SERVING SOUTHWEST OREGON THROUGH ADAPTIVE RESEARCH AND EDUCATION

fir report

forestry intensified research

SUMMER 1981 VOL. 3 NO. 2

"FIR REPORT" is a quarterly publication containing information of interest to individuals concerned with forest management in southwest Oregon. It is mailed free on request. Requests should be sent to: FIR REPORT, 1301 Maple Grove Drive, Medford, Oregon 97501.

FIR REPORT communicates recent technological advances and adaptive research pertinent to southwest Oregon, and alerts area natural resource specialists to upcoming educational events. Comments and suggestions concerning the content of "FIR REPORT" are welcome and should be sent to the Maple Grove address.

The Southwest Oregon Forestry Intensified Research Program (FIR) is an Oregon State University, School of Forestry program designed to assist region foresters and other specialists in solving complex biological and management problems unique to southwest Oregon. FIR specialists organize, coordinate, and conduct educational programs and adaptive research projects specifically tailored to meet regional needs.

Established in October, 1978, the FIR project is a cooperative effort between Oregon State University, the Bureau of Land Management, U.S. Forest Service, O & C Counties, and southwest Oregon timber industries. It represents a determined effort by the southwest Oregon forestry community and county governments to find practical solutions to important forest management problems.

For the FIR Staff

David H. Lysne
Harvesting Specialist

inside...

Agriculture, Home Economics, 4-H Youth, Forestry, Community Development, and Marine Advisory Programs. Oregon State University, United States Department of Agriculture, and Oregon Counties Cooperating.

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current research

adaptive fir

OVERSTORY REMOVAL STUDY PRELIMINARY RESULTS

An Adaptive FIR problem analysis workshop conducted during the fall of 1979 identified a local need for improved technology on removing shelterwood overstories while retaining satisfactory understory stocking. In the spring of 1980, Adaptive FIR and the Medford District, Bureau of Land Management, initiated a study entitled "An Evaluation of Current Procedures for Removing a Shelterwood Overstory with a Cable Logging System." The intent of the study is to quantify the damage to understory seedlings as an overstory is removed using a typical small skyline system.

The study was installed on a 22-acre BLM overstory removal timber sale in a small basin between two side ridges. Slopes within the unit averaged 65 percent. The overstory timber consisted of 434 trees over 7.5-inches d.b.h. with an average of 19.7 trees per acre. The scaled merchantable timber volume removed was 280 Mbf which is an average of 12.7 Mbf per acre. The overstory volume was slightly more concentrated in the lower portion of the unit. Understory regeneration height averaged 2.0 feet. The upper two-thirds of the unit was uphill logged to two landings, almost all of the timber being yarded to a fan-shaped setting located on a small central ridge between two small draws. The two small draws joined to form one main draw in the lower half of the unit. The lower one-third of the unit was downhill logged to yarder settings on both sides of the main draw. A Skagit GT-3 yarder with a Danebo MSP carriage equipped with 120-feet of dropline was used to log the entire unit. Deflection was typically low. Generally, falling followed a contour pattern; however, many trees were felled downhill.

Because understory stocking was unevenly distributed, metal survey pins were located throughout the timbered portion on the unit on 14-foot horizontal centers. The intent of the pins was to provide logging damage sample points evenly distributed across the unit. If an understory tree fell within a 1 m (39.4 in.) radius circle from the pin, the tree became the sample element, otherwise the pin would be the sample element. Subjectively, pin damage was related to tree damage by the study participants as logging impacts were recorded. Logging impacts for both the falling and yarding logging phases were recorded for trees and pins in the portion of the unit which was uphill logged. Personnel and time limitations precluded recording falling and yarding impacts separately for the lower portion of the unit which was felled and downhill yarded in two stages. Various logging impact rankings, from no observable impact to mortality, were recorded for each tree or pin. These impact rankings are shown in the following table.

Table 1. Percent of Total Trees or Pins Impacted, by Logging Phase.

