazing was not readily apparent. Of all the Ceanothus species on this study area, it is the most site specific, showing a marked preference for slightly disturbed and lightly burned areas, moderate to xeric habitat types, talus slopes and SSW exposures, and being almost virtually excluded from all other sites. Apparent differences in various site requirements of the three Ceanothus species appears to insure not only co-existence, but maximum site coverage by this genus.

Deerbrush did not affect levels of foliar nitrogen. Though soil nitrogen was lower on plots containing this species, this is probably related to the generally harsher environment associated with these sites, rather than the influence of the shrub itself. Similarly, reduced stocking and size of Douglas-fir and the absence of western hemlock on plots with deerbrush cover is probably due to limiting site factors rather than competition, although site factors and competition are likely to interact.

Vine maple was the only residual shrub species studied because of its ubiquitous nature and the relatively high foliar nitrogen content associated with this species. The effects of slash burning are still prevalent though almost twenty years have passed since the original disturbance. Almost twice as much cover was associated with sites undisturbed by burning than on any other disturbance class. Although present on all habitat types, maximum coverage appeared to be centered on Rhma/Gash, Acci/Gash and Acci/Bene communities. Vine maple was unaffected by variations in soil type or aspect, though regosols seemed to be slightly preferred. Higher mineralizable nitrogen levels were found on plots where vine maple was present, indicating perhaps the enhancing effects of its nitrogen rich litter (Gholtz, manuscript in prep.). Current Douglas-fir foliar nitrogen content was slightly (.10 percent) lower on sites with vine maple but not year old foliage. This may indicate competition between vine maple and Douglas-fir for available nitrogen. Though vine maple was widespread and frequently had high cover values, it did not influence Douglas-fir stocking or development. Significantly greater numbers of western hemlock, however, occurred on plots containing vine maple. Whether this is an example of beneficial effects accruing from vine maple or the preference of both vine maple and western hemlock for sites undisturbed by burning and regosol soil types or a combination of the two, was not readily discernable.

SUMMARY AND CONCLUSIONS

The confounding effects of interrelationships among both measured and unmeasured variables are often of great magnitude. Though empirical relations can be discerned, these are for the most part hypothetical and their significance remains to be seen.

In summation, though effects from logging and burning are still apparent, factors such as prelogging habitat type, aspect and soil association are becoming increasingly important in determining the distribution of shrub cover as well as the growth and establishment of Douglas-fir and western hemlock.

Redstem ceanothus was an effective competitor, apparently limiting the development of Douglas-fir. More attention should be focused on it than has been in the past.

The three Ceanothus species and vine maple differed in their responses to site factors and their effects on conifer growth and establishment. Ceanothus was not in general found to be associated with increased nitrogen nutrition.

Site factors and shrub cover affected Douglas-fir stocking and growth in different ways, indicating that extrapolation of results from short term growth studies must be done with caution when used to interpret field studies.

Relatively low foliar nitrogen levels and positive correlations between mineralizable nitrogen and the average basal diameter, basal area and relative density of Douglas-fir as well as the number of western hemlock, suggests at least during the growing season, the possibility of nitrogen limiting Douglas-fir. Since total soil nitrogen supplies appear to be adequate, it is likely that other factors are responsible for reducing nitrogen availability and/or uptake.

The limited distribution of western hemlock, while partially attributed to unfavorable environmental factors, could possibly be indicative of a disturbance induced phosphorus deficiency. If this is the case, it argues strongly that the effects of harvesting and slash burning have yet to subside.

REFERENCES

Anderson, H. G. 1969. Growth form and distribution of vine maple (Acer circinatum) on Marys Peak, Western Oregon. Ecol. 50(1): 127-130.

Austin, R. C. and D. H. Baisinger. 1955. Some effects of burning on forest soils of Western Oregon and Washington. J. For. 53: 275-280.

Banwart, W. L., M. A. Tabatabai and J. M. Bremner. 1972. Determination of ammonium in soil and water samples by an ammonia electrode. Comm. in Soil Science and Plt. Anal. 3(6): 449-458.

Binkley, D., K. Cromack Jr. and R. L. Fredriksen. 1982. Nitrogen accretion and availability in some snowbrush ecosystems. For. Sci. 28(4): 720-724.

