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A Survey of Sites and Management Experiences on the Gifford Pinchot, Mt. Hood and Willamette National Forests

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REFORESTATION IN THE CASCADES PACIFIC SILVER FIR ZONE

A Survey of Sites and Management Experiences on the Gifford Pinchot, Mt. Hood and Willamette National Forests.

By Nancy M. Halverson[1] and William H. Emmingham[2]

[1]ASSISTANT AREA ECOLOGIST, AREA 6 (MT. HOOD, SIUSLAW AND WILLAMETTE N.F.), USDA-FOREST SERVICE PACIFIC NORTHWEST REGION

[2]EXTENSION SILVICULTURE SPECIALIST, OREGON STATE UNIVERSITY, DEPT. OF FOREST SCIENCE.

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SUMMARY OF RESULTS, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY OF RESULTS, CONCLUSIONS AND RECOMMENDATIONS

This publication contains a general discussion of reforestation in the Pacific Silver Fir Zone (PSFZ) (Franklin and Dyrness, 1973) and documents a study of clearcuts in six ecologically and geographically distinct subunits of the PSFZ on the Gifford Pinchot, Mt. Hood and Willamette National Forests in Washington and Oregon (Fig. 1). We measured seedling density, stocking, leader growth and several environmental and site factors on 20-25 clearcuts per subunit in a wide range of environments during 1979. The conclusions and recommendations in this summary are based on our study results, review of pertinent literature, experience and knowledge provided by Forest Service silviculturists and reforestation specialists.

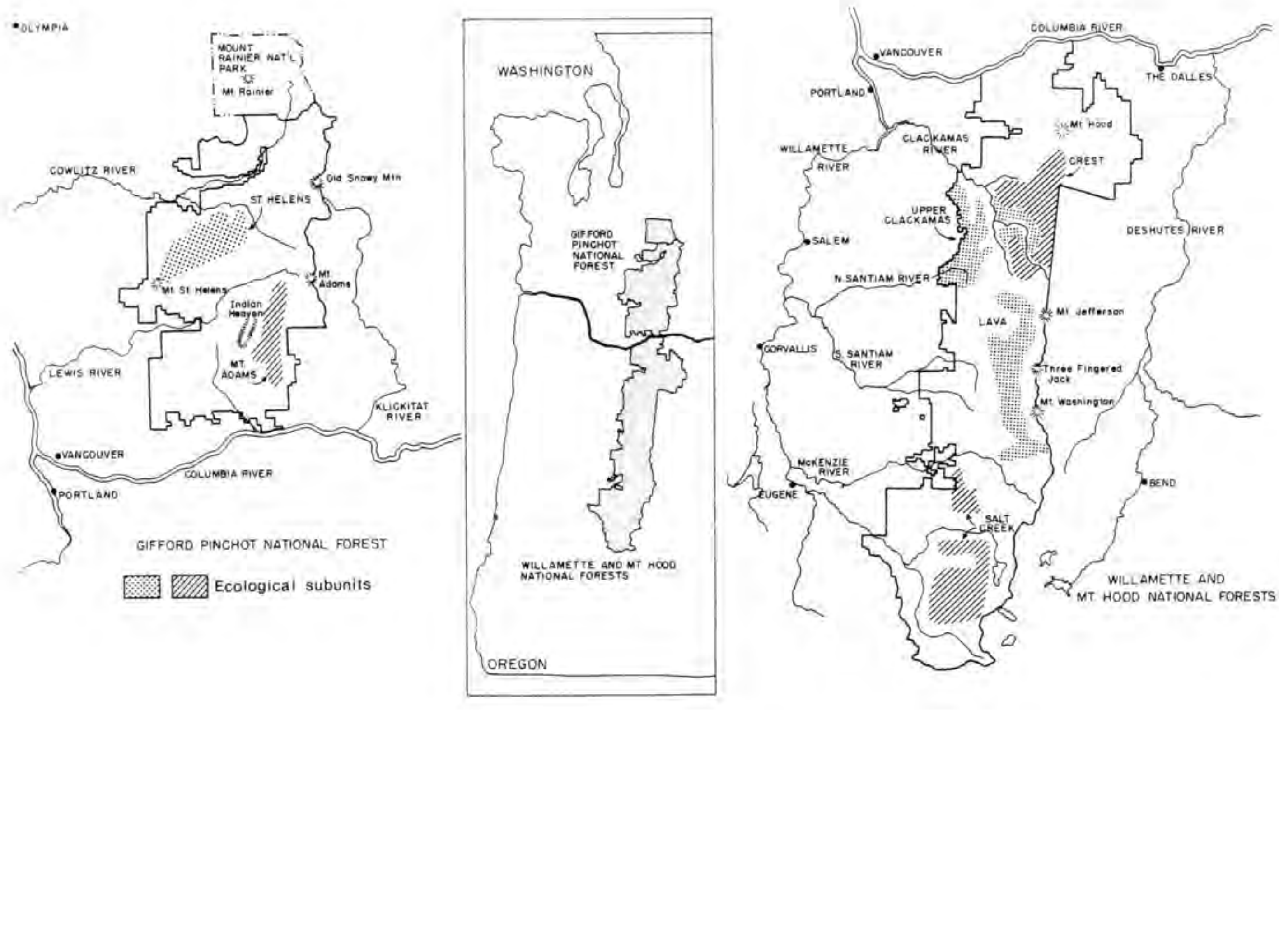


Fig. 1 Pacific silver fir zone reforestation study: ecological subunits and vicinity map.

DENSITY & GROWTH

Density (# seedlings/total # plots; trees per acre) of tree seedlings[1] in clearcuts in the six ecological subunits was variable, averaging from 350 (Salt Creek Subunit) to 570 (St. Helen Subunit) trees per acre (TPA). About 17 percent of the clearcuts had less than 200 TPA (including both planted and natural seedlings) while 28 percent had greater than 500 TPA. The patchiness of regeneration left many acres with no seedlings at all; 14.5 percent of our plots were nonstocked [2]. Pacific silver fir (usually advance regeneration) grew in very dense stands, but due to scarification and slash burning (Fig. 2) occurred on only 8 percent of our plots. Planted and post-harvest natural seedlings were usually less dense, but occurred on 30 to 90 percent of the plots, depending on ecological subunit. Planted Douglas-fir seedlings averaged 105 TPA and occurred on 39 percent of the plots, while planted noble fir averaged 84 TPA and occurred on 30 percent. Forty-three percent of all seedlings tallied in our study were of natural origin, and the remaining 57 percent were planted. Estimated mortality of planted seedlings averaged from 55 percent to 81 percent. In general, higher numbers of seedlings were found at lower elevations and on northwest to northeast aspects, although there was much variability. Sideslopes emerged as the most favorable topographic position, except in the Mt. Adams subunit where flat areas had the greatest seedling density. Generally, ridgetops, valleys and large flat areas may be slow to regenerate following clearcutting because of severe environmental conditions.

Average previous year's height growth of the best-growing seedlings varied from 8.9 to 15.0 cm across ecological subunits. The best-growing planted Douglas-fir per plot averaged from 9.0 cm to 17.2 cm height growth, and planted noble fir averaged 6.9 cm to 12.3 cm. The St. Helens and Lava subunits consistently showed greatest growth. As with seedling density, there was a great deal of variation in height growth.

Fig. 2 Old tractor trails are apparent from the distribution of residual Pacific silver fir and mountain hemlock in this clearcut.

ENVIRONMENTAL STRESS

Although it was not measured in our study, we believe shade from small objects near seedlings which are just becoming established may provide critical protection from desiccation where solar radiation is high (south slopes or large, open clearcuts) or where planting takes place when evaporative demand is high in late spring. Completely exposed areas at high elevations are likely to be very frosty, even in summer.

On all ecological subunits, both average seedling density and growth were best on unburned plots, and least on extreme-burned plots. This is partly due to dense advance Pacific silver fir regeneration found on many unburned plots. Growth may be influenced by nutrient depletion associated with burning.

Extremes in environment are probably the major cause of regeneration failure in the PSFZ. Frost during the growing season, high summer surface temperatures, cool rooting zone temperatures, lack of sufficient moisture, short growing season due to late snowmelt, and the weight and movement of deep snow all contribute to seedling stress.

Repeated measurements of predawn plant moisture stress in established seedlings during the growing season showed that moisture stress did not reach extremes likely to cause mortality but did achieve levels at which photosynthesis is significantly reduced. Seedlings which are properly preconditioned and planted do not often die as a direct result of moisture stress within the study area.

Soil surface temperatures in unshaded areas commonly reach 50^{0} to 70^{0} C. during sunny weather from July through September. These temperatures are high enough to kill emergent seedlings (Silen, 1960). Natural regeneration often is restricted to shaded microclimates, such as those provided by logging debris.

Rooting zone temperatures generally rise sharply after snowmelt to a high of 10^{0} to 15^{0} C. in July and then steadily decline until snow accumulates. In much of the PSFZ, rooting zone temperatures above 5^{0} C. last only three or four months. Root growth in Douglas-fir seedlings may be significantly reduced below 15^{0}-20^{0} C. (Lavender and Overton, 1972), and in Pacific silver fir and noble fir, below 2-3 degrees C. (Hinckley, et al., 1981). A Forest-wide network of temperature monitoring points would help establish which soils, plant associations and topographic positions are prone to soil temperature and frost problems.

1/ Seedlings between 1 dm and 2 m tall.

2/ Stocked plots = those with $\geq$ 1 seedling between 1 dm and 2 m tall.

Conditions are very severe during the transition between snowmelt and the time soils warm sufficiently for root growth. During this period, hot sunny days are common and evaporative demand is high, while soils are still relatively cold. It is precisely this period in which seedlings are usually planted. At high elevations, particularly on north aspects, favorable conditions for planting may last only a few days or weeks. It may also be more difficult to obtain fully dormant seedlings that can withstand such conditions.

PROBLEM PLANT ASSOCIATIONS

Plant associations aid in predicting reforestation success because they broadly reflect the environmental factors acting on sites. Although we were unable to statistically analyze the relationship between plant associations and reforestation success, field observations lead us to infer that four Pacific silver fir associations (big huckleberry/beargrass, rhododendron/beargrass, Cascades azalea/beargrass and Cascades azalea/queencup beadlily) and two mountain hemlock associations (big huckleberry/beargrass and grouse huckleberry) are particularly difficult to reforest following clearcutting (Hemstrom et al., 1982). On flat topography in these types, the growing season is short, growing season environment extreme, and artificial reforestation within five years following clearcutting and burning may not be possible.

REGENERATION STRATEGIES

Management-related factors which influence survival and growth of seedlings include planting date, planting spot chosen, slash disposal method and choice of species to be planted. Conifer seedlings planted in high elevation clearcuts must be dormant in order to insure frost resistance and to help seedlings respond with rapid root and shoot growth once soil temperatures become favorable. Proper handling of seedlings during planting is essential. Seedlings must be kept moist, bags must be kept cool, the relative humidity must be monitored, and wind speed and temperature checked so that seedlings are not planted under desiccating conditions.

Ranger District records indicate that modest success has been attained with fall planting in the Mt. Adams, Lava and Salt Creek ecological subunits. Fall planting must be undertaken with extreme care. It must be done after the soil moisture supply has been replenished by fall rains but before freezing weather occurs or snow accumulates. Seedlings planted in the fall must be carefully preconditioned so as to be fully dormant and have adequate carbohydrate reserves. This will require early withdrawal of watering and fertilization in the nursery. Spring planting is far more common in our area and seems less risky, although success has been variable.

Shelterwood cutting can be used to moderate the severe seedling environment during the regeneration period in flat areas or depressions, upper elevations, south or southwest slopes, or where beargrass is a dominant species in the understory. Frost resistant species (noble fir, Engelmann spruce, western white pine, lodgepole pine, or larch) should be favored in all but the most environmentally moderate sites of the PSFZ.

In clearcuts on harsh sites, management of advance Pacific silver fir regeneration is often the easiest, most economical and surest way to obtain a new stand. Site preparation and slash disposal methods greatly affect survival of residual seedlings. Modifying harvest operations to protect advance regeneration can secure high stocking levels of Pacific silver fir. With proper planning and careful operation, machine piling or yarding and burning of slash can leave patches of residual seedlings. A drawback to managing residual Pacific silver fir is its susceptibility to infestation by the balsam woolly aphid, but the risk decreases with decreasing site quality and should be least on severe sites where such treatments would be applied (Mitchell, 1966; Gara and Souto, 1975).

Properly matching species to site is a key to successful artificial reforestation in the PSFZ. Douglas-fir is generally suited only to warmer sites. Noble fir, western white pine, Engelmann spruce and lodgepole pine are more appropriate for sites where summer frost is likely. Noble fir is a good choice for most of the PSFZ since it maintains good growth in dense stands (even better than Douglas-fir). However, it can be frost-damaged so should not be planted in extreme frost pockets.

PART 1 - REFORESTATION IN THE PACIFIC SILVER FIR ZONE

INTRODUCTION

This publication contains two major sections. Part 1 is a general discussion of reforestation in the Pacific silver fir zone, in the context of the environment, and past and present management. It is based on our own and others' observations in the field, research documented in the literature, and in part on the survey of high elevation clearcuts discussed in Part 2. Part 2 documents a survey of Pacific silver fir zone clearcuts in the Gifford Pinchot, Mt. Hood and Willamette National Forests (Fig. 1). The objective was to develop hypotheses regarding the rather widespread failure to obtain adequate and rapid artificial regeneration in these areas. We concentrated on environmental factors and did not examine planting operations, seedling handling and storage, or nursery practices, all of which affect regeneration success.

In this paper, the PSFZ is defined as the area where Pacific silver fir is the major regenerating species. It includes both Douglas-fir and true fir-mountain hemlock forests where Pacific silver fir (rather than western or mountain hemlock) is the dominant regeneration species in natural stands. Since this study was conducted prior to the classification of upper-slope plant associations for this area, our definition differs somewhat from that currently in use (Emmingham and Hemstom, 1981; Hemstrom et al., 1982). The upper boundary of the PSFZ is now considered to be the point where regenerating mountain hemlock exhibits more than 2 percent cover. Thus, our study includes some lower elevation mountain hemlock zone clearcuts.

MANAGEMENT HISTORY

Forest Service management experience in PSFZ forests is generally limited to the last 20 to 30 years. Prior to that time, management activities in the western Cascades were confined to lower elevation forests with a milder climate and longer growing season. Therefore, it is not surprising that some problems developed upon entry into the less favorable environments of the upper Cascades.

Foresters in the past may have been misled by the wide elevational range of Douglas-fir in the Cascades. The mix of species harvested from the PSFZ included most low elevation conifers (especially Douglas-fir) with the addition of noble fir, Pacific silver fir, white fir/grand fir, western white pine, subalpine fir, mountain hemlock, western larch and lodgepole pine. Foresters, correctly assuming that the Douglas-fir originated in old burns, perpetuated the clearcut-burn-and-plant Douglas-fir management scheme developed at lower elevations. But two major differences between natural and artificial stand regeneration caused problems when this scheme was used in the PSFZ. First, the environment following wildfires was considerably more sheltered than that usually created by clearcutting, having standing dead trees and slash to provide shade and moderate temperature extremes. In contrast, the wide-open conditions resulting from clearcutting and slash disposal are often too severe for Douglas-fir seedlings at high elevations to survive. Second, the time it took to reforest old burns in the PSFZ was probably far longer than is considered acceptable by silviculturists managing clearcuts. National Forest objectives generally require adequate reforestation of clearcuts within 5 years. Neither natural nor artificial reforestation consistently produce such rapid results in the PSFZ. Williams (1966) recommended that lower stocking standards and longer regeneration periods be allowed in high elevation areas.