Impact Level	Uphill Yarding: Falling Only	Uphill Yarding: Falling & Yarding	Downhill Yarding: Falling & Yarding
None	57	35	27
Slight	18	9	19
Moderate	6	12	13
Severe	2	17	9
Mortality	17	27	32

"Slight" impact was recorded for seedlings, or pins representing seedlings, which were damaged but which should suffer no significant growth loss. "Moderate" damage indicates the seedlings certainly would suffer growth loss but would survive. "Severe" damage was recorded for seedlings given a reasonable probability of survival; however, growth would be minimal. "Mortality" was recorded for trees definitely killed by logging or deeply buried by logging debris.

Felled trees in the uphill yarding area frequently slid to a draw before coming to rest. The sliding of the trees after falling and the deep accumulation of trees in the draws contributed to the 17 percent falling mortality. Twenty-seven percent mortality following uphill falling and yarding resulted from a high proportion of side-hill yarding, low carriage clearance which led to wide areas of disturbance on the downhill side of the sidehill corridors, and the close corridor spacing immediately below the central fan-shaped setting where 11 corridors converged. Thirty-two percent mortality in the downhill yarded area resulted from a similar falling impact to that discussed for the uphill yarded area as well as poor control of the trailing end of logs, and the convergence of 7 corridors on either side of the main draw. The downhill yarding caused heavy seedling mortality in spite of stage falling and yarding. Because logging impacts were measured after both falling and yarding phases for the uphill yarding area, the impact of yarding alone may be separated from falling. The impact of uphill yarding alone is shown in Figure 1. Because seedling impact following yarding could be precisely separated from falling impacts only for the "none" and "mortality" impact levels, the "slight", "moderate", and "severe" impact codes are combined. The lateral slope classes are the slopes measured perpendicular to the skyline corridor.

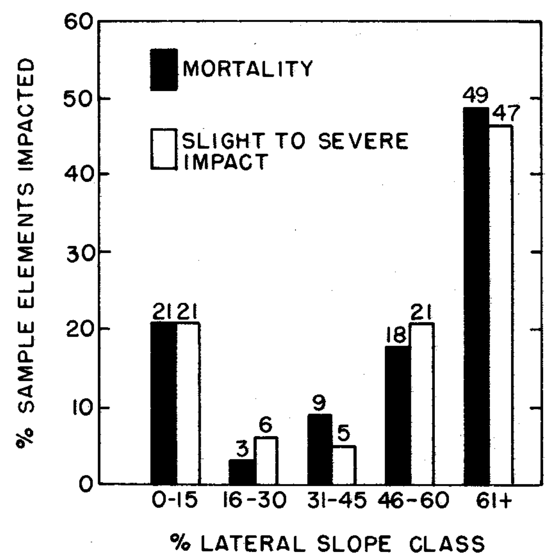


Figure 1. Percent of Seedlings Impacted by Lateral Slope Class, During Uphill Yarding.

The relatively high impact on seedlings located in the flattest lateral slope class can be attributed to the convergence of 11 corridors at the central ridge. Converging corridors, perpendicular to the contours, appear to cause less seedling damage than sidehill logging, at least for lateral slopes in excess of 60 percent. Excluding the area of converging corridors, seedling damage increases rapidly with increasing lateral slope because the trailing end of the logs swung downhill during inhaul. Fifty-eight percent of all seedlings impacted by uphill yarding (excluding falling impacts) suffered mortality while the remaining 42 percent suffered damage ranging from slight to severe. This study found that trees impacted by yarding will likely suffer mortality rather than some lesser impact. Falling damage, however, tended to spread the impacts over all impact levels with most of the seedlings suffering no impact.

Not all of the data has been analyzed from this study. However, data analysis is progressing and ultimately a publication will be prepared with a complete description of the study design and results. Seedling fate will be monitored over a 5-year period and a separate publication prepared on the long-term effects of an overstory removal.