Binkley, D. and L. Husted. 1983. Nitrogen accretion, soil fertility, and Douglas-fir nutrition in association with redstem Ceanothus. Can. J. For. Res. 13: 122-125.

Brix, H. 1971. Effects of N fertilization on photosynthesis and respiration in Douglas-fir. For. Sci. 17: 407-414.

Brix, H. 1979. Effects of plant water stress on photosynthesis and survival of 4 conifers. Can. J. For. Res. 9(2): 160-165.

Brown, G. W. 1976. The impact of timber harvest on soil and water resources. Oregon State University Extension Service, Extension Bulletin 827. 17p.

Cairns, J. Jr. 1980. The recovery process in damaged ecosystems. Ann Arbor Science, Michigan. 167p.

Campbell, R. K. 1979. Genecology of Douglas-fir in a watershed in the Oregon Cascades. Ecol. 160(5): 1036-1050.

Conard, S. G., A. E. Jaramillo, K. Cromack Jr. and S. Rose. 1982. The role of the genus Ceanothus in western forest ecosystems. Proceedings of a workshop held November 22-24 at Oregon State University, Corvallis, OR. 110p.

Daniel, T. W., J. A. Helms and F. S. Baker. 1979 Principles of silviculture. McGraw-Hill, New York. 2nd edition. 500p.

DeBano, L. F. 1966. Formation of non-wettable soils involves heat transfer mechanism. Pac. S. W. Forest and Range Exp. Stn. Res. Note PSW-132. 8p.

DeByle, N. V. and P. E. Packer. 1972. Plant nutrient and soil losses in overland flow from burned forest clearcuts. p. 296-307. In: Watersheds in Transition. Proc. Amer. Water Resources Assoc.

Delwiche, C. C. and J. Wijler. 1956. Non-symbiotic nitrogen fixation in soil. Plant and Soil. 7(2): 113-129.

Delwiche, C. C., P. J. Zinke and C. M. Johnson. 1965. Nitrogen fixation by Ceanothus. Plt. Physiol. 40: 1045-1047.

Dyrness, C. T. 1960. Soil-vegetation relationships within the Pinus ponderosa type in the Central Oregon pumice region. Ph. D. Thesis. OSU, Corvallis, OR. 217p.

Dyrness, C. T. 1973. Early stages of plant succession following logging and burning in the Western Cascades of Oregon. Ecol. 54(1): 57-69.

Dyrness, C. T. 1965a. Soil surface conditions following tractor and highlead logging in the Oregon Cascades. J. For. 63(4): 272-275.

Dyrness, C. T. 1965b. The effect of logging and slash burning on understory vegetation in the H. J. Andrews Experimental Forest. USDA For. Serv. Res. Note PNW-31. 13p.

Dyrness, C. T., J. F. Franklin and W. H. Moir. 1976. A preliminary classification of forest communities in the Central Portion of the Western Cascades in Oregon. Coniferous Forest Biome. IBP-Bulletin No. 4. Univ. of WA, Seattle. 123p.

Dyrness, C. T. and C. T. Youngberg. 1957. The effect of logging and slash burning on soil structure. Soil Sci. Soc. of Amer. Proc. 21(4): 444-447.

Dyrness, C. T. and C. T. Youngberg. 1966. Soil-vegetation relationships within the Ponderosa pine type in the Central Oregon pumice region. Ecol. 47(1): 122-138.

Everard, J. 1973. Foliar analysis sampling: methods, interpretation and application of results. Quat. J. For. 67: 51-66.

Foster, H. D. 1912. Interrelation between brush and tree growth of the Crater National Forest, Oregon. Soc. Am. For. Proc. 7: 212-225.

Franklin, J. F. 1979. Vegetation of the Douglas-fir region. p. 93-112. In: P. E. Heilman, H. W. Anderson and D. M. Baumgartner (eds). Forest soils of the Douglas-fir region. Washington State University. Cooperative Extension Serv. Pullman, WA. 298p.

Franklin, J. F. 1982. The importance of Ceanothus species in U. S. forest ecosystems. p. 6-32. In: S. G. Conard, A. E. Jaramillo, K. Cromack Jr. and S. Rose. The role of the genus Ceanothus in western forest ecosystems. Proceedings of a workshop held Nov. 22-24, 1982. Oregon State University. Corvallis, OR. 110p.