An indication of the size of the reforestation problem in the Western Cascades PSFZ was obtained from USDA-Forest Service Total Resource Inventory (TRI) records[3/]. On the Gifford Pinchot National Forest, for example, 10 to 15 percent of the more than 30,000 acres that have been clearcut in the PSFZ are not adequately stocked at present. Another 10 percent are within the 5-year period allowed for reforestation under National Forest objectives. On the Mt. Hood NF, some clearcuts in the PSFZ were planted with a noncommercial Ponderosa pine nurse crop, resulting in a 50 percent backlog ratio (pending establishment of a more suitable species) for one Ranger District. Information from the Willamette NF is incomplete, but some Districts list over 40 percent of the area cut in the PSFZ as inadequately restocked. Among the plantations in our study, estimated mortality[4/] of planted seedlings (primarily Douglas-fir) ranged from 11 to 100 percent per clearcut, averaging 66 percent. Reforestation success has varied widely, with unacceptably high mortality in many PSFZ plantations.

The problem of obtaining adequate stocking has led to changes in management strategies. Managers have recognized the importance of matching species to site and have begun planting noble fir and western white pine in the PSFZ. Shade cards have been used to decrease desiccation and increase survival of planted seedlings. Frost has been recognized as a major problem and the shelterwood system has been used to modify seedling environments. Logging and slash removal operations have been reoriented toward protection of residual Pacific silver fir seedlings, which has removed the need to plant. But use of these techniques has been far from widespread in the PSFZ, and regeneration failures continue to occur.

3/ TRI is the resource data base used throughout Oregon and Washington by the USDA-Forest Service. The acreage within the PSFZ is difficult to determine from TRI because the zone was not defined the same way by all Ranger Districts.

4/ Mortality was estimated by subtracting current planted seedling density measured on our plots from that shown in Ranger District activity records as originally planted. This method is limited by the accuracy of the records, which varies considerably.

THE ENVIRONMENT OF THE PACIFIC SILVER FIR ZONE

Clearcut reforestation in the PSFZ must be viewed within the ecological context of the zone as a whole. The Pacific silver fir zone occurs on the high plateau and western flanks of the Cascades, from northern Washington to central Oregon (Franklin and Dyrness, 1973) at elevations between 2500 and 4500 feet (760 and 1370 meters) at the northern end to between 3500 and 6000 feet (1060 and 1830m) at the south end. Climax Pacific silver fir forests also occur on the Olympic Peninsula in Washington.

Mature forest stands are composed of Pacific silver fir associated with western hemlock at lower elevations and mountain hemlock at upper elevations, and with noble fir, western white pine and Douglas-fir. A distinctive feature of PSFZ forests is the widespread presence of dense, shade-tolerant Pacific silver fir advance regeneration in the understory (Fig. 3). These "seedlings" often persist for decades in a suppressed condition. The major physiographic division of the area (dissected Old Cascades to the west vs. rolling High Cascades to the east) is reflected in the overstory species that dominate seral forests. The composition of seral stands in the Old Cascades (the location of our St. Helens, Upper Clackamas and Salt Creek ecological subunits) often resembles that of Douglas-fir forests at lower elevations in the Western Hemlock Zone, while seral stands in the High Cascades (where our Mt. Adams, Crest and Lava subunits are located) often contain species characteristic of more interior forests-- subalpine fir, lodgepole pine, western white pine, and western larch, in addition to Pacific silver fir, Douglas-fir and mountain hemlock (Franklin, 1965).

Fig. 3 Advance Pacific silver fir regeneration grows in dense stands, suppressed for decades. Yet it retains its ability to resume growth once the canopy is removed.

The climate of the PSFZ is cold and wet, with sharp transitions between seasons. The growing season is short, averaging only 40 to 50 days (Franklin and DeBell, 1972), roughly half that of the Western Hemlock Zone (Emmingham and Waring, 1977). Spring and fall frosts are common, particularly in the High Cascades. Frost may occur throughout the growing season in topographic depressions or created frost pockets (Fig. 4). A previous study in the Crest ecological subunit recorded freezing temperatures at night at least every two weeks throughout the summer (Meador, 1979). Less than 10 percent of the precipitation falls in summer (Franklin, 1965). The remaining 90 percent contributes to the heavy snowpack characteristic of the zone, a major cause of slow growth and damage to young seedlings (Emmingham and Waring, 1977).

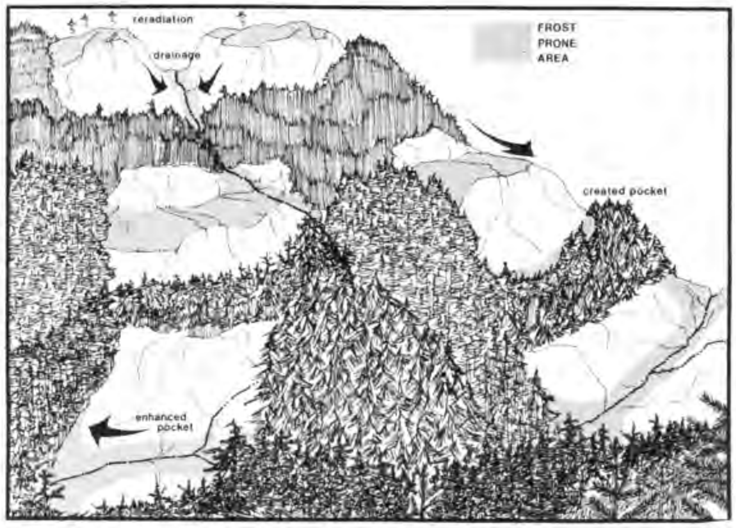


Fig. 4 Frost-prone areas in the Pacific silver fir zone.

High surface temperatures and evaporative demand may combine with cold rooting zone soils to create moisture stress during the growing season. Desiccating fall winds may extend the dry season into September or October, until fall rains or early snows arrive.

A vertical stress zone through which seedlings in high elevation openings must grow is illustrated in Fig. 5. The greatest amount of mortality among conifer seedlings occurs while they are within the stress zone. As a seedling grows up out of the stress zone, its chances for survival increase. The effect of the stress zone was seen by Williams (1968), who found height growth of saplings (greater than 6 feet tall) to exceed that of seedlings (up to 6 feet tall).

Temperature variation in the stress zone is high and increases toward the surface. This can lead to heat-caused mortality in emergent seedlings, premature bud burst and excessive evaporative demand. The soil moisture is rapidly depleted from the surface decimeter. Potential for snowbreak increases in the stress zone, as does animal damage.

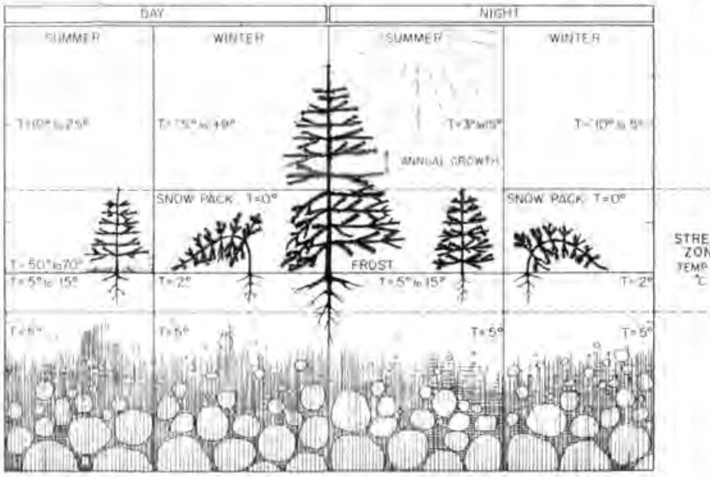


Fig. 5 The stress zone.

The depth of the stress zone and the relative emphasis of the factors that operate in it vary by site. Successful reforestation depends in part on an understanding of environmental factors that may be reaching critical limits in the stress zone of a particular site.

Soil parent materials in the Washington portion of the study area are predominantly pumice and ash deposits (Franklin, 1965). South of the Columbia River, soil parent materials are mainly derived from glacial erosion/deposition and colluvial processes on weathering basalts and andesites. Extensive deposits of volcanic pumice and ash occur south of Mt. Jefferson in the High Cascades. Except in the area of thick ash and pumice accumulations in the Mt. Adams, St. Helens and Lava subunits, soils in the study area tend to be coarse, stony, shallow and may be somewhat low in nutrients, particularly nitrogen (Gessel and Cole, 1973; Emmingham and Halverson, 1981). Surface rock in clearcuts often makes good planting sites difficult to find.

MAJOR INFLUENCES ON REFORESTATION SUCCESS

After three decades of timber management in the PSFZ, patterns in reforestation are beginning to emerge. Our study is one of many that have contributed pieces to the puzzle of where and why attempts to regenerate clearcut PSFZ stands have failed or succeeded.

Our survey found that temperature and moisture conditions from the surface to the rooting zone, slope position, burn intensity and seedling origin and species are significantly related to stocking, density and growth of conifer seedlings in PSFZ clearcuts. A more thorough discussion of these factors and our methods is found in Part 2.

This part of the report is an integration of our own observations and speculations, the experiences of silviculturists, researchers and reforestation specialists. We believe the important considerations in PSFZ reforestation can be grouped in the following categories: operational factors, silvicultural practices, seedling physiology and environmental factors.

OPERATIONAL PROCEDURES

Operational procedures play a major role in determining the success of artificial reforestation. Jenkinson (1980) discussed the importance of accurately timing planting of seedlings to coincide with the "planting window", a period of time during which temperature and moisture conditions are suitable for seedling establishment. A major difficulty in establishing the endpoints of a planting window is that weather conditions vary greatly from year to year. There are two planting windows in the PSFZ, one in early spring, the other in fall. Most planting takes place in the spring; fall planting is considered by many to be risky.

The spring planting window begins when rooting zone soil temperature begins to warm to levels favorable for root growth. The critical temperature varies by species; R. O. Teskey (University of Washington, personal communication, 1982) has found resistance to water absorption at soil temperatures of 10° C. for Douglas-fir and 2° to 3° C. for noble fir and Pacific silver fir.

The timing of the planting window is strongly influenced by the increase in daylength and dry weather during and immediately following snowmelt. Seedlings must endure rapid transition from winter to summer conditions. At the same time, days may be hot and sunny, causing seedlings to break dormancy (van den Driessche, 1969), while freezing still occurs at night. On one open, flat PSFZ clearcut in the Clackamas Ranger District of the Mt. Hood NF, freezing nighttime temperatures occurred throughout the summer (Meador, 1979). In addition, while rooting zone soils remain cold in early summer at high elevations, air temperatures increase dramatically on sunny days. Spring is a season of temperature extremes at high elevations: from winter to summer, from day to night, and from seedling roots to tops.

The end of the spring planting window comes when high transpiration rates begin to exceed the ability of seedling roots to obtain water from the soil, reducing photosynthesis and growth. At the highest elevations, the spring planting window is often drastically shortened by late snowmelt coupled with early sunny weather. Unfortunately, in practice planting often commences at the earliest date tree planters can get to a clearcut. Snow-impeded access is a continuing problem in high elevation reforestation efforts; some clearcuts are not accessible during their planting window unless roads are plowed or crews are transported over the snow.

In the late summer, seedlings generally cease shoot and root growth for a time, then may experience a "flush" of root growth once the rainy season commences (Hermann et al, 1972). If soil moisture is adequate, seedlings may be planted during the "dormancy deepening" period preceding the fall flush, as long as roots are not in an active phase when planted (J. Edgren, USDA - Forest Service, personal communication, 1982). The end of the fall planting window comes when rooting zone soil temperatures begin to drop below favorable levels for growth. In the PSFZ this usually occurs in late October to early November.

Because of their style of branching and foliage, newly-planted Douglas-fir and noble fir seedlings are susceptible to snowbreak (Williams, 1966). Without a preceding season of on-site root and diameter growth, poor growth and mortality can result. In addition, fall-planted seedlings must be fully dormant before they are lifted or they are highly prone to frost injury. Fall-planted seedlings in the PSFZ may not have had exposure to short day length, which is necessary to induce and deepen dormancy. Spring planting overcomes these problems, and takes advantage of the greater root growth potential of tree seedlings in spring. More work needs to be done to clarify the effect of planting date on survival and growth of seedlings in high elevation clearcuts.

Much research has been done on the effects of nursery practices (lifting dates, storage, conditioning, manipulation of roots, etc.), seedling transport and planting techniques on seedling survival and growth. Much of it has focussed on Douglas-fir, an inappropriate species for planting in much of the PSFZ; similar efforts should be concentrated on some of the cold-resistant species. Accurate record-keeping helps silviculturists evaluate the effects of these factors on reforestation success. A more unified effort to correlate such information over the PSFZ would probably prove enlightening.

Species selection and seed source are critical factors in the success of artificial reforestation in extreme environments. Unfortunately, knowledge of the abilities and tolerances of PSFZ tree species other than Douglas-fir is incomplete. Seed source can be very important. Height growth, timing of bud burst and bud set, length of growth period and root formation in Douglas-fir all vary with changes in aspect and elevation of the seed source (Hermann and Lavender, 1968). Seed batches categorized by broad elevation ranges may not be well-adapted to local severe environments; perhaps aspect and possibly plant association of seed sources should be taken into account when selecting seedlots for planting in severe sites.

Characteristics of candidate species for artificial reforestation in the PSFZ are listed in Table 1. In general, Douglas-fir is suited to only warmer sites found at lower elevations in the PSFZ. Noble fir, while growing well in these areas, is more frost-resistant than Douglas-fir, and can be planted at higher elevations. It is particularly suited to south-facing, well-drained sites with slopes greater than 10 percent. If a suitable seed source can be found, noble fir is a good choice on even higher elevation sites (the Pacific silver fir/big huckleberry/ beargrass association[5/], for example) on slopes greater than 10 percent. Engelmann spruce is a good choice for frost-prone areas with a high water table. White pine is the best choice for flats or plateaus which are extremely frost-prone (Fig. 6). Rust resistant stock may soon be available through the Dorena Project[6/] or can be obtained from seed of rust resistant parents in the field. In drier areas, especially on the east side of the Cascade Crest on the Gifford Pinchot and Mt. Hood NFs, western larch is a fast-growing and frost-resistant species.

Lodgepole pine is extremely frost-resistant and may be a good choice for areas requiring rehabilitation. However, its often poor form and small size restrict its usefulness. Pacific silver fir may be used on cold sites with abundant soil moisture. Western hemlock can be used on moist sites at lower elevations, but in most cases Douglas-fir or noble fir would be better choices. Douglas-fir and western hemlock have rapid early growth rates, but noble fir usually catches up and by 100 years is often taller (Fig. 7) (Herman, 1967). See Part 2 for additional discussion of seedling origin and species.

SILVICULTURAL ACTIVITIES

The use of the shelterwood system to moderate the seedling environment should be considered in the PSFZ. Suitable location, remaining overwood density, and the effects of final removal are considerations that need to be addressed in further research. Experience suggests that shelterwood cutting would be most beneficial on ridgetops and southwest or south aspects and at very high elevations, except where local wind patterns or soil conditions create a windthrow hazard. Flats with depressions or cold air pockets are also good candidates for shelterwood

Fig. 6 Western white pine and lodgepole pine were the best choices for planting in this flat, frost-prone site at the upper end of the Pacific silver fir zone.

5/ Plant associations are from Hemstrom (1981) and Hemstrom et al. (1982).

6/ USDA - Forest Service Dorena Tree/Improvement Center, 34975 Government Road, Cottage Grove, OR 97424.