DL

UNDERCUTTING OF BARE-ROOT SEEDLINGS

In 1980 a cooperative research project to study the impact of undercutting seedlings in the nursery was initiated between FIR, the USDA Forest Service Medford Forest Nursery, Siskiyou National Forest, and the USDI Bureau of Land Management Medford District. Undercutting is a nursery cultural practice during which a narrow, sharpened blade is drawn under the seedbed to cut seedling roots at the desired depth. The practice is designed to limit shoot growth and stimulate lateral root development, thus decreasing the shoot-root ratio. Our objective was to determine if undercutting could be used to produce 2-0 bare-root Douglas-fir and ponderosa pine seedlings better adapted to droughty sites. The desired morphological changes were a decreased shoot-root ratio, a more compact fibrous root system, and increased diameter. To do this we tested six treatments at the Medford Forest Nursery starting in the winter of 1980. The treatments consisted of various combinations of undercutting at different depths and stages of phenological development. The treatments were as follows:

1. undercut at 15 cm at the initiation of root growth;
2. undercut at 15 cm at the end of budswell, but prior to budbreak;
3. undercut at 20 cm at the end of needle expansion;
4. undercut at 15 cm at the initiation of root growth and at 20 cm at the end of budswell, but prior to budbreak;
5. undercut at 15 cm at the initiation of root growth and at 20 cm at the end of needle expansion; and
6. control (not undercut).

The experimental design was a randomized complete block with four replications.

The experimental seedlings were lifted from the nursery bed in January 1981. One hundred sixty seedlings from each treatment (40 per replication) were used to measure 14 morphological variables. An analysis of variance was used to evaluate each variable for treatment effects with 5 and 15 degrees of freedom. Treatment mean values for 6 of the 14 variables measured and the corresponding results of the analysis of variance are shown for each species in the table.

Variable	TREATMENT 1	2	3	4	5	Control
	Means					
DOUGLAS-FIR						
Height (cm)***	25.67	27.00	24.90	22.23	23.21	31.09
Diameter (mm)	5.60	5.64	5.22	5.10	5.14	5.88
Taproot biomass (g)*	1.11	1.19	0.97	0.94	0.95	1.54
Lateral root biomass (g)	1.41	1.22	1.10	1.12	1.15	1.05
Total root biomass (g)	2.53	2.43	2.10	2.06	2.11	2.65
Shoot-root ratio*	2.01	2.16	2.15	1.93	1.96	2.32
PONDEROSA PINE						
Height (cm)***	12.77	13.18	14.62	12.51	12.48	16.92
Diameter (mm)*	5.24	5.29	5.33	5.04	5.10	5.95
Taproot biomass (g)***	1.01	0.99	0.95	0.87	0.89	1.68
Lateral root biomass (g)*	1.00	0.97	0.76	0.82	0.88	0.58
Total root biomass (g)	2.01	1.98	1.71	1.70	1.78	2.27
Shoot-root ratio***	2.08	2.14	2.44	2.14	1.98	2.70

*Statistically significant at P = 0.05; ** P = 0.01; *** P = 0.01.

Undercutting had a highly significant impact on seedling height growth in both species. Although there was a significant treatment effect on Douglas-fir taproot biomass, the overall effect on root development was disappointing. However, the shoot-root ratio was reduced by the treatments. Diameter was unaffected. Overall, the undercutting treatments had a more profound impact on ponderosa pine morphology. In addition to the height and shoot-root ratio reductions, lateral root biomass was significantly increased by undercutting.

These test results are now being analyzed in detail and a more definitive paper on the nursery phase will be prepared for publication in the near future. However, the ultimate test of any nursery cultural practice is field survival and growth. Consequently, 160 seedlings from each treatment have been outplanted on south aspects in both the Illinois Valley Ranger District of the Siskiyou National Forest and the Rogue Resource Area of the Bureau of Land Management. The progress of these seedlings will be followed for at least 2 years and the results published as they become available.