Franklin, J. F. and C. T. Dyrness. 1973. Natural vegetation of Oregon and Washington. U.S. For. Serv. Gen. Tech. Rep. PNW-8. 417p.

Fredriksen, R. L. 1971. Comparative water quality - natural and disturbed streams. In: Symposium on forest land uses and stream environment. Oregon State University. Corvallis, OR.p. 125-138.

Gessel, S. P., K. J. Turnbull and F. T. Tremblay. 1960. How to fertilize trees and measure responses. Wash. D.C. National Plt. Food Institute. 67p.

Gessel, S. P., D. W. Cole and E. C. Steinbrenner. 1973. Nitrogen balances in forest ecosystems of the Pacific Northwest. Soil. Biol. Biochem. 5: 19-34.

Gratkowshi, H. and P. Lauterbach. 1974. Release of Douglas-fir from varnishleaf Ceanothus. J. For. 72(3): 150-152.

Grier, C. C. and D. W. Cole. 1971. Influence of slash burning on ion transport in a forest soil. N. W. Sci. 45(2): 100-106.

Harmsen, G. W. and G. J. Kolenbrander. 1965. Soil inorganic nitrogen. p. 43-92. In: W. V. Bartholomew and F. E. Clark (eds). Soil nitrogen. Agronomy 10. Amer. Soc. of Agron. Inc. Madison, Wisc. 615p.

Harr, D. R. 1976. Forest practices and streamflow in Western Oregon. U.S. For. Serv. Gen. Tech. Rep. PNW-49. 18p.

Heilman, P.E. and G. Ekuan. 1980a. Phosphorus response of western hemlock seedlings on Pacific coastal soils from Washington. Soil Sci. Soc. Amer. J. 44(2): 392-395.

Heilman, P. E. and G. Ekuan. 1980b. Effects of phosphorus on growth and mycorrhizal development of Douglas-fir in greenhouse pots. Soil Sci. Soc. Am. J. 44: 115-119.

Heilman, P. E. and S. P. Gessel. 1963. The effect of nitrogen fertilization on the concentration and weight of nitrogen, phosphorus and potassium in Douglas-fir trees. Soil Sci. Soc. Am. Proc. 27: 102-105.

Hellmers, H. and J. M. Kelleher. 1959. Ceanothus leucodermis and soil nitrogen in southern California mountains. For. Sci. 5(3): 275-278.

Howard, R. F. and M. J. Singer. 1981. Measuring forest soil bulk density using irregular hole, paraffin clod and air permeability. For. Sci. 27(2): 316-322.

Issac, L. A. 1940. Vegetation succession following logging in the Douglas-fir region with special reference to fire. J. For. 38: 716-721.

Issac, L. A. and H. G. Hopkins. 1937. The forest soil of the Douglas-fir region and changes wrought upon it by logging and slashburning. Ecol. 18(2): 264-279.

Keeney, D. R. and J. M. Bremner. 1966. Comparison and evaluation of laboratory methods of obtaining an index of soil nitrogen availability. Agron. J. 58: 498-503.

Leyton, L. 1954. The growth and mineral nutrition of spruce and pine in heathland plantations. Inst. Pap. Imp. For. Inst. Oxford. No. 31.

Leyton, L. 1956. The relationship between the growth and mineral composition of the foliage of Japanese larch (Larix leptolepis, Murr.). Plt. and Soil. 7(2): 167-177.

Leyton, L. 1957. The relationship between growth and mineral composition of Japanese larch. II. Evidence from manurial trials. Plt. and Soil. 9(1): 31-48.

Leyton, L. and K. A. Armson. 1955. Mineral composition of the foliage in relation to the growth of Scots pine. For. Sci. 1(3): 210-218.

Lowry, G. L. and C. T. Youngberg. 1955. The effect of certain site and soil factors on the establishment of Douglas-fir on the Tillamook burn. Soil Sci. Soc. Amer. Proc. 19: 318-380.

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

McNabb, D. H., R. L. Fredriksen and K. Cromack Jr. 1978. Mineralizable soil nitrogen in some forest habitat types in the Oregon Cascades. Am. Soc. Agron. Abstracts. p. 190.

Miller, R. E., D. P. Lavender and C. C. Grier. 1976. Nutrient cycling in the Douglas-fir type - silvicultural implications. p. 359-390. In: Proc. 1975 Annual Convention. Soc. of Amer. For.