Table 1. Regeneration characteristics of Pacific silver fir zone conifer species, Mt. Hood and Willamette National Forests

Species	Acceptable Association/Slope	Remarks
Alaska cedar	ABAM/RHAL/CLUN[1/] ABAM/RHAL/XETE	Frost tolerant. Requires high soil moisture. Slow growth. May be important as advanced regeneration.
Douglas-fir	All associations except: ABAM/RHAL/CLUN ABAM/RHAL/XETE ABAM/MEFE TSME/VAME/XETE TSME/VASC ABAM/TIUN (15% slope) ABAM/ACCI/TIUN ABAM/RHMA/XETE (15% slope) ABAM/VAME/CLUN (15% slope) ABAM/VAME/XETE	Good early growth, slower diameter growth in dense stands than noble fir. At upper elevations seedlings must be from high elevation seed collections.
Engelmann spruce	ABAM/RHAL/CLUN ABAM/RHAL/XETE ABAM/OPHO ABAM/VAME/CLUN (15% slope) ABAM/VAME/XETE (15% slope)	Very frost tolerant. Grows best with abundant soil moisture.
white fir	Substitute for Pacific silver fir on warm slopes at the south end of the Willamette National Forest.	Climax species on many sites south of the McKenzie River.
larch	ABAM/VAME/XETE (15% slope) ABAM/MEFE TSME/VAME/XETE TSME/VASC	Data lacking. Probably adapted to the Pacific silver fir zone north of the Willamette National Forest. Very frost tolerant.
lodgepole pine	ABAM/VAME/XETE (15% slope) TSME/VAME/XETE (15% slope) TSME/VASC (15% slope)	Good for rehabilitation. Exceptionally frost and drought tolerant.
mountain hemlock	ABAM/MEFE ABAM/VAME/XETE (15% slope) ABAM/RHAL/XETE ABAM/RHAL/CLUN TSME/VAME/XETE TSME/VASC	Slow early growth. Very frost tolerant. Noble fir will usually do better on slopes over 15%.
noble fir	All associations except: ABAM-TSHE/RHMA-GASH (15% slope) TSME/VAME/XETE (15% slope) TSME/VASC (15% slope) ABAM/RHAL/XETE (15% slope) ABAM/RHAL/CLUN (15% slope)	Slow early growth. Rapid sustained late growth in dense stands. Tolerant of cold soils.
Pacific silver fir	All associations.	Slower growth than noble fir or Douglas-fir. Important natural advanced regeneration on cold sites. Shade tolerant, drought intolerant.

Table 1 contine

western hemlock	ABAM/ACCI/TIUN ABAM/BENE ABAM/RHMA-BENE ABAM/VAAL-GASH ABAM-TSHE/RHMA-GASH	Not usually a good choice. Douglas-fir will grow better on sites where western hemlock could be used. shade tolerant.
western redcedar	ABAM/OXOR ABAM/OPHO	Relatively slow growth. Best on moist sites. Shade tolerant.
western white pine	All associations except: ABAM/OPHO ABAM/OXOR	Very frost tolerant. Rapid height growth. Try to get rust-resistant stock.

1/ Plant associations from Hemstrom et al, 1982.

Fig. 7 Noble fir is often the best-growing conifer in the Pacific silver fir zone. The tallest trees in this photo are noble fir, dominating a canopy that also includes Pacific silver fir, mountain hemlock and Douglas-fir.

application. Sideslopes over 15 percent and north aspects are often less frost prone and therefore are not usually candidates for shelterwood. Jaszkowski (1975) recommended the use of the shelterwood system in plant communities dominated by beargrass in the Pacific silver fir and mountain hemlock zones on the Willamette NF. Williamson (1973) found the shelterwood system to provide adequate natural regeneration in the PSFZ, and recommended removal of about 25% to 50% of the canopy on sites where windthrow could be a problem. Otherwise, fewer trees (experience suggests perhaps 10 to 20 per acre) may suffice to moderate environmental extremes while minimizing damage to seedlings during the final harvest.

Experience in managing residual Pacific silver fir is lacking in our area, although data are available from British Columbia (Herring and Etheridge, 1976). On sites with an extreme environment (e.g. those at very high elevations, in frost-prone areas or in plant associations dominated by beargrass) protection of residual Pacific silver fir should be considered (Seidel, 1979), since artificial reforestation in clearcuts is likely to be difficult. It has been shown that Pacific silver fir exhibits release (Fig. 8) after an initial response lag of about five years. Herring and Etheridge (1976) measured average annual height growth rates from .19 to .40 m on a range of sites in British Columbia. This average includes the response lag period, and therefore underestimates annual growth rate after the tree has adapted to an open environment. The same study evaluated the likelihood of infection and decay by Echinodontium tinctorum, and found the effects on trees less than 60 years old or less than 5 cm in diameter to be negligible. Infestation by balsam woolly aphid is a risk, but decreases with increasing elevation, where management of residual Pacific silver fir is most likely to occur (Mitchell, 1966).

Fig. 8 Advance Pacific silver fir regeneration can release dramatically following removal of the canopy.

Costs associated with management of residual stocking in the PSFZ are not known. On the east side of the Cascades, the Deschutes NF found it to be economically feasible with Ponderosa pine. 180 Ponderosa pine seedlings per acre were marked as leave trees prior to logging (Barrett et al,1976). Two alternative slash piling methods (tractor with brush blade, and front end loader with grapple) were then carried out and the effects on residual stocking were observed. About 25% of the marked seedlings were lost. More than half of those lost were destroyed during the tree-falling stage. The tractor method of slash disposal did more damage to seedlings, but was more effective at piling fine slash. The cost associated with this experiment was a little lower than if the area had been clearcut, broadcast-burned and artificially planted. See Part 2 for additional discussion of the effects of burn intensity on seedling density, stocking and growth.

SEEDLING PHYSIOLOGY

The data presented in Part 2 suggest that soils in the PSFZ are cool enough to restrict root growth and function in some conifers. We have no proof that such a reduction actually occurs, however. In a rough survey, we found that roots of Douglas-fir seedlings planted in high elevation clearcuts generally grew slowly and laterally and that taproot formation was minimal. By contrast, more cold-adapted mountain hemlock, Pacific silver fir, noble fir and lodgepole pine seedlings showed vigorous taproot development, as did planted Douglas-fir in low elevation clearcuts. Field and laboratory studies of the effects of cold (below 10^{o} C.) soils on root growth of candidate species for artificial reforestation will help match species to appropriate sites.

We found that seedlings generally recover sufficiently at night from daytime moisture stress to survive (see Part 2). However, knowledge of daytime moisture stress in seedlings is lacking. Moisture stress and leaf conductance data, if obtained for a variety of species on different sites and related to photosynthesis, would provide an additional basis for species selection. See Part 2 for more details on the effects of temperature and moisture on PSFZ seedlings.

The abrupt end of the growing season at high elevations may create dormancy problems in seedlings. For example, Douglas-fir seedlings, which rely on decreasing day length to initiate and deepen dormancy (van den Driessche, 1969) may experience frost damage when nighttime freezing occurs before daylength decreases significantly. This is especially hazardous to fall-planted Douglas-fir seedlings taken from low elevation, well-watered nursery sites, but generally applies to stock from any off-site, lower-elevation seed source. Since dormancy characteristics of seedlings vary by seed source (Herman and Lavender, 1968), further research could help establish which species and seed sources are best suited to different sites in the PSFZ.

Estimated mortality in planted seedlings (planted trees per acre recorded in this study subtracted from trees per acre planted[7/]) in the six ecological subunits averaged from 55% to 81%, two to three times that considered acceptable at lower elevations (Bill Nautel, USDA - Forest Service, personal communication, 1981). National Forests recently initiated a system to monitor mortality of planted seedlings in different seedlots. The data generated will be extremely valuable, particularly if site characteristics (such as slope, aspect, elevation, etc.) can be correlated with mortality. In addition, the causes and timing of mortality need to be analyzed. A study of mortality in natural seedlings would also prove helpful in establishing which species are most successful on a given site.

[7/] From Ranger District activity records.

ENVIRONMENTAL CONDITIONS

Plant Associations

Because the species composition of the plant association on a site reflects its climate, plant associations should aid in predicting regeneration risk. We attempted to correlate plant associations with seedling density and growth, but found it difficult to assign one plant association to an entire clearcut in most cases. Often vegetation is so disturbed that climax plant association is difficult to determine for clearcuts sites, with the present lack of knowledge of successional stages.

Both data and field observations have shown that seedling density is highly variable within and between plant associations, and that no forested plant association is completely unstockable. Severe sites such as those in the mountain hemlock zones and those dominated by beargrass (Emmingham and Hemstrom, 1981; Hemstrom et al., 1982) are generally frost-prone on gentle slopes. It is unlikely that clearcuts in these types can be consistently stocked within a five-year period.

Sullivan (1978) found that habitat types with beargrass as an understory dominant as well as the Pacific silver fir/vanilla-leaf habitat type had both low stocking and seedling density. Interestingly, seedlings in his Pacific silver fir/vanilla-leaf clearcuts (which generally occur on warm, south-facing slopes) exhibited greater growth than those in other habitat types, suggesting that good growth can be attained if seedlings can become established. Where sedges (Carex spp.) and beargrass invade following clearcutting, competition is severe (Fig. 9). Advance Pacific silver fir regeneration is almost always present in the mature stands of these associations and may be saved by careful logging. We believe long-term studies of the success of different species in reforestation of clearcuts with various plant associations will provide an important tool in prescribing treatments for PSFZ stands.

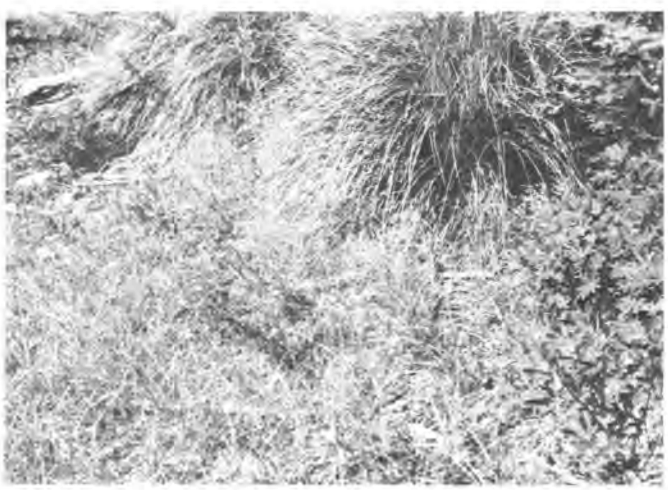


Fig. 9 Rhizomatous sedges (primarily Carex pensylvanica) and beargrass often completely occupy sites when the ground is scarified and/or burned following clearcutting in beargrass-dominated plant associations.

Shade

Shading planted conifer seedlings can greatly reduce moisture stress-related mortality (Peterson, 1979). However, our analysis of shade duration showed that seedlings shaded by the adjacent stand did not exhibit better growth or higher density than unshaded seedlings. We did not measure shading by smaller objects (Fig. 10), which we feel is more beneficial to seedlings. A major difference between the two types of shade (that from the adjacent stand vs. that from small objects) is their effect on soil temperature. Mean daily temperature, and thus rooting zone soil temperature, remains cooler longer in heavily shaded areas (Geiger, 1965), such as those adjacent to stand edges. In the PSFZ, where cold soil temperature may be a major factor in seedling root function failure, the negative effects of cold soil may offset the beneficial influence of reduced evaporative demand and nighttime heat loss.

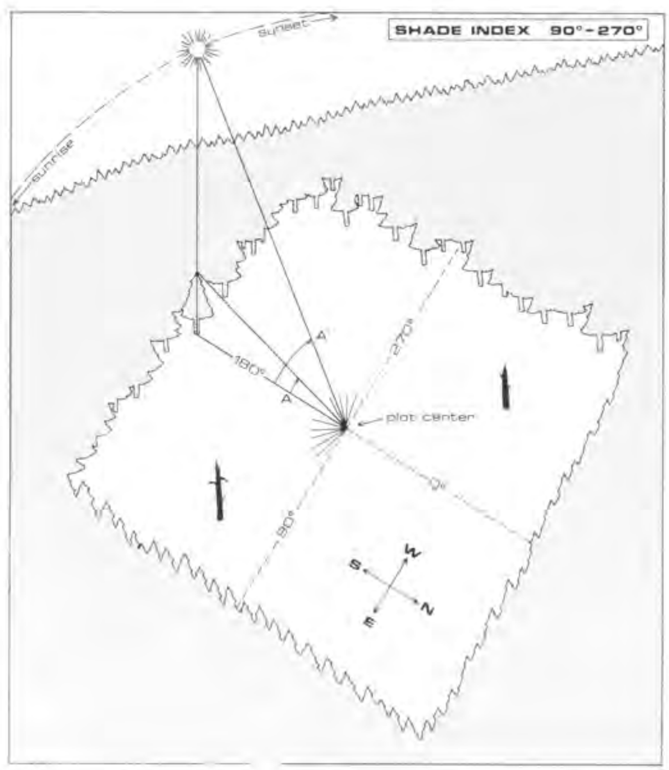


Fig. 10 Shade duration was indexed by comparing the height of objects surrounding the plot (angle A) from 90 to 270 azimuth with the altitude of the sun (angle A') on July 22.

Furthermore, many of our shaded sites were near stand edges on the low ends of sloping clearcuts where cold air collects, exacerbating cold soil temperatures and sometimes producing frost injury to foliage. On the other hand, objects that provide only a small area of shade have a negligible effect on soil temperature in the rooting zone (S. Childs, Oregon State University, personal communication, 1982). Shade from smaller objects moderates the evaporative demand on seedlings by keeping the needles out of full sunlight, while allowing the rooting zone to warm sufficiently for root function and growth. Thus, we suggest that both artificial shade blocking and the shelterwood method of timber harvest can provide beneficial shade.

View Factor

View factor is a measure of the "protectedness" of sites in clearcuts (Fig. 11). It is defined as the amount of radiation leaving a surface in all directions that is intercepted by another surface and reradiated back (Reifsnyder and Lull, 1965). A high view factor for a site indicates a large degree of protection by surrounding objects. In the PSFZ, view factor is important because it indicates the likelihood of nighttime radiation frost and exposure to weather extremes. Nighttime frost can occur in two different situations (Fig. 4). First, cold air can stagnate in "frost pockets", resulting in a temperature inversion. Frost pockets occur where air drainage is impeded, such as in topographic depressions or the lower portion of sloping clearcuts that have standing timber at the bottom. This type of site commonly has a high view factor, being surrounded by tall objects. The second frost-producing condition is the opposite of the first, i.e., sites that are completely exposed. Exposure can result from topographic characteristics or clearcut size. Cochran (1969) found that clearcuts wider than 4-6 times the height of the adjacent stand are totally exposed in the center. Heat loss from these surfaces at night is maximum and there is no moderation of the ambient air temperature if it drops below freezing. These sites are also exposed to maximum insolation and wind desiccation during the day.

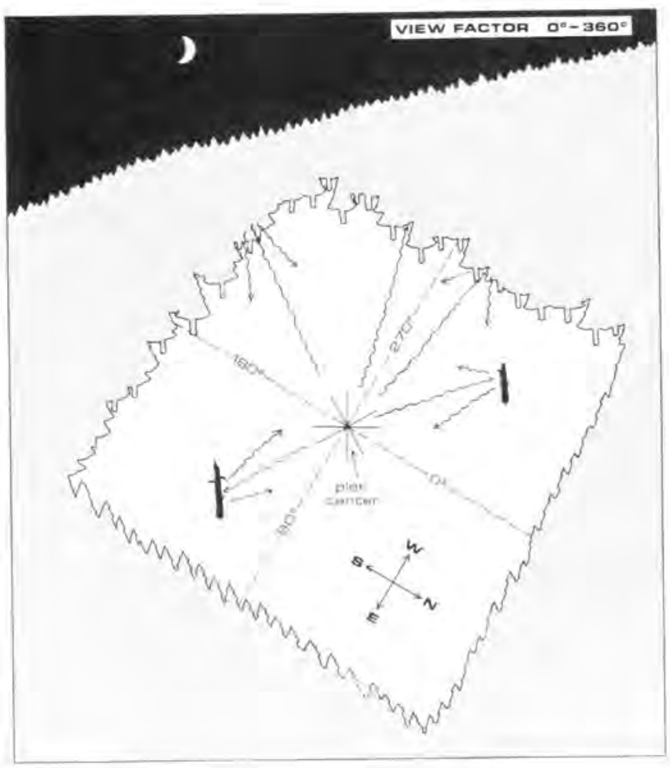


Fig. 11 View factor provides a measure of exposedness of sites within clearcuts. Technically, it is the amount of radiation leaving a point (plot center) that is intercepted by other surfaces (Reifsnyder and Lull, 1965). It was estimated by averaging the height of objects surrounding a plot.