SH

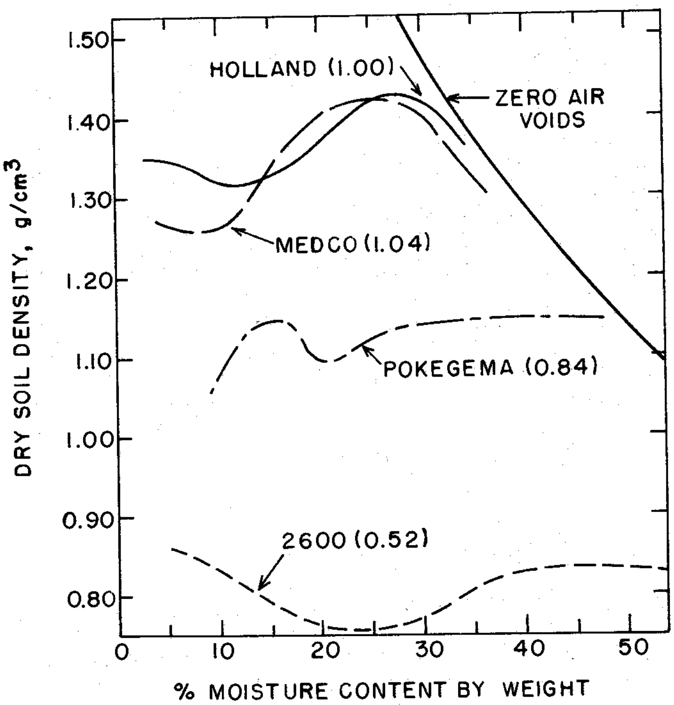
COMPACTION OF SOUTHWEST OREGON SOILS - EFFECTS OF SOIL MOISTURE

In the last issue of the "FIR REPORT" (Spring 1981), the effects that compaction had on soil shear strength were discussed. This time, these same soils will be used as examples to discuss the effects that soil moisture has on the compaction of soil.

Data from the five blow-count moisture-density tests ae used to make comparisons among soils since the densities obtained were the closest to those produced by ground-based logging vehicles in the woods. The shape and slope of these curves are important for interpreting the role of soil moisture in the compaction process; however, since soil density and shear strength of all soils increased over the natural densities, these factors have to be considered also.

Soil moisture is not a significant factor in the compaction of some soils. Soils having a relatively flat moisture-density curve, with only minor deviations, are defined as moisture insensitive. Moisture density curves for the 2600 and Pokegema soils are examples (see figure). Soils with steep moisture density curves (at least 0.01 g/cm^3 increase in density per one percent increase in moisture) are considered to be moisture sensitive. The Holland Medco soils are examples of moisture sensitive soils. The natural density (g/cm^3) of each soil is given in parenthesis.

Defining a soil as moisture sensitive only refers to the behavior of the soil in the vicinity of field capacity. Soil moisture samples collected from well-drained study sites approximately two days after the soil profile was recharged were all below the peak of the moisture-density curve; however, the moisture contents did



fall along the upper one-half of the steepest portion of the moisture-density curve. At moisture contents 4 to 6 percent below this approximation of field capacity, the moisture-density curves generally became flatter. Thus, even for moisture sensitive soils, soil moisture should only be considered a significant factor in the laboratory compaction process at moisture contents around field capacity. The increases in bulk density over the undisturbed soil bulk density range from 33 percent to 56 percent in the four soils given above.

Soils can be fairly easily identified as either moisture sensitive (MS) or moisture insensitive (MI). Criteria within the Unified Soil Classification System and USDA Soil Taxonomy can be used to separate all soils into four basic groups.

	Cohensionless	Cohesive
MS	Well-graded soils	Expandable clay minerals; montmorillonite, chloritic intergrades
MI	Poorly-graded soils	Non-expandable clay minerals; kaolins, micas, chlorite

Cohensionless soils must be analyzed by gradation tests. Particle diameters for calculating gradation were obtained from a particle size analysis of less than 7.62 cm (3-inch) material. Clay mineralogy of cohesive soils was determined by X-ray diffraction, but USDA classification of soil series to families can also be used. Thus, families classified as montmorillonitic would be MS, and kaolinitic families would be MI. Mixed and other mineralogical classes would be either MS or of intermediate sensitivity depending on the kinds and amounts of clay minerals present. The more plastic a given texture class of cohesive soil is, the higher is the expandable clay content, and the more moisture sensitive the soil will be.