Minore, D. and M. E. Dubrasich. 1981. Regeneration after clearcutting in subalpine stands near Windago Pass, Oregon. J. For. 79(9): 619-621.

Mitchel, R. F. 1979. Soil formation, classification and morphology. p. 157-172. In: P. E. Heilman, H. W. Anderson and D. M. Baumgartner (eds). Forest soils of the Douglas-fir region. Washington State University. Cooperative Extension Serv. Pullman, WA. 298p.

Mitchell, H. L. and R. F. Chandler. 1939. The nitrogen nutrition and growth of certain deciduous trees of northeastern United States. Black Rock For. Bull. 11. Cornwall-on-the-Hudson, N.Y. 94p.

Morris, W. G. 1958. Influence of slash burning on regeneration, other plant cover and fire hazard in the Douglas-fir region. (A progress report) U.S. For. Serv. Res. Pap. PNW-29.

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

Nie, N. H., C. H. Hull, J. G. Jenkins, K. Steinbrenner and D. H. Bent. 1975. SPSS - Statistical package for the social sciences. 2nd edition. McGraw-Hill Book Co. N.Y. 675p.

Peet, R. K. and O. L. Loucks. 1977. A gradient analysis of southern Wisconsin forests. Ecol. 58: 485-499.

Perry, D. A. 1978. Variation between and within tree species. p. 71-98. In: E. D. Ford, D. C. Malcolm and J. Atterson (eds). The ecology of even-aged forest plantations. Proc. of the Meeting of Division I International Union of For. Res. Organizations, Edinburgh, Sept. 1978. 582p.

Perry, D. A., S. L. Rose, D. Pilz and M. M. Schoenberger. 1984. Reduction of natural ferric iron chelators in disturbed forest soils. Soil Sci. Soc. Am. J. 48: 379-382.

Powers, R. F. 1980. Mineralizable soil nitrogen as an index of nitrogen availability to forest trees. Soil Sci. Soc. Am. J. 44: 1314-1320.

Reineke. L. H. 1933. Perfecting a stand density index for even-aged forests. J. Agr. Res. 46: 627-638.

Rothacher, J., C. T. Dyrness and R. L. Fredriksen. 1967. Hydrologic and related characteristics of three small watersheds in the Oregon Cascades. USDA For. Serv. Pac. NW For. and Range Expt. Stn. 54p.

Scott, W. 1969. Effect of snowbrush on establishment and growth of Douglas-fir seedlings. M.S. Thesis. OSU. Corvallis, OR.

Shumway, J. S. and W. A. Atkinson. 1977. Measuring and predicting growth response in unthinned stands of Douglas-fir by paired tree analysis and soil testing. Dept. of Nat. Res. DNR Note 15. 10p.

Smith, D. W. 1970. Concentration of soil nutrients before and after burning. Can. J. Soil Sci. 50: 18-28.

Smith, R. B., R. H. Waring and D. A. Perry. 1981. Interpreting foliar analysis from Douglas-fir as weight per unit leaf area. Can. J. For. Res. 11(3): 593-598.

Stanford, G. and S. J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Amer. Proc. 36: 465-472.

Stewart, W. D. P. 1966. Nitrogen fixation in plants. The Athlone Press, Univ. London, London. 168p.

Sullivan, M. J. 1978. Regeneration of tree seedlings after clearcutting on some upper slope habitat types in the Oregon Cascade Range. USDA For. Serv. Res. Pap. PNW-245. 17p.

Swank, W. T. and J. B. Waide. 1979. Interpretation of nutrient cycling research in a management context: Evaluating potential effects of alternative strategies on site productivity. p. 137-158. In: R. H. Waring (ed.) Forests: Fresh perspectives from ecosystem analysis. Oregon State University Press. Corvallis, OR. 198p.

Tarrant, R. F. 1954. Effect of slash burning on soil pH. USDA For. Serv. PNW-102.

Tarrant, R. F. 1956a. Effect of slash burning on some physical soil properties. For. Sci. 2: 18-22.

Tarrant, R. F. 1956b. Effect of slash burning on some soils of the Douglas-fir region. Soil Sci. Soc. Amer. Proc. 20: 408-411.

Tarrant, R. F., L. A. Issac and R. F. Chandler. 1951. Observations on litter fall and foliage nutrient content of some Pacific Northwest tree species. J. For. 49: 914-915.