The plots in our study area had view factors ranging from 0 to about 55%, with most falling in the 0 to 40% range. As with shade duration, we did not measure protection from smaller objects, which may be very important. Seedling densities were generally greatest where view factor was between 20% and 35%, although the results were not statistically significant.

Nutrients

We did not evaluate soil nutrient levels in our study, but further research may find nutrients are related to regeneration success in the PSFZ. PSFZ soils are generally poorly developed and low in nitrogen (Gessel and Cole, 1973). The effect of nitrogen levels in the PSFZ on seedling survival and growth needs to be evaluated. R. O. Teskey (University of Washington, personal communication, 1982) found that shoot/root ratio in Pacific silver fir seedlings decreased with decreasing nitrogen, but hypothesized this may actually be beneficial, because seedlings with greater absorptive capacity in relation to transpirational surface resist drought better. However, the effect on later growth may be negative. C. Topik (University of Oregon, personal communication, 1982) found that the proportion of a site's organic matter (and thus, nutrient capital) resident in litter and duff layers (as opposed to incorporated in mineral soil) increased significantly with elevation. Thus, destruction of litter and duff in high elevation clearcuts may severly deplete available nutrients.

Topography

See Part 2 for additional discussion of slope position. Generally, sideslopes are more easily reforested than valleys, ridges or flat areas. The fact that planted seedlings in the Mt. Adams ecological subunit (in contrast to the others) seemed to do better on flat areas than slopes, in spite of extreme surface conditions (Snyder et al, 1968), is worth investigating. The results of such a study may help increase the success of reforestation efforts on flat areas in other parts of the PSFZ where flat topography is common.

Seedbed Type

While seedling density and growth did not vary significantly by seedbed type, stocking was generally highest on bare or stony soil and least in dead wood, litter, and duff. This raises the question of effect of seedbed type on survival of natural seedlings. Cochran (1969) demonstrated that sites composed of pure litter and duff are unfavorable for emergent seedlings because: (1) surface temperature fluctuates greatly, and (2) they conduct heat to the rooting zone very slowly. The decomposing plant tissues in litter also hold water that might otherwise be available to plant roots. On the other hand, scarification may remove the existing organic matter (and nutrients) or protecting objects that ameliorate the seedling environment. Residual Pacific silver fir seedlings, for the most part rooted in deep duff, often were denser and grew faster that other seedlings, even though results were not significantly different. Once established, seedlings in our area seem to grow in any suitable substrate found in a clearcut, but the effects on survival of seedlings of different origins and species need to be examined.

PART 2 - SURVEY OF REFORESTATION IN PACIFIC SILVER FIR ZONE CLEARCUTS

INTRODUCTION

In 1979 and 1980, a survey of PSFZ clearcuts on the Gifford Pinchot, Mt. Hood and Willamette National Forests in Oregon and Washington was carried out. Our purpose was to develop hypotheses regarding the failure to obtain adequate and timely regeneration in many PSFZ clearcuts and to assist timber managers in prediction of future problems and appropriate remedies.

Our sampling strategy was designed to characterize the various environmental conditions found in PSFZ clearcuts within each of six ecologically and geographically distinct subunits. Our intention was not to study individual clearcuts as discrete units, but to focus on different types of sites.

Temperature, moisture, and solar radiation are the primary environmental factors we studied. We analyzed several site factors, all of which relate directly or indirectly to temperature, moisture, and insolation, to see which are useful predictors of reforestation problems or successes. At the same time, we assessed the relationships of seedling origin and species, and seedbed condition.

Because of high environmental variability within the area surveyed, we found few statistically significant relationships on our data analysis. We did isolate some important relationships between environment and regeneration, and pointed out many possibilities for further research.

THE STUDY AREA

This survey was carried out on six subunits (two on each of the three participating National Forests) in the PSFZ west of the Cascade Crest, between the Cowlitz River in Washington and the Calapooya divide near Diamond Peak in Oregon (Figs. 12a and b). Subunits were differentiated on the basis of geology, topography, vegetation, and soils. Table 2 summarizes some of the major characteristics of the six subunits. More complete descriptions of these ecological subunits are in an Appendix available from the Willamette National Forest Supervisor's Office, Eugene, Oregon.

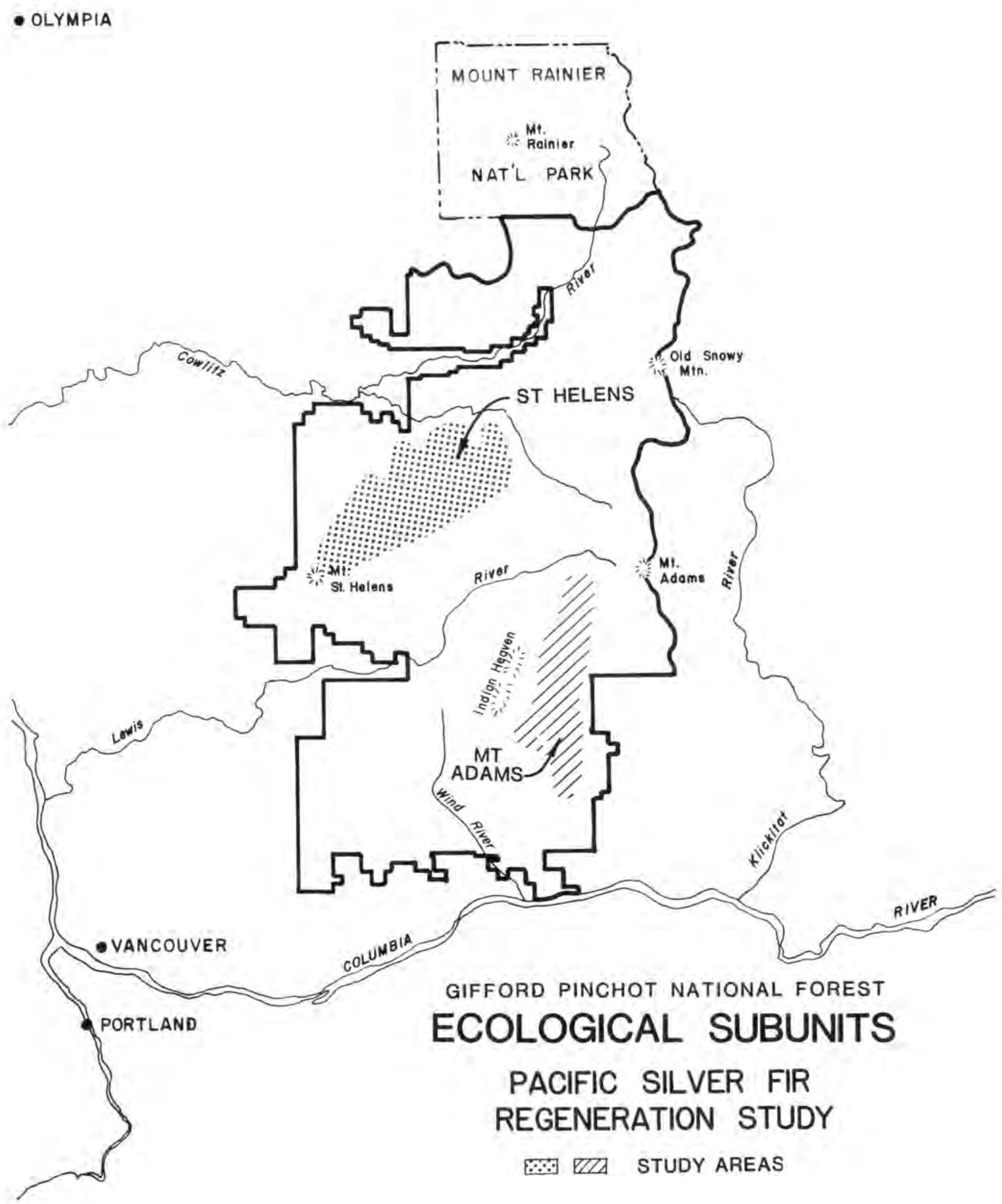

OLYMPIA
MOUNT RAINIER
Mt. Rainier
NAT'L PARK
River
Cowlitz
Old Snowy Mtn.
ST HELENS
Mt. St. Helens
River
Mt. Adams
River
Indian Heaven
Lewis
MT ADAMS
Wind River
Klickitat
RIVER
VANCOUVER
COLUMBIA
PORTLAND
GIFFORD PINCHOT NATIONAL FOREST
ECOLOGICAL SUBUNITS
PACIFIC SILVER FIR
REGENERATION STUDY
STUDY AREAS

Fig. 12a

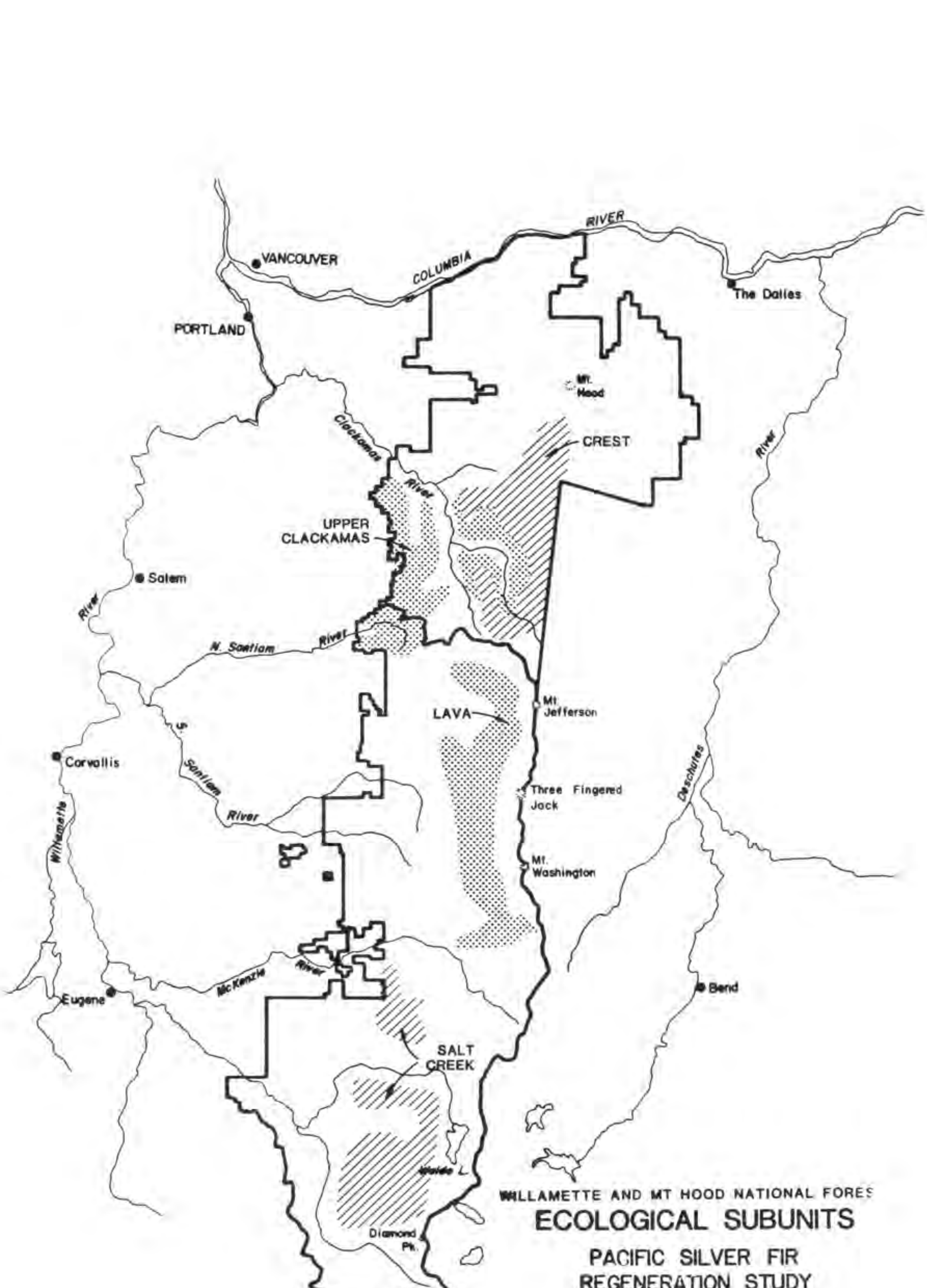

RIVER
COLUMBIA
VANCOUVER
PORTLAND
The Dalles
Mt. Hood
Clackamas
River
CREST
UPPER CLACKAMAS
Salem
River
N. Santiam
River
Mt. Jefferson
LAVA
Corvallis
Santiam
River
Three Fingered Jack
Mt. Washington
Deschutes
Willamette
McKenzie
River
Eugene
Bend
SALT CREEK
Waldo L.
Diamond Pk.
WILLAMETTE AND MT HOOD NATIONAL FORES
ECOLOGICAL SUBUNITS
PACIFIC SILVER FIR
REGENERATION STUDY
STUDY AREAS

Fig. 12b

TABLE 2. Some Characteristics of Six Ecological Subunits in the Pacific Silver Fir Zone.

	Gifford Pinchot NF		Mt. Hood NF		Willamette NF	
	St. Helens	Mt. Adams	Upper Clackamas	Crest	Salt Creek	Lava
Physiographic Province	Western (Old) Cascades	High Cascades	Western (Old) Cascades	High Cascades	Western (Old) Cascades	High Cascades
Topographic[1] Relief	Rolling, Undulating	Undulating Flat	Rolling	Undulating, Flat	Dissected, Rolling	Rolling, Undulating
Elevation Range-feet (Meters)	2400-4300 (730-1310)	3000-4300 (910-1310)	3200-4500 (975-1370)	3500-4200 (1060-1280)	3500-5900 (1060-1800)	3500-5000 (1060-1525
Soil Parent Material[2]	Surface layers dominated by volcanic ejecta including popcorn pumice. Colluvial & glacial material from basalt & andesite.	Volcanic ejecta over residual & glacial andesite.	Colluvial, residual, & glacial material from basalt and andesite.	Colluvial, residual, material from basalt & andesite.	Volcanic ejecta glacial, residual & colluvial materials from basalt & andesite. High surface pumice content.	Volcanic ejecta glacial, residual & colluvial materials from basalt & andesite. High pumice content.
Climate[2]	Cool, moist growing season; little summer drought	Decreasing annual & growing season precipitation.	Increasing growing season temperature, summer drought.	Increasing growing season temperature, summer drought.	Warm dry growing season; marked summer drought.	Increasing growing season temperature, summer drought.
Forest Characteristics (Pacific Silver Fir Zone)	Confined to ridges, high proportion of Pacific silver fir, associated with Douglas-fir and w. hemlock.	Continuous. Stand has mixed species, showing influences of eastern Cascades.	Same as St. Helens with the addition of noble fir.	Similar to Mt. Adams. Mt. hemlock important at higher elevations.	Confined to ridges. Major spp. are Pacific silver fir, noble fir-Shasta red fir, Douglas-fir.	Fairly continuous. Major species are of Pacific silver fir, Douglas-fir w. & Mt. & hemlock & noble fir.

1/ In order of steepness: flat, undulating, rolling, dissected.

2/ From Franklin, 1965.

DATA COLLECTION & ANALYSIS METHODS

Fig. 13 displays the variables measured in this study.