In conclusion, soil moisture is not as important a factor in the compaction of soil as we previously had thought. While puddling of soil, primarily the cohesive soils, is still a serious concern at the higher moisture contents, soil moisture at or just below field capacity is not the most important factor determining how a soil will compact. Soil density increases because of compaction are generally considerable at any moisture content, and from earlier results, the shear strength of all soils increase with compaction regardless of initial densities. Thus, any soil can be compacted and have its productivity potential reduced. Reducing the area in skid trails will be a far more effective method of reducing productivity losses from compaction than developing quantitative soil moisture guidelines.

DM

continuing education

NORTHWEST FOREST SOILS COUNCIL SUMMER FIELD TRIP

July 22-24, 1981. Pacific Northwest Forest and Range Experiment Station and Umatilla and Wallowa-Whitman National Forests, LaGrande, OR. Field trip subjects include timber harvesting system comparisons, regeneration, soil fertility and review of the riparian research project. The field trip is open to non-council members. CONTACT: Mike Geist, Range and Wildlife Laboratory, "C" Avenue and Gekeler Lane, Route 2, Box 2315, LaGrande, OR 97850, (503)963-7122.

CALIFORNIA FOREST SOILS COUNCIL FIELD TRIP

July 31 and August 1, 1981. McCloud-Hilt, California. The topic for the first field trip is "Assessing Site Productivity." The tentative plan is to visit plantations and discuss the short- and long-term effects of a variety of site preparation methods. The field trip is open to non-council members. CONTACT: Gary Nakamura, Champion Timberlands, P.O. Box 2317, Redding, CA 96001, (916)365-7631.

PLANNING EXPERIMENTS

August 4-6, 1981. Oregon State University, Corvallis. The workshop will cover basic statistics, experimental design, and data analysis concepts for people doing research or conducting experiments. Enrollment is limited to 30. CONTACT: Conference Assistant, School of Forestry, Oregon State University, Corvallis, OR 97331, (503)754-3709.

NURSERY MANAGEMENT

August 26-27, 1981. Oregon State University, Corvallis. The program will be most beneficial to nursery managers and will cover all aspects of nursery management. Emphasis will be placed on addressing topics raised by program participants. Enrollment is limited to 50 with no more than 2 persons attending from any one nursery. CONTACT: Conference Assistant, School of Forestry, Oregon State University, Corvallis, OR 97331, (503)754-3709.

REFORESTATION WORKSHOP

October, 1981. Oregon State University, Corvallis. Program is in the planning stage. CONTACT: Conference Assistant, School of Forestry, Oregon State University, Corvallis, OR 97331, (503)754-3709.

REFORESTATION OF SKELETAL SOILS

November 18-19, 1981. Southwest Oregon Forestry Intensified Research Program (FIR), Medford, Oregon. This two-day workshop will cover the nuts and bolts of reforesting sites in southwest Oregon with rocky soils, particularly in steep terrain. Seventeen different speakers will give presentations on a wide variety of subjects ranging from soil interpretation, genetic adaptation, and site preparation strategies, to stocktype selection. The workshop will be held at the Medford Holiday Inn. CONTACT: Steve Hobbs or Ole Helgerson, FIR.

of interest

ERRATA: SPRING 1981 VOL. 3 NO. 1

"Performance of Container-Grown Douglas-fir" Table 2 should read, "*Statistical significance with 8 d.f. at the P = 0.05 probability level."

"Grass Control Increases Soil Moisture" Table should read:

Treatment	Mean	Standard Deviation	$\hat{t}$
Unsprayed	9.07	1.75	-3.51*
Sprayed	13.03	3.05	

*Significant at the P = 0.05 probability level.

NEW STAFF MEMBERS

Drs. Ole T. Helgerson and Steven D. Tesch recently joined the Adaptive FIR staff in Medford as silviculture specialists. Ole received his Ph.D. from Oregon State University and also has the M.S. and B.S. degrees in Forestry from Iowa State University. He will concentrate on reforestation problems. Steven Tesch received his B.S., M.S., and Ph.D. degrees in Forestry from the University of Montana. He will conduct research and education programs in general silviculture. Both are also Assistant Professors in the Department of Forest Science at OSU and bring substantial additional expertise to the Medford FIR staff.