Tarrant, R. F. and E. Wright. 1955. Growth of Douglas-fir seedlings after slash burning. USDA For. Serv. Res. Note PNW-115.

Turner, J. 1977. Effect of nitrogen availability on nitrogen cycling in a Douglas-fir stand. For. Sci. 23: 307-316.

Van Den Driessche, R. 1969. Tissue nutrient concentrations of Douglas-fir and Sitka spruce. Brit. Col. For. Serv. Res. Note 47.

Van Den Driessche, R. 1974. Prediction of mineral nutrient status of trees by foliar analysis. Bot. Rev. 40: 347-394.

Viereck, L. A. and C. T. Dyrness (eds). 1979. Ecological effects of the Wickersham Dome fire near Fairbanks, Alaska. USDA For. Serv. Gen. Tech. Rep. PNW-90. 71p.

Vitousek, P. M. and J. M. Melillo. 1979. Nitrate losses from disturbed forests: patterns and processes. For. Sci. 25(4): 605-619.

Wahlenberg, W. G. 1930. Effect of Ceanothus brush on western yellow pine plantations in the northern Rocky Mountains. J. Agric. Res. 41(8): 601-612.

Waring, R. H. 1976. Reforestation in the U. S. Pacific Northwest. Envir. Conserv. 3(4): 269-272.

Waring, R. H., J. J. Rogers and W. T. Swank. 1981. Water relations and the hydrologic cycle. p. 205-264. In: D. E. Reichle (ed.). Dynamic properties of forest ecosystems. IBP-23. Cambridge Univ. Press. London. 683p.

Waring, R. H. and C. T. Youngberg. 1972. Evaluating forest sites for potential growth response of trees to fertilizer. N. W. Sci. 46(1): 67-75.

Waring, S. A. and J. M. Bremner. 1964. Ammonium production in soil under waterlogged conditions as an index of nitrogen availability. Nature. 201(4922): 951-952.

Wierman, C. A. and C. D. Oliver. 1979. Crown stratification by species in even-aged mixed stands of Douglas-fir - western hemlock. Can. J. For. Res. 9(1): 1-9.

Wollum, A. G. II. 1962. The role of certain non-leguminous woody species in nitrogen nutrition of some conifer seedlings. M.S. Thesis. OSU. Corvallis,OR.

Wollum, A. G. II. and C. T. Youngberg. 1964. The influence of nitrogen fixation by non-leguminous woody plants on the growth of pine seedlings. J. For. 62: 316-321.

Wollum, A. G. II. and C. T. Youngberg. 1965. Are we overlooking important nitrogen-fixing plants? Crops and Soils. 17(8): 16-17.

Wollum, A. G. II., C. T. Youngberg and F. W. Chichester. 1968. Relation of previous timber stand age to nodulation of Ceanothus velutinus. For. Sci. 14: 114-119.

Worthington, N. P. 1959. Reproduction following small group cuttings in virgin Douglas-fir. USDA For. Serv. PNW-84.

Youngberg, C. T. 1955. Effects of soils on establishment of tree crops. Soil Sci. Soc. Amer. Proc. 19: 86-90.

Youngberg, C. T. and A. G. Wollum II. 1976. Nitrogen accretion in developing Ceanothus velutinus stands. Soil Sci. Soc. Amer. J. 40: 109-118.

Youngberg, C. T., A. G. Wollum II and W. Scott. 1979. Ceanothus in Douglas-fir clear-cuts: nitrogen accretion and impact on regeneration. p. 224-233. In: J. C. Gordon, C. T. Wheeler and D. A. Perry (eds). Symbiotic nitrogen fixation in the management of temperate forests. Proc. of a workshop held April 2-5, 1979.

Zavitkovski, J. 1966. Snowbrush, Ceanothus velutinus Dougl., its ecology and role in forest regeneration in the Oregon Cascades. Ph. D. Thesis. OSU. Corvallis, OR. 102p.

Zavitkovski, J. and M. Newton. 1968. Ecological importance of snowbrush, Ceanothus velutinus, in the Oregon Cascades. Ecol. 49(6): 1134-1145.

Zavitkovski, J., M. Newton and B. El-Hassan. 1969. Effects of snowbrush on growth of some conifers. J. For. 67: 242-246.