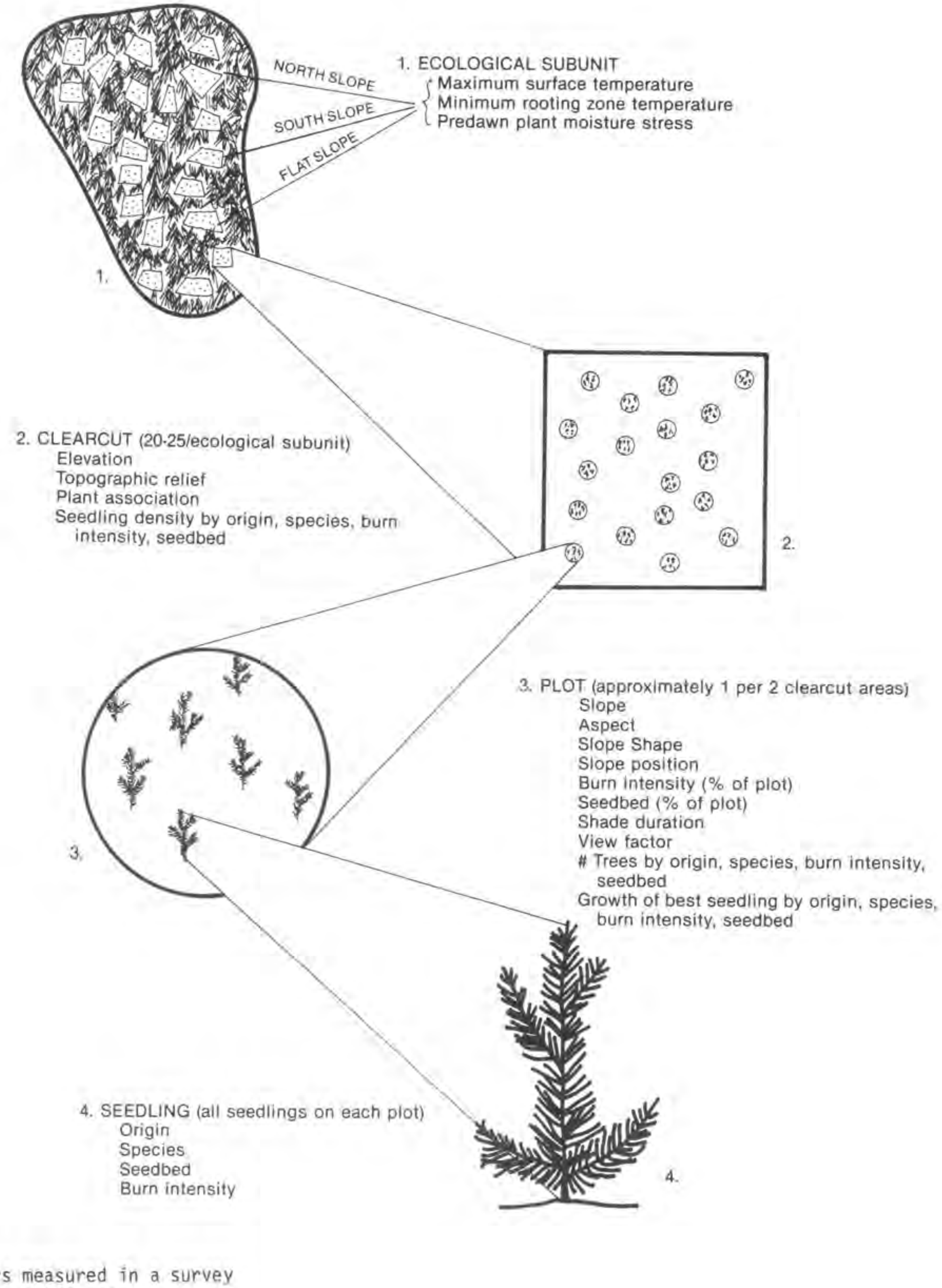


Fig. 13 Factors measured in a survey of Pacific silver fir zone clearcuts.

ECOLOGICAL SUBUNITS

In all phases of data analysis except for plant moisture stress, surface and rooting zone temperature, data from different ecological subunits were treated as separate data sets. In each subunit, three clearcut sites were selected (one each on a north, south and flat aspect, Table 3) on which to measure maximum temperature at the soil surface, minimum rooting zone temperature and predawn plant moisture stress (PPMS). Surface maxima were obtained by the use of Tempil temperature-sensitive wax pellets ranging in melting temperature from 51° to 73° C., placed at the soil surface. Rooting zone minima were measured by maximum-minimum thermometers buried in the soil at a depth of 20 cm. Surface maxima and rooting zone minima were recorded every two weeks from June to October, 1979, from one site per clearcut.

TABLE 3. Aspect, Slope and Elevation of Clearcuts Selected for Measurement of Predawn Plant Moisture Stress and Soil Temperature

Ecological Subunit	North Aspect Slope (%)	North Aspect Elevation (ft.)	South Aspect Slope (%)	South Aspect Elevation (ft.)	Flat Slope (%)	Flat Elevation (ft.)
St. Helens	27	3320	40	3900	--	Not. Rec.
Mt. Adams	20-25	2900	20-25	3300	--	2600
Upper Clackamas	55	4250	44	4350	--	3200
Crest	Not Recorded		Not Recorded		--	3575
Lava	20	5000	14	3800	--	3755
Salt Creek	30	4500	50	4800	--	5200

PPMS for planted and natural Douglas-fir, Pacific silver fir and noble seedlings approximately 0.5 m tall was measured with a pressure bomb. Readings were made once per month from June to October, between 2300 and 0400 hours. Measuring PMS at night gives an indication of a seedling's ability to balance daytime moisture loss with water uptake.

Soil temperatures for each subunit were graphed and compared to critical temperatures for seedling growth--50° C. maximum at the surface for emergent seedlings (Silen, 1960), 15° C. minimum (Cleary and Waring, 1969) and 2°-3° C. minimum (Hinckley et al., 1981) in the rooting zone for Douglas fir and Pacific silver fir/noble fir respectively.

Analysis of variance (factorial design) was used to assess differences in PPMS based on aspect, species, origin and month of reading.

CLEARCUTS

A total of 125 clearcuts, between 20 and 25 per ecological subunit, were selected for sampling. Candidate clearcuts must have been planted or replanted between spring 1974 and spring 1977. This ensured a pool of established planted seedlings past the planting-check stage, yet largely free of the effects of competing vegetation. Our objective was to examine a planted seedling's environment as it existed shortly after planting.

We selected clearcuts that had an adjacent undisturbed stand which could be used to determine the plant association of the sampled clearcut. We tried to avoid clearcuts with highly heterogeneous vegetation or topography, to minimize within-clearcut variability. The selected clearcuts represented the range of environmental conditions found within each ecological subunit.

Four data items were recorded for each clearcut. Midpoint elevation was obtained by averaging altimeter readings from plots. Topographic relief was recorded by placing each clearcut in one of four categories according to the ruggedness of its topography: (in order of increasing ruggedness) flat, undulating, rolling, dissected. Plant association was inferred from an examination of the vegetation in the clearcut and that of the adjacent stand. Stands used for this purpose had slope, aspect, elevation, soil type and climax plant species equivalent to those of the adjacent clearcut. Plant associations in the study area are described in Emmingham and Hemstrom (1981) and Hemstrom et al. (1982). Number of trees per acre (seedling density) for each clearcut were obtained by averaging plot data. Percent mortality was estimated by comparing Ranger District records of numbers and species planted to plot measurements of planted trees remaining.

Non-linear regression was used to analyze the relationship between seedling density and elevation. Analysis of variance was used to assess differences in seedling density among clearcuts based on topographic relief. Since our method for determining mortality yielded only a rough estimate, the data were not statistically analyzed.

PLOTS

Within each clearcut, one-hundredth-acre plots were located on a systematic grid using a random starting point. The number of plots per clearcut was based on clearcut size and varied among the ecological subunits; on the average we sampled one plot per two clearcut acres. We avoided locating plots in sites which would not normally be stockable, such as streamcourses or large rock outcroppings. Ten data items were recorded for each plot. Slope percent was measured with a clinometer, and slope aspect (degrees azimuth) was determined with a compass. Slope position was categorized as either a valley bottom, midslope, ridgetop or large flat area several 10's of acres in size. Burn intensity was recorded as the percent of a plot in each of three classes: unburned or low (some litter or duff intact, logs no more than scorched); moderate (loss of surface material, logs partially burned); or extreme (surface completely exposed and reddened, logs severely burned). Seedbed material was recorded as the percent of a plot with each of six substrates as a rooting medium for plants: bare soil, stony soil, gravelly soil, bedrock, duff ≥ 1 inch thick, or dead wood.

The duration of shade potentially available to plots (assuming no cloud cover) on a typical midsummer day was determined using a comparison of the height of objects on the southern horizon and the altitude (height) of the sun (Fig. 10) (Geiger, 1965). We used a clinometer to measure the angle from the plot center to the top of surrounding objects at 15-degree increments from 90^{0} to 270^{0} azimuth. Since the sun travels across the sky at 15 degrees per hour, the number of 15-degree increments shaded approximates the number of hours of shade received during the day. Solar altitudes for the reference date (July 22) and the appropriate latitude were obtained from Buffo, et al, 1972. The midsummer reference date provided an index to minimum shading. The number of shaded increments (those where the height of surrounding objects was higher that the solar altitude) was then summed to give the duration of daytime shade. The methods of determining shade duration and view factor (below) are more fully documented by Halverson (manuscript in preparation).

VIEW FACTOR is a measure of the "exposedness" of a site, particularly to nighttime reradiation of heat (Reifsnyder and Lull, 1965; Cochran, 1969), which influences the frequency and intensity of frost. It is a function of the height of surrounding objects above the horizon (regardless of direction), which in turn depends on clearcut size, shape, and the distance of the plot from and the actual height of the surrounding objects (Fig. 11). View factor was measured using a clinometer to determine the angles between the plot center and the top of surrounding objects at 30-degree increments from 0^{0} to 90^{0} and 270^{0} to 360^{0} azimuth plus the 15-degree increments from 90^{0} to 270^{0} azimuth used to calculate shade duration. This gave 18 measurements of the proportion of the hemisphere of space above the plot center that was protected by surrounding objects. The 18 readings were then averaged to give an index of exposure (view factor) for the entire plot.

To obtain number of trees per acre, each conifer tree seedling between 0.1 m and 2 m tall on a plot was counted and placed into a category based on four attributes: species, origin (planted, advance regeneration or post-harvest natural), burn intensity and seedbed material in which the seedling was rooted. For each category, the best 1978 leader growth was then measured, to give an estimate of the maximum potential growth for each seedling category.

Linear and polynomial regression were used to separately evaluate the relationships between number of trees per acre and 1978 leader growth (dependent variables), and slope, aspect, shade duration and view factor (independent variables). In addition, we used multiple regression to see which combinations of the above independent variables could best predict stocking and growth. Slope position, burn intensity and planting medium were also analyzed separately using one-way analysis of variance, with density and growth as dependent variables. Differences between category means were analyzed using Duncan's New Multiple Range test.

SEEDLINGS

For each coniferous tree seedling on a plot, four items were recorded: species, origin (planted, advance regeneration or post-harvest natural[8]), seedbed material (bare soil, stony soil, gravelly soil, duff≥1 inch thick, bedrock or dead wood) and burn intensity (unburned or low, moderate, extreme).

Number of trees per acre and growth among plots for each of the four factors were analyzed separately using one-way analysis of variance and Duncan's New Multiple Range test. An additional analysis was made combining species and origin into one set of treatments.

RESULTS

Note: The following definitions are in effect throughout this paper:

> seedling density (trees per acre) = (total number of seedlings tallied/total # of plots) x 100
> stocking = percent of total plots with one seedling between 1 dm and 2 m tall.

Average seedling density by ecological subunit ranged from 350 to 570 trees per acre in the study area (Fig. 14). The St. Helens ecological subunit, most northerly of the six, had both the highest density and the most stocked plots[9] (96%). The lowest density was found in the Salt Creek subunit, at the south end of the study area, while the Crest ecological subunit had the least stocked plots (79%).

Mean 1978 leader growth of the best-growing seedlings in each species/origin/burn intensity/seedbed category on plots ranged between about 9 cm and 15 cm (Fig. 14), with growth in the St. Helens and Lava subunits exceeding that of the other four.

SURFACE TEMPERATURE

Maximum surface temperatures on north, south, and flat aspects in our study area regularly exceeded 50° C. when recorded at 2-week intervals during July, August, and September (Fig. 15). North aspects often had slightly lower maxima than south slopes, but still exceeded the lethal limit for emergent Douglas-fir. Surface temperature was higher in the ecological subunits farther south, reflecting the greater likelihood of sunny conditions. Variation in the pattern of maximum surface temperatures emphasize the fact that it takes only a few minutes or hours of solar radiation to produce intense heat at the soil surface.

ROOTING ZONE SOIL TEMPERATURE

Soil temperatures at 20 cm depth generally warmed in June and July to a peak in early August (Fig. 16), although the patterns fluctuated widely between and sometimes within (i.e., Upper Clackamas) ecological subunits. Rooting zone temperatures of less than 15°-20° C. decrease Douglas-fir root growth (Lavender and Overton, 1972). Temperatures less than 2-3 C slow Pacific silver fir or noble fir root growth (Hinckley et al., 1981).

PREDAWN PLANT MOISTURE STRESS (PPMS)

PPMS, measured in selected established Douglas-fir, noble fir, and Pacific silver fir seedlings on north, south and flat aspects, ranged from 0 to -11 bars (0 to -.10 Mpa) during the summer of 1979 (Fig. 17), with values between -2 and -8 bars (-.2 and -.8 Mpa) predominating. The general pattern of increasing stress through the season fits that observed previously (Waring and Cleary, 1967). In five of the six ecological subunits, drought was relieved in September by rain and reduced evaporative demand. The exception was the Crest subunit where PPMS continued to rise into September. This area is subject to desiccating east winds in September, which may account for the continued moisture stress. In some cases, relatively high stress was encountered as early as July (for example, planted seedlings on the south-sloping clearcut in the Lava subunit). The measured seedlings all recovered sufficiently from daytime moisture stress to survive. There were no consistent differences based on origin or species, and PPMS on south slopes was only 1 bar (.1 Mpa) greater than that on north slopes. The northern-most subunits had less variation seasonally and between stock types and aspects than did the southern subunits.

ELEVATION

Elevation explained little of the variation in density of all seedlings within the study area (Table 4). A contributing factor is that some of the stocking in our clearcuts is advance Pacific silver fir regeneration, which occurs throughout the zone independent of elevation. Density of planted seedlings decreased with increasing elevation on four subunits (St. Helens, Mt. Adams, Upper Clackamas and Crest), suggesting that artificial regeneration is generally less successful as elevation increases, except in the southern, warmer part of the study area.

8/ Advance regeneration seedlings are those that germinated and grew before logging took place. Post-harvest naturals are those seedlings that germinated and grew after logging.

9/ Stocked plots are those with one or more tree seedlings.

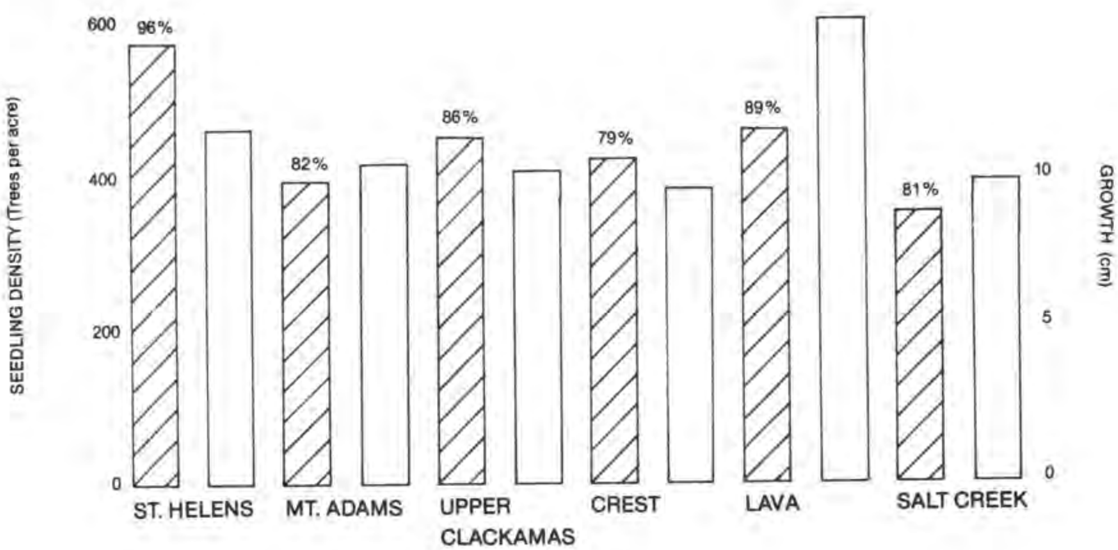
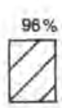


Fig. 14 Average seedling density, stocking and growth on six ecological subunits in the Cascades Pacific silver fir zone.