SH

ROSEBURG BLM GRASS CONTROL STUDY

In January 1980, Jake Ritter, Luke Templin, and Jesse Higdon initiated a grass control study on Boomer Hill in southern Douglas County on land managed by the Bureau of Land Management Roseburg District. Five treatments were applied to six different types of seedlings arranged in a split-plot experimental design with three replications. The grass control treatments were: (1) backpack sprayer application of Atrazine in April; (2) backpack sprayer application of Atrazine and Dowpon M in April; (3) paper mulch (3' x 3') in April; (4) hand scalp (3 1/2' x 3 1/2') in January at the time of planting; and (5) no treatment (control). The test site was on old pastureland on the top of an exposed ridge line. Cattle were excluded from the area.

First year survival differences shown as percentages in the table below were dramatic.

	Treatment				
Test Seedlings (n = 90)	Atrazine	Atrazine and Dowpon M	Paper Mulch	Hand Scalp	Control
2-0 Douglas-fir (nursery A)	91	94	98	2	2
2-0 Douglas-fir (nursery B)	89	95	99	0	3
1-0 Douglas-fir 4 in.^{3} plug	92	85	82	2	8
2-0 Ponderosa pine	99	97	99	16	30
1-0 Grand fir 10 in.^{3} plug	77	86	79	0	2

Survival rates for all seedling types were much higher where grass competition had been controlled with herbicides or the paper mulch. The hand scalping treatment was almost a total failure and in some cases produced poorer results in terms of seedling survival than did no control of grass competition. Unfortunately a comparison between Douglas-fir stocktypes would not be valid as the containerized seedlings were in poor physiological condition when planted, probably because of a prolonged storage period. Although paper mulching produced excellent results, its application cost per acre was extremely high as shown below on a comparative basis with the other treatments.

Treatment Method	Cost Per Acre[1]
Atrazine	$ 31.00
Atrazine and Dowpon M	40.00
Paper mulch	400.00
Hand scalp	450.00
Control	0.00

[1]The cost of necessary materials is included.

These test results clearly demonstrate the need to control grass competition when establishing new plantations, and the cost effectiveness of herbicide treatment.

SH

THE LOG DRIVE

OSU Smallwood Harvesting Research Review Notes - Copies of the handout material given to those who attend the OSU Smallwood Harvesting Research Review held in Corvallis April 14-15, 1981, are now available. The notes are being sold separately or in a 3-ring binder. Contact: Pam Henderson, Forestry Conference Assistant, School of Forestry, Oregon State University, Corvallis, OR 97331, (503)754-3709.

New Oregon Logging Code - A revised "Logging" section of the "Oregon Occupational Safety and Health Code" has been issued. The code will be mailed to everyone on the mailing list, and will be available at local offices of the Accident Prevention Division of the Oregon Worker's Compensation Department and from compliance inspectors. People wanting to be placed on the mailing list should contact:

Darlene Blanchard
Accident Prevention Division
Worker's Compensation Department
Room 204, Labor and Industries Bldg.
Salem, OR 97310
(503)378-3272

Recently, Adaptive FIR presented a one-day program on multispan logging to local BLM, Forest Service, and industry personnel. At that program, the size of the support line for a multispan jack was related to support tree compressive loading, the correct procedure at that time. The new code states that the support line shall be "...a single piece of line that is one-eighth (1/8) inch larger than the tong or skidding line or rigged to provide a strength equal to a line one-eighth (1/8) inch larger than the tong or skidding line."

Rockbolt Demonstration - Recently, a demonstration of rockbolt installation procedures was presented by personnel from Williams Form Engineering Corporation and the Siskiyou National Forest. The rockbolt was an expanding sleeve type suitable for skyline or guyline anchoring. The one and three-eights-inch diameter, 10-foot-long rockbolt was installed in rock with a seismic velocity of 10,000 fps. Once in the hole, the rockbolt was spun, causing the rockbolt expanding sleeve to be forced against the sides of the hole. With the expanding sleeve firmly seated, a hydraulic ram, in stages, tensioned the rockbolt to 68,000 lbs. The load was transferred from the ram entirely to the bolt by tightening a nut against a washer-like plate on the exposed end of the bolt. After grouting, the rockbolt would be able to withstand loadings, such as might occur in a skyline logging operation, up to 68,000 lbs.