Seedling density. Numbers above bars indicate percent of 1/100-acre plots stocked with at least 1 seedling.

Mean of total per plot 1978 leader growth of best-growing seedlings in each species/origin/burn intensity/seedbed category on a plot.

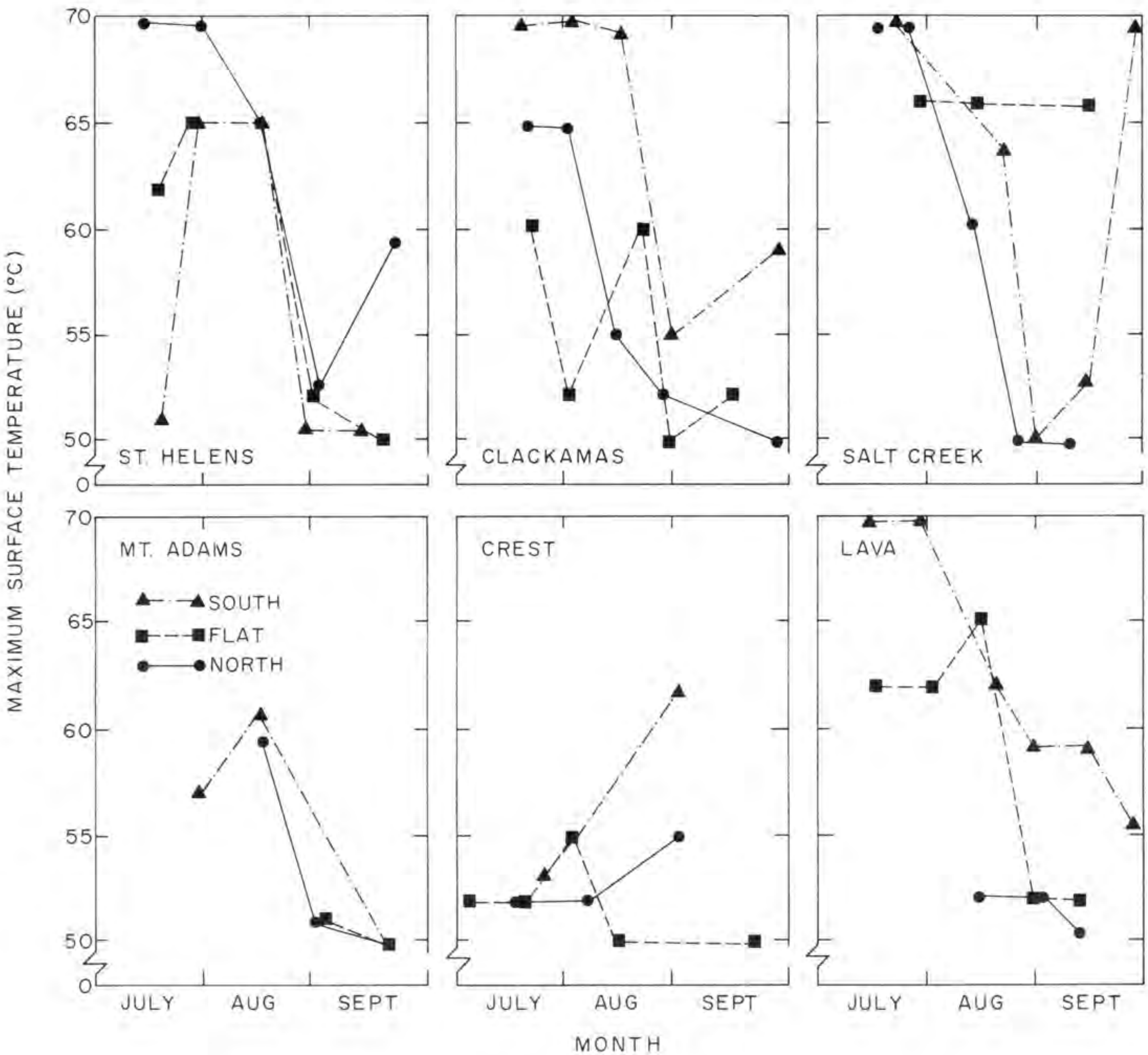


Fig. 15 Maximum surface temperature measured biweekly on a north, south and flat aspect in six ecological subunits in the Cascades Pacific silver fir zone, July-Sept. 1979.

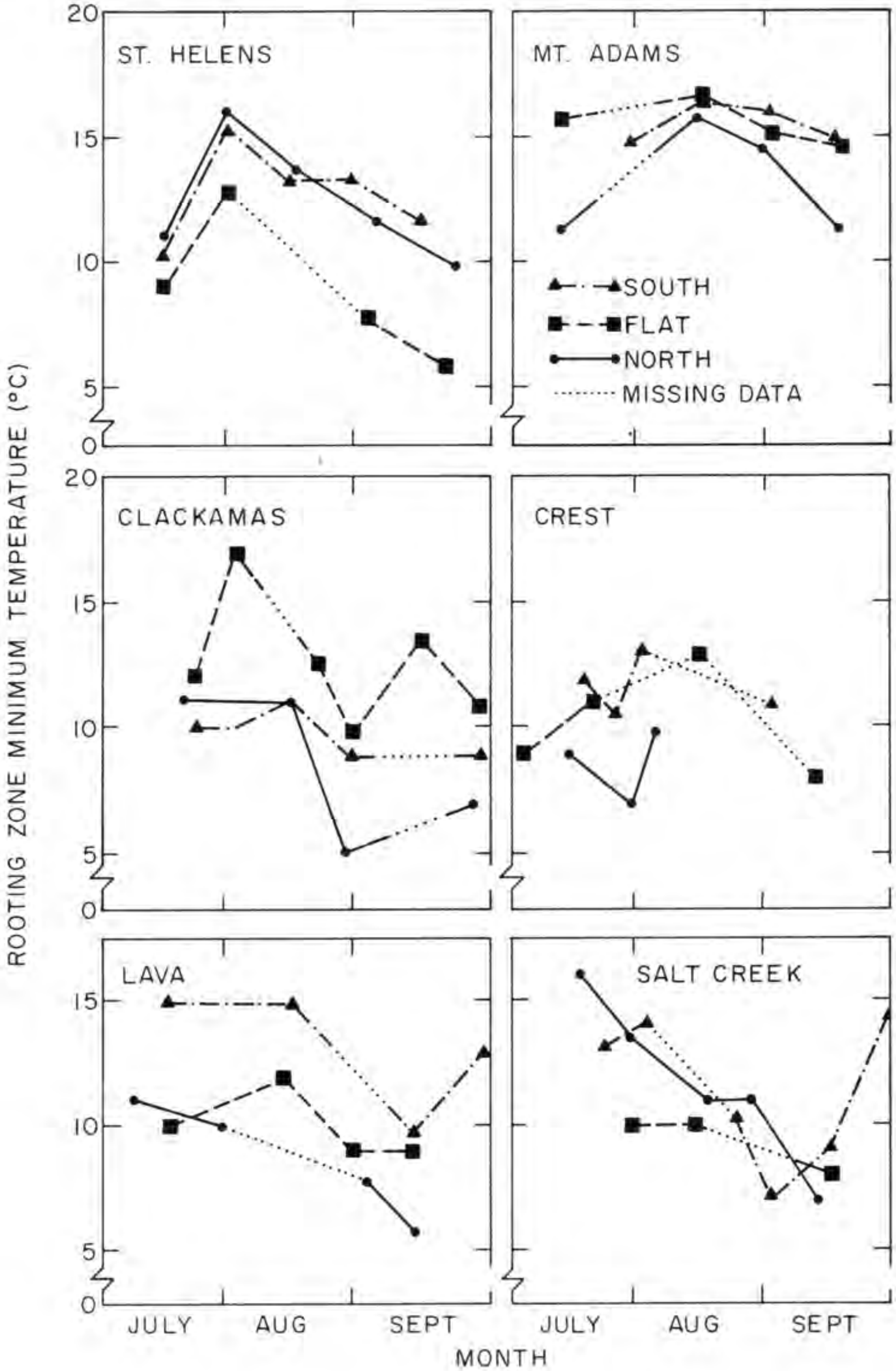


Fig. 16 Minimum rooting zone temperature in six ecological subunits in the Cascades Pacific silver fir zone, July-Sept. 1979.

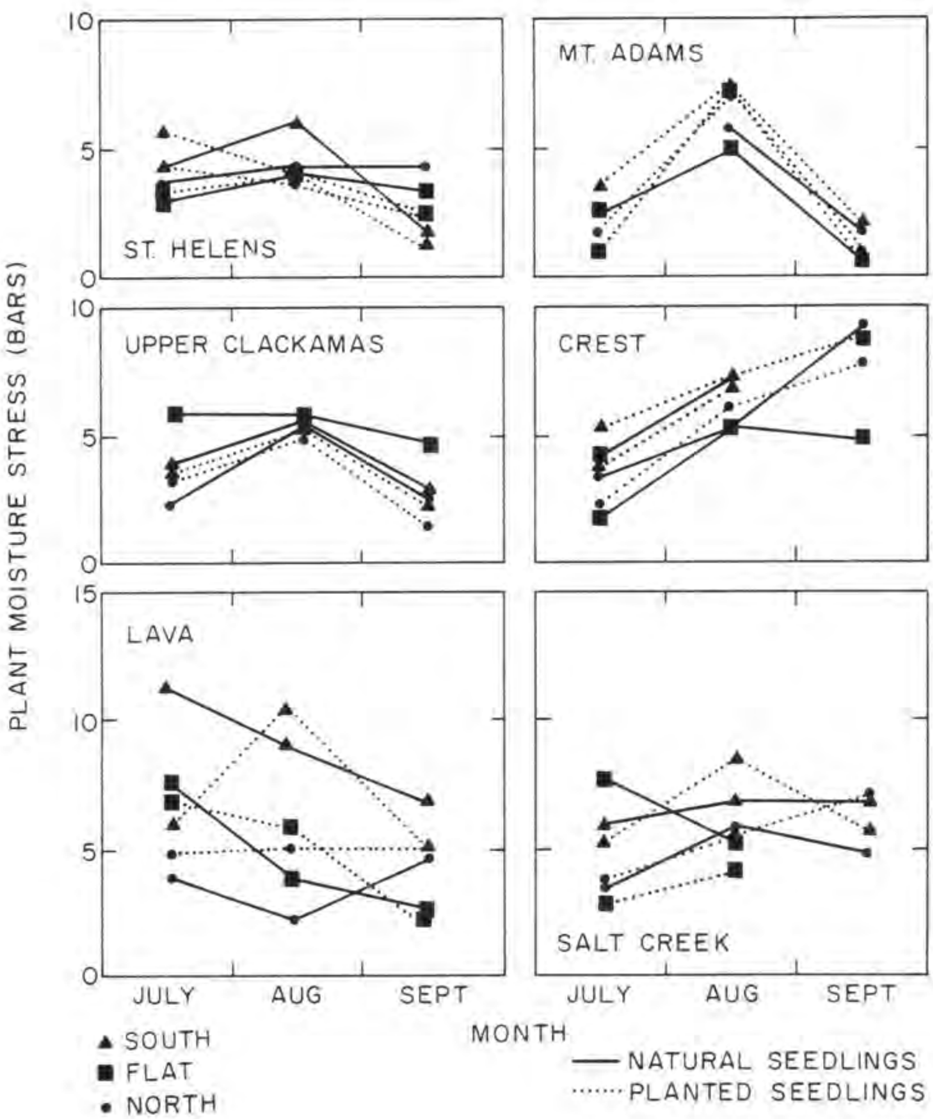


Fig. 17 Predawn plant moisture stress in six ecological subunits in the Cascades Pacific silver fir zone, July-Sept. 1979.

TABLE 4. Percent of elevation-related variation in stocking (R^2 x 100) in six ecological subunits in the Cascades Pacific silver fir zone.

Ecological Subunit	All Seedlings	Planted Seedlings
St. Helens	45%	73%
Mt. Adams	33%	50%
Upper Clackamas	23%	42%
Crest	53%	53%
Lava	30%	12%
Salt Creek	11%	29%

TOPOGRAPHIC RELIEF

Topographic relief (roughness of terrain) and seedling density were significantly related only in the Mt. Adams subunit, where large flat areas had the greatest number of planted seedlings per acre (Fig. 18). Total seedlings were apparently more numerous on flat topography in the Mt. Adams subunit, but the differences were at only the 0.06 level. In all other cases, variability was great and differences in seedling density by topographic class were not statistically significant.

PLANT ASSOCIATIONS

Because even relatively homogeneous clearcuts often appeared to contain more than one plant association, we could not correlate density and growth with plant association.

SLOPE STEEPNESS AND ASPECT

Since slope steepness and aspect are interacting factors that affect temperature and moisture conditions, they were analyzed both separately and together. By itself, slope was never strongly related to seedling density (R^2 never exceeded .10). Aspect by itself was similarly unrelated. When an analysis was done of those plots with slope greater than 20 percent, aspect was a slightly bettter indicator of seedling density; but R-squared values were still very low. The highest seedling densities consistently occurred on the more northerly aspects (which also had greatest variability), while south aspects were generally less variable and had lower seedling density. This corresponds with results obtained by Sullivan (1978) who found stocking of tree seedlings in high elevation clearcuts to be negatively related to radiation index (a variable that integrates slope and aspect) and elevation.

SLOPE POSITION

With the exception of the Mt. Adams ecological subunit, tree seedlings were generally more numerous on sideslopes or ridges than in valleys or flat areas (Fig. 19). In the Mt. Adams subunit, total density and Douglas-fir (planted) seedling density were greatest on flat areas, while planted noble fir was more abundant on sideslopes and ridges. Clearcut records show that more noble fir than Douglas-fir seedlings were planted on sideslopes, explaining the difference between the two species. However, these records also show that Douglas-fir was planted at an average rate of 700 trees per acre on both sideslopes and flat areas, suggesting mortality may have been greater on sideslopes.

BURN INTENSITY

Both overall seedling density and stocking were greater on unburned or low-intensity burned areas than on moderately or severely-burned areas (Fig. 20). Growth did not appear to vary by burn intensity, but the shortage of severely burned plots may have influenced this result. The results reflect the high density of residual Pacific silver fir in some unburned areas.

SEEDBED TYPE

Stocking was greatest on stony (St. Helens, Upper Clackamas, Crest, and Salt Creek subunits) or bare (Mt. Adams, Lava) soil in our study area (Fig. 21). Seedbeds composed primarily of dead wood, litter, or duff were less often stocked with tree seedlings. Seedling density and growth did not vary significantly by seedbed type, and there was great variability within types.

SHADE DURATION

Our analysis of shade duration and seedling density failed to show any significant correlation. We measured only shading from the adjacent stand and not that from short objects within the plot. Shade from small objects may be extremely important to the survival of seedlings because it ameliorates environmental extremes for small seedlings without preventing soils from warming.

VIEW FACTOR

We found no significant relationship between seedling density and exposure as measured by view factor.

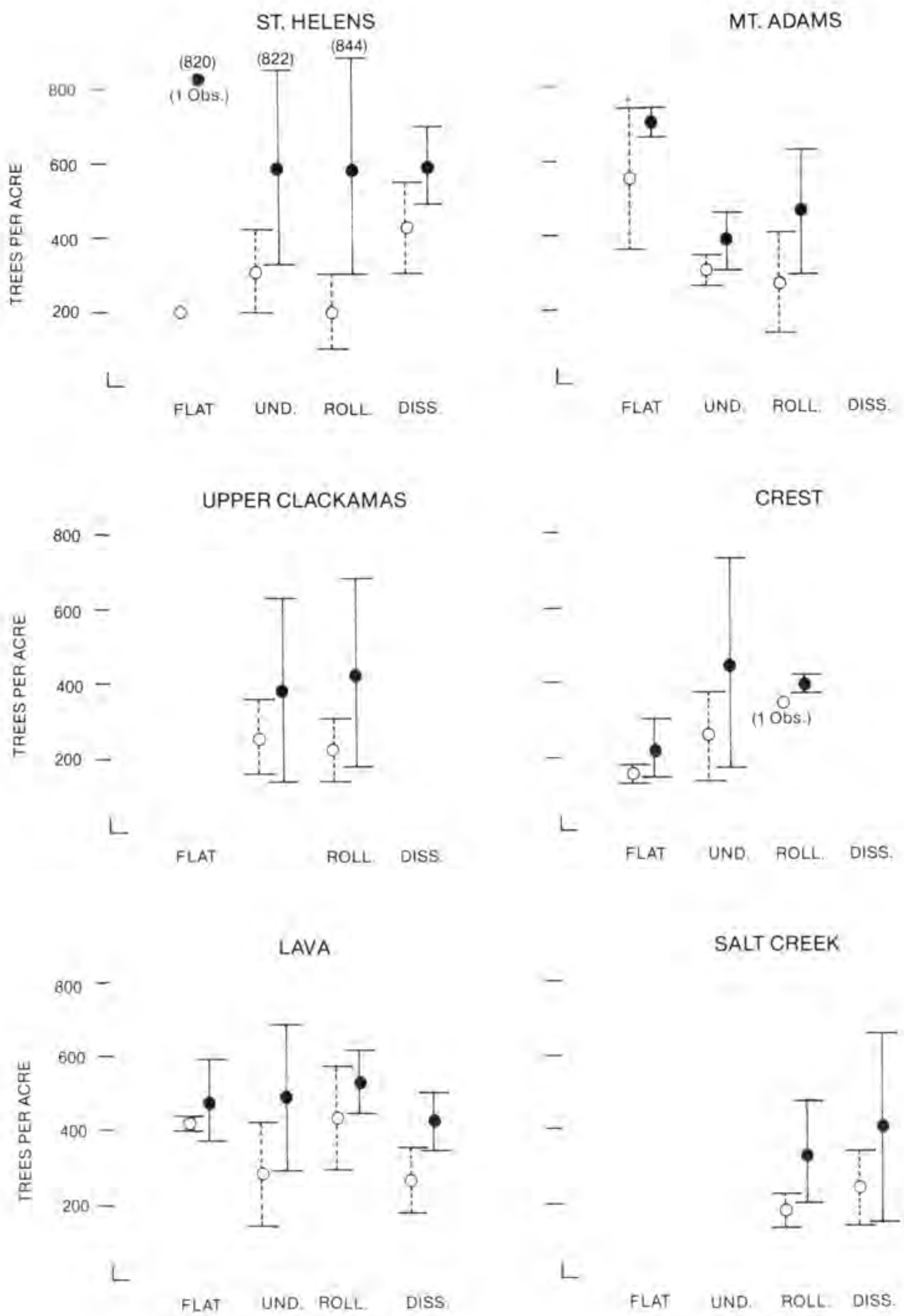


Fig. 18 Seedling density by topographic relief class (flat, undulating, rolling or dissected) on six ecological subunits in the Cascades Pacific silver fir zone. Bars are ± 1 standard deviation from the mean. None of the differences were statistically significant.

——— All seedlings

– – – – – Planted seedlings

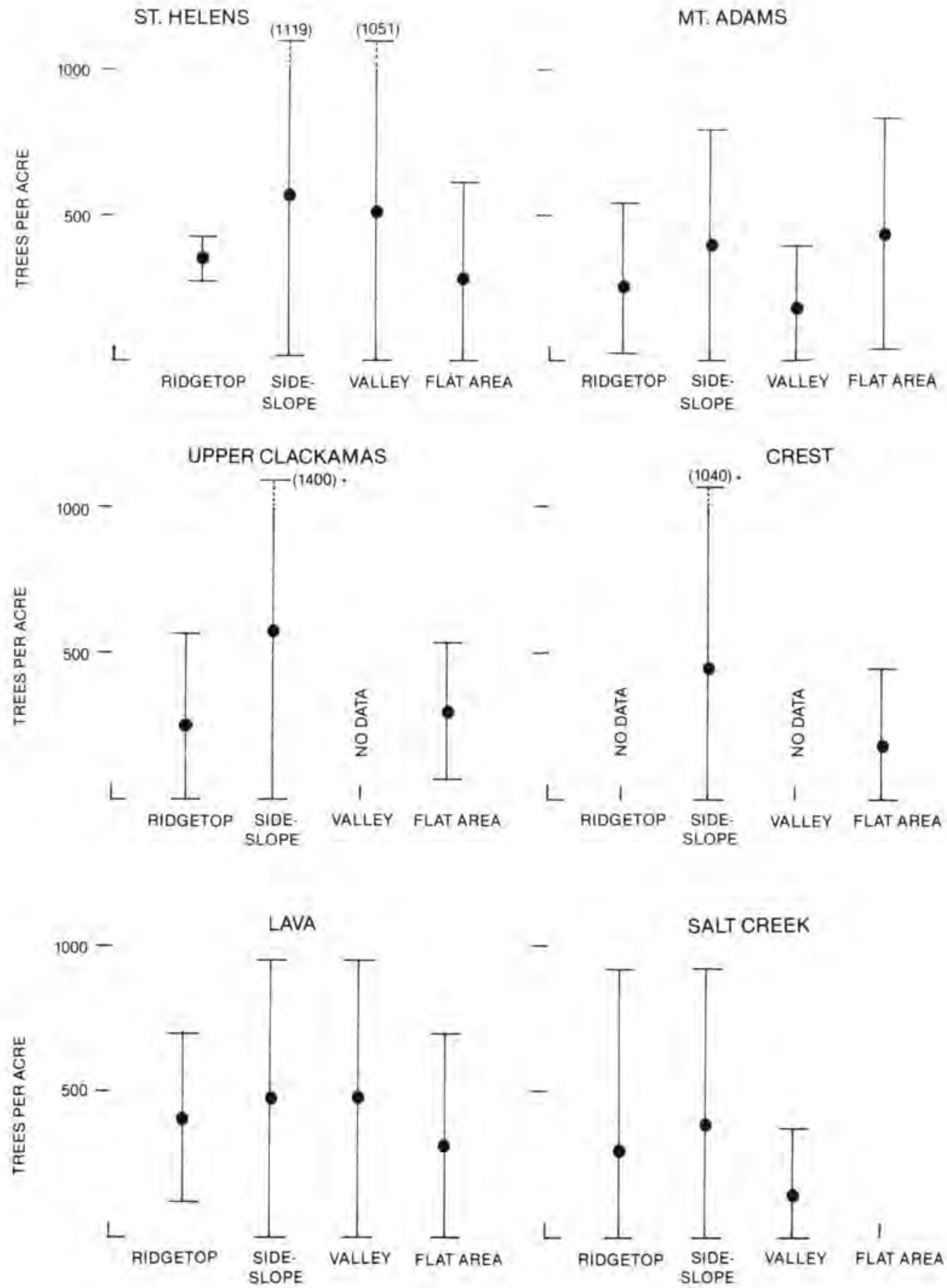


Fig. 19 Seedling density by slope position. Bars are ± 1 standard deviation around the mean.

* Statistically greater than other categories at the 5% level of significance.

O ALL SEEDLINGS X PLANTED DOUGLAS-FIR O PLANTED NOBLE FIR

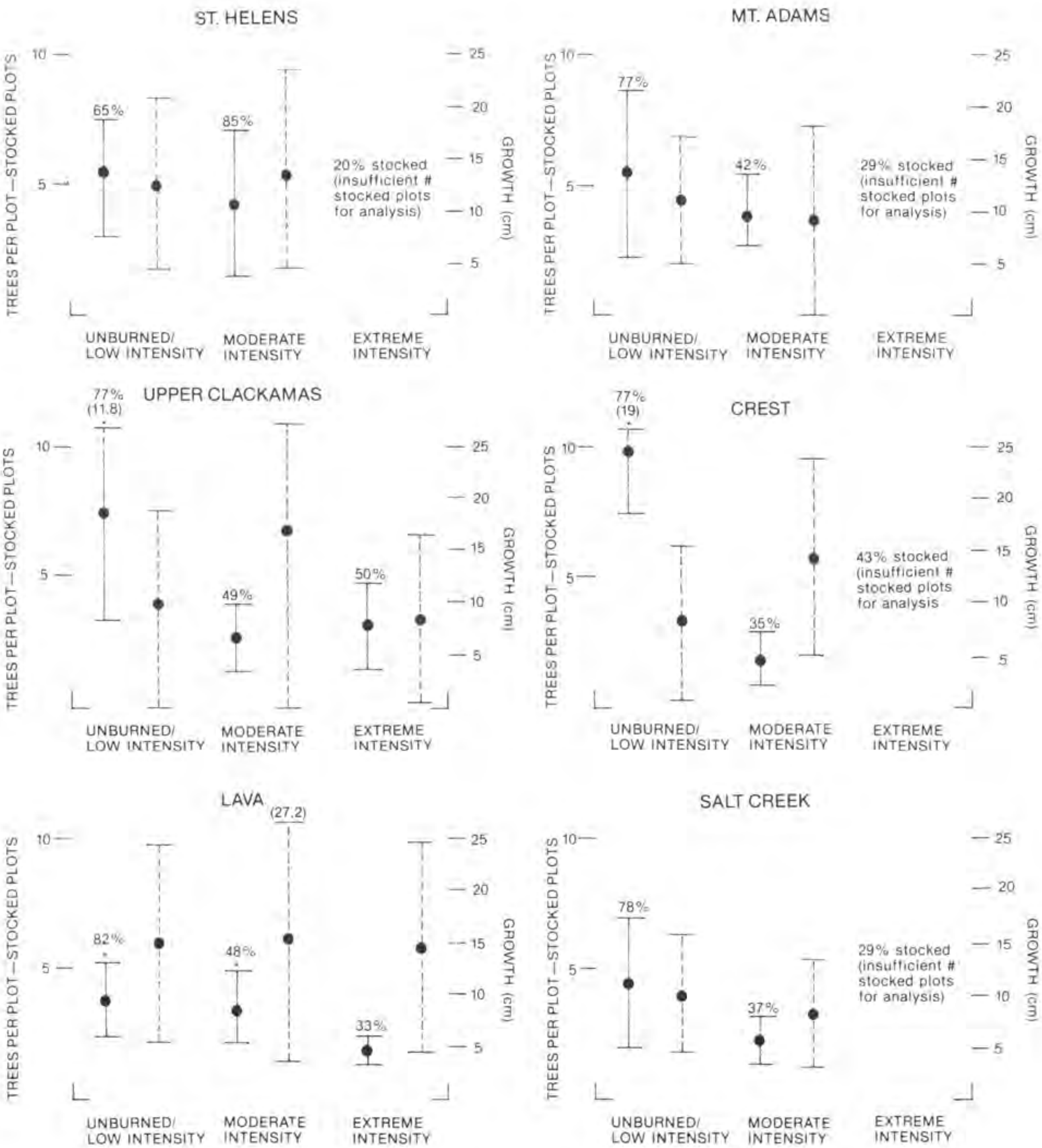


Fig. 20 Seedling density on stocked plots, growth and percent of stocked plots by burn intensity on six ecological subunits in the Cascades Pacific silver fir zone. Bars are ± 1 standard deviation around the mean. Small numbers above seedling density bars indicate percent of plots in each category with one or more seedlings.

* Statistically greater than other categories at the 5% level of significance

———— Seedling density

— — — — Average 1978 leader growth of best-growing seedlings in each burn intensity category on a plot

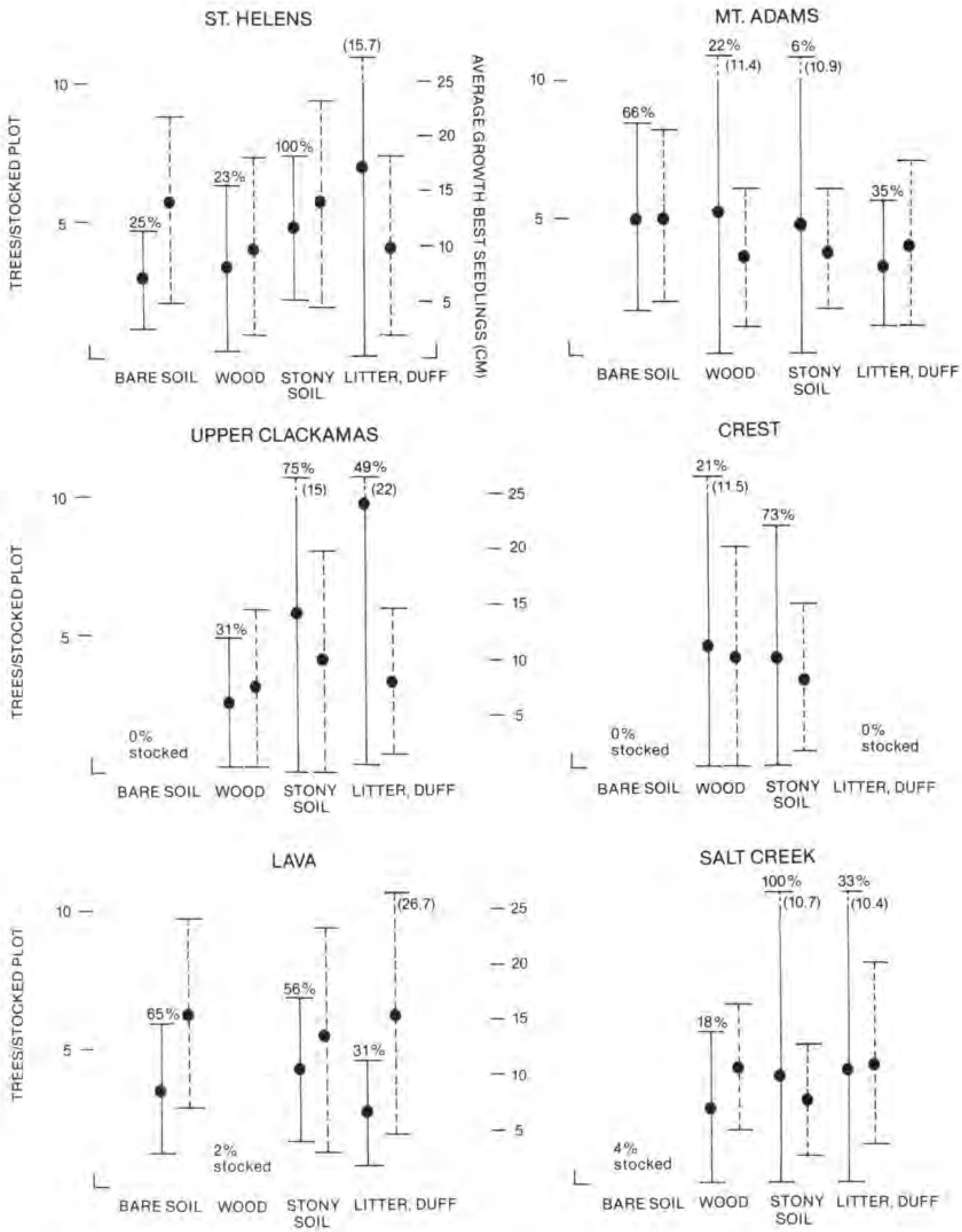


Fig. 21 Density, stocking and growth of seedlings by seedbed type. Bars are ± 1 standard deviation around the mean. Numbers above density bars are % of plots in each category with ≥ 1 seedling.