The pull from a cable attached to a rockbolt should be along the axis of the bolt. This may be ensured by strategically placing a log beside the rockbolt and running the cable over the log or by using manufactured frames for attachment to the exposed end of the rockbolt. Frames for keeping the cable pull in line with the rockbolt axis can be commercially manufactured according to the user's specifications.

The rockbolt installed in the demonstration was manufactured in Portland, Oregon. All required installation equipment is either commonly available road construction equipment or may be rented. Cost collection was not a goal of the demonstration; however, similar installations near Estacada, Oregon, cost $560.00 per rockbolt.

Additional information on rockbolts and installation procedures may be obtained from:

Bruce Jensen, Sales Representative
Williams Form Engineering Corporation
13411 Northrup Way
Bellevue, WA 98005
(206)746-1625

RESULTS OF PRESCRIBED FIRE PROBLEM ANALYSIS WORKSHOPS

Problem analysis workshops on the use of prescribed fire as a site preparation tool were held in Roseburg, Grants Pass, and Medford in late April to determine what issues were of greatest concern to foresters and other specialists in southwest Oregon. Preliminary discussions with land managers indicated that the issues were quite complex and were not limited to just technical topics. Thus, the problem analysis workshops were used to gain insight into the problems associated with using prescribed fire. A total of 61 silviculturalists, land managers, land management specialists, and fuels management personnel attended the meetings.

The ten most important issues identified by participants are as follows:

1. Survival, growth and spacing of seedlings planted on burned sites;
2. Costs and benefits of hazard reduction and impacts on other management practices;
3. Public attitudes toward prescribed fire;
4. Changes in site productivity;
5. Effects on competing vegetation;
6. Changes in soil fertility and nutrient cycling;
7. Smoke management;
8. Season to burn;
9. Being able to meet prescription; and
10. Soil erosion.

The results of the problem analysis workshops will be used to guide Adaptive FIR research and extension projects.

DM

recent publications

For copies of the publications cited, mail your requests to the appropriate address as indicated by the number following each summary. Requests should be sent to:

1 Publications
Pacific Northwest Forest and Range Experiment Station
P.O. Box 3141
Portland, OR 97208

LARGE STOCK AND FERTILIZER IMPROVE GROWTH OF DOUGLAS-FIR PLANTED ON UNSTABLE GRANITIC SOIL IN NORTHERN CALIFORNIA, by R. O. Strothmann. 1980. USDA Forest Service Research Note PSW-345. Pacific Southwest Forest and Range Experiment Station, Berkeley. 7 pp. Two size classes (regular and large) of 2-0 bare-root Douglas-fir seedlings were outplanted in an old clearcut with granitic soils and slopes averaging between 60 and 70 percent. The aspect was northeast. Both size classes were either fertilized or unfertilized with 10 replications of each treatment. A 9-gram, slow-release fertilizer tablet was placed in a hole 6 inches deep and 3 inches upslope from the seedling. Neither the use of large stock or fertilizer significantly increased survival over a 3-year period. However, both the use of large planting stock and fertilizer improved height growth.

1

SOIL MOISTURE USE BY MIXED CONIFER FOREST IN A SUMMER DRY CLIMATE, by R. J. Arkley. 1981. Soil Sci. Soc. Am. J. 45:423-427. Soil moisture regimes under a mixed conifer forest were measured at 16 sites in the San Bernardino Mountains of southern California for 5 years. Soil moisture depletion was found to occur to depths of 274 cm from coarse loamy and sandy-skeletal soils and underlying decomposed granite. The evidence suggests water use by trees extends to considerably deeper depths. Moisture depletion was most rapid from the upper soil layers early in the season and deeper soil layers later in the summer. The survival and productivity of forest trees in this summer-dry climate appear to depend on moisture stored at considerable depth.

1

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