——— Density   – – – – Average 1978 leader growth of best-growing seedlings in each seedbed type on a plot.

SEEDLING ORIGIN AND SPECIES

Planted Douglas-fir and noble fir occurred on far more plots than natural Pacific silver fir (39% and 30% vs. 8%), but were not usually as dense (mean densities of 2.8 and 2.6 vs. 4.7 trees per stocked plot) (Fig. 22). This is partly because planted seedlings are usually more widely spaced than natural residual Pacific silver fir and partly because mortality in planted seedlings in the PSFZ is high. Since strongly suppressed residual Pacific silver fir seedlings sometimes are so small as to appear very young, we suspect that the post-harvest natural category actually included some advance Pacific silver fir regeneration that the data collectors did not recognize as such. Figure 22 may therefore underestimate the significance of residual Pacific silver fir. Height growth (Fig. 23) did not vary significantly by species and origin, although the maximum values are generally achieved by natural (residual or post-harvest) Pacific silver fir and planted Douglas-fir.

DISCUSSION

Numerous interacting factors influence the density and growth of conifer seedlings in clearcuts, making it difficult to separate the effects of individual factors. A great amount of unexplained variation in stocking in clearcuts has been found in our study and others (Carkin and Minore, 1974; Seidel, 1979). Stocking is a function of the density of seeds, planted seedlings or residual trees modified by inherent genetic characteristics, man's activities and environmental conditions.

Several site factors appear to be significantly related to seedling density, stocking and growth: temperature and moisture conditions from the surface to the rooting zone, slope position, burn intensity, and seedling origin and species.

TEMPERATURE AND MOISTURE CONDITIONS

High temperature may have an extremely adverse effect on emergent seedlings. Silen (1960) found high mortality in emergent Douglas-fir at surface temperatures above 50^{o} C. Minore (USDA - Forest Service, personal communication, 1982) observed virtually 100% mortality in emergent seedlings in experiments in high elevation clearcuts, probably attributable to heat and moisture stress. We did not observe heat damage to stems of planted seedlings, suggesting that by planting age (usually two years in our area), sufficient bark has developed to insulate the cambium (Meador, 1979). Since we frequently measured surface temperatures above 50^{o} it seems likely that significant heat-related mortality occurs in emergent natural seedlings.

The greatest effect of high surface temperature on established seedlings is to warm the layers of air near the ground, causing a rise in evaporative demand. Predawn plant moisture stress (PMSS) is a measure of the ability of seedlings to recover from daytime moisture stress caused by high evaporative demand. Seedlings which cannot recharge their water supply at night become increasingly stressed and will die if not watered. At high internal moisture tension, photosysthesis is restricted, reducing carbohydrate accumulation and growth potential.

The moisture stress levels we measured in seedlings were not lethal, but probably reduced growth. In southwest Oregon Emmingham and Waring (1977) found that daytime leaf conductance (which controls transpiration and photosynthesis) in Douglas-fir dropped rapidly as PPMS progressed from -3 to -10 bars (-.3 to -1.0 Mpa), and at -5 bars (-.5 Mpa) was less than half that at -2 bars (-.2 Mpa). Our measurements of PPMS, which did not vary by species or slope aspect, fall within this range, implying significant reductions in photosynthesis.

Cold rooting zone temperatures, especially early in the growing season, limit root growth and mineral and water uptake (Ritchie, 1971; Lavender and Overton, 1972). A substantial decrease in root length of Douglas-fir seedlings occurs between 20^{o} C. and 15^{o} C. soil temperature (Lavender and Overton, 1972). In only a few cases did minimum rooting zone temperatures in our study exceed 15^{o}C. This suggests that root elongation, particularly in off-site Douglas-fir seedlings, may be inhibited by cold soils in the study area, preventing growth into deep layers of soil where moisture is available in the dry season. Roots of Pacific silver fir and noble fir, however, can continue to actively function at temperatures as low as 2^{o} to 3^{o} C. (R. O. Teskey, University of Washington, personal communication, 1981). This is an important adaptation which makes these species better candidates for both natural and artificial regeneration on cold sites.

In summary, since snowmelt at high elevations takes place during high summer insolation, warm air temperatures occur while the ground is still very cold. The temperature gradient between the rooting zone and the surface can be steep. We believe the exposure of planted seedlings (especially if off-site or not thoroughly cold-conditioned) to these conditions is a major factor in their reduced growth and survival.

SLOPE POSITION

Regardless of the ruggedness of the topography, sideslopes (except in the Mt. Adams ecological subunit) in the study area generally had the greatest density of seedlings. We believe this is because cold air drainage on sideslopes is generally better than in valleys or large flat areas, and exposure is less than on ridgetops. Why seedling density should be greatest on flat areas in the Mt. Adams subunit is puzzling. Snyder et al. (1968) showed that these flat areas, which generally have pumice at the surface, have a much greater mortality rate amoung emergent seedlings than the adjacent slopes. Part of the explanation may lie in the fact that established seedlings may actually be rooted in soil layers below the pumice, or perhaps different stock types or seedling handling/planting procedures may have been used.

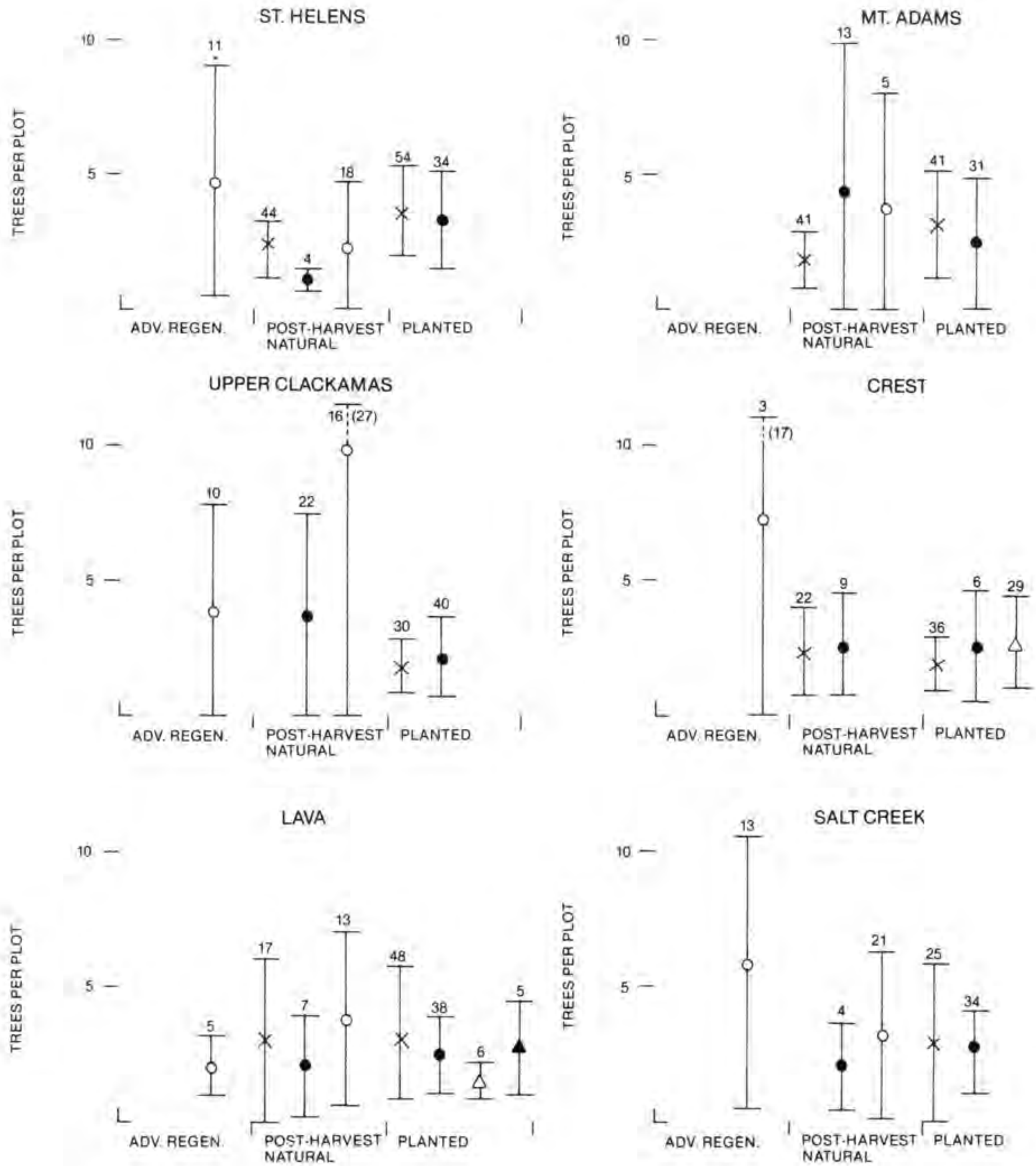


Fig. 22 Seedling density on stocked plots by origin and species for six ecological subunits in the Cascades Pacific silver fir zone. Numbers above bars indicate percent of plots stocked with each category of seedlings. Bars are ± 1 standard deviation from the mean.

* Statistically greater than other categories at the 5% level of significance.

○ Pacific silver fir ✕ Douglas-fir ● Noble fir △ Ponderosa pine ▲ Lodgepole pine

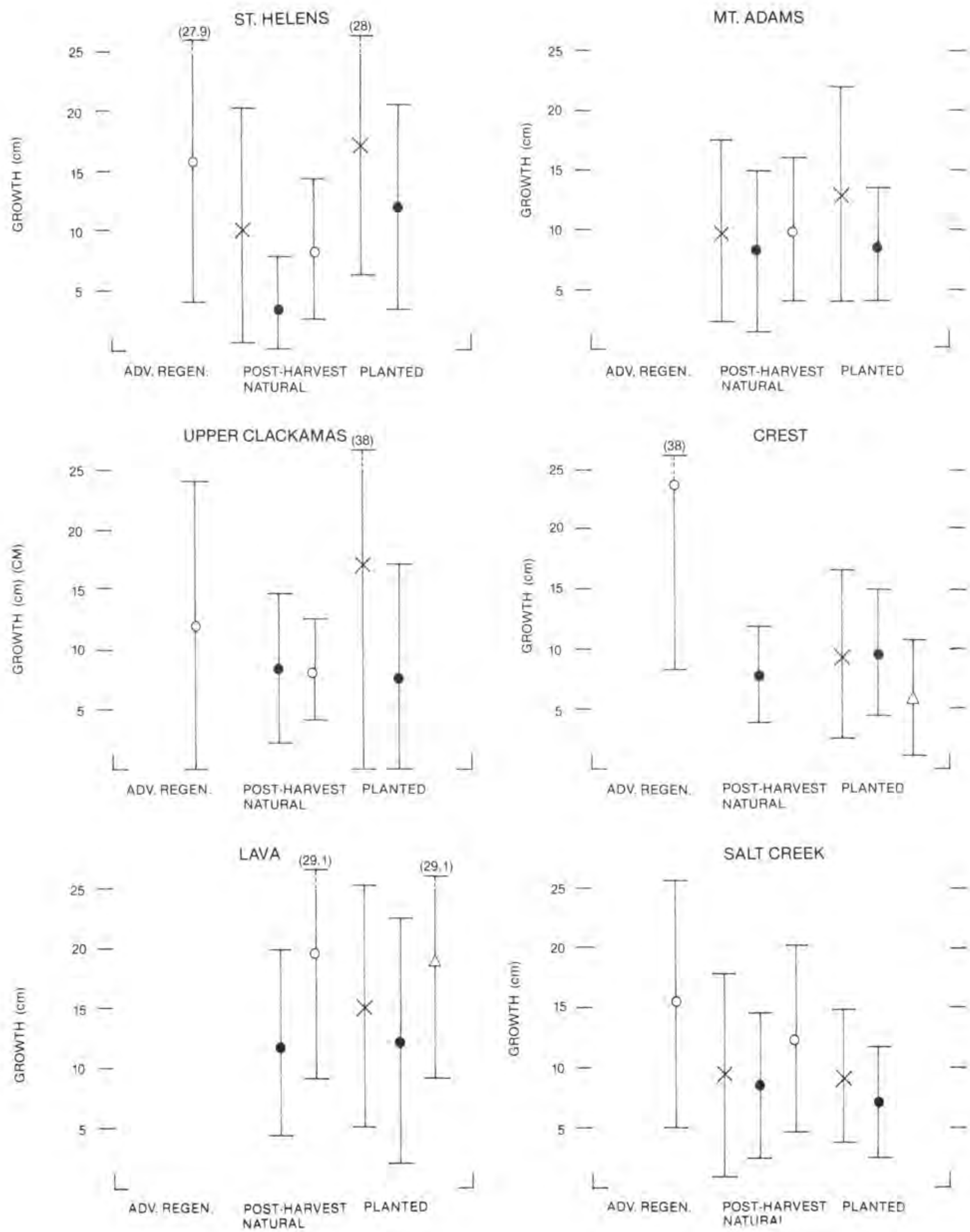


Fig 23 Average 1978 leader growth of best-growing seedlings of each species/origin on a plot. Bars are ± 1 standard deviation from the mean.
O Pacific silver fir ✕ Douglas-fir ● Noble fir △ Ponderosa pine

BURN INTENSITY

Although differences in density between levels of burn intensity were not always statistically significant, unburned or low-intensity burned plots generally have the highest overall seedling density and the highest proportion of stocked plots. This agrees with results obtained by Vogl and Ryder (1969) in clearcuts between 4,750 and 5,600 feet in elevation in the Mission Range in Montana, where burn piles in clearcuts had up to 90 percent less tree reproduction than adjacent unburned areas. In Northern California, Gordon (1970) found survival of seedlings after the first year was greater on sites with litter or slash. Although leaving logging residues on a clearcut may increase fire hazard and prevent some natural seeding from taking place, it may have a favorable effect on the microclimate (Ruth, 1974). Shading reduces temperature extremes and evaporation of moisture from the soil surface. Litter, duff and slash also protect soils from erosion and nutrient loss. Fig. 24 shows the effects of burning vs. not burning on one PSFZ clearcut.

Fig. 24 The road bisects a clearcut, the upper half (right side) of which was successfully burned and the lower half (left side) of which was not. The unburned side is now fully stocked with residual Pacific silver fir. The burned portion is currently understocked.

SEEDLING ORIGIN AND SPECIES

Of the approximately 85.5 percent of our plots with one or more seedlings, less than 1/2 were stocked with planted seedlings, and less than 10 percent had residual Pacific silver fir. The remaining plots contained post-harvest natural seedlings, primarily Pacific silver fir, Douglas-fir, and noble fir. Neither artificial nor natural reforestation has consistently provided good stocking in the Pacific silver fir zone.

The comparison of leader growth between Douglas-fir and noble fir is of interest. Although we expected planted noble fir to grow better than Douglas-fir in high elevation clearcuts because it is more tolerant of cold temperatures, our data actually showed the opposite, although in no subunit were the differences statistically significant. This may be due to the different juvenile height growth patterns between Douglas-fir and noble fir. Douglas-fir is capable of better height growth at an earlier age than noble fir (Franklin, 1981). However, over the long term (100 years), noble fir generally equals or exceeds Douglas-fir in height growth (Williams, 1968). We have often observed better diameter growth in pole-size noble fir compared to Douglas-fir of the same crown class.

Low growth rates for residual Pacific silver fir in three subunits may be a reflection of time since release, rather than true height growth potential. Several years may be required for Pacific silver fir height growth to respond to release since accelerated root growth, diameter growth, and conversion of shade-adapted to sun-adapted leaves all must take place first (Herring and Etheridge, 1976). However, both Williams (1968) and Sullivan (1978) found growth of noble fir and Douglas-fir to exceed that of Pacific silver fir (at equal ages).

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