

SHRUB SPROUTING RESPONSE TO FIRE IN A  
DOUGLAS-FIR/WESTERN LARCH ECOSYSTEM

By

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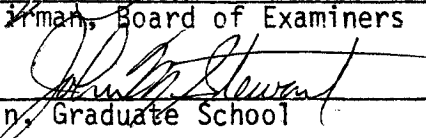
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ABSTRACT

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Shrub sprouting response to fires in a Douglas-fir/western larch ecosystem (124 pp.)

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The use of prescribed fire as a management tool in northern Rocky Mountain forests is increasing. Little quantitative information is available relating fire characteristics to the effects of fire on shrubs. The role which shrubs play after fire is extremely important, since newly regenerated shrubs take up released nutrients, inhibit erosion, provide wildlife forage and can offer significant competition to newly established tree seedlings. The effects which fire has on shrub communities should be considered when preparing fire-management guidelines.

Mean comparison testing and multiple linear regression were used to analyze shrub data collected before, and 1 and 2 years after 20 prescribed fires in Douglas-fir/western larch stands in western Montana. Both spring and fall fires increased the diversity in the shrub community. Fire-pruned plants continued to sprout for at least 2 years. Sprouting of Vaccinium globulare was apparently controlled by the intensity and duration of fire heating. There was no evidence of seasonal variation in the physiological ability of Vaccinium to produce sprouts. The quantity of heat released by the fire and the amount of duff and soil moisture were the factors most important in controlling the number and distribution of pruned sites on stems and rhizomes of Vaccinium. Fall fires resulted in greater heat release and deeper heat penetration into duff and soil layers than spring fires. Rhizome mortality resulted in the temporary elimination of Vaccinium on many more data quadrats after fall burns than after spring burns.

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## TABLE OF CONTENTS

	Page
ABSTRACT . . . . .	ii
LIST OF TABLES . . . . .	vii
LIST OF FIGURES . . . . .	ix
 Chapter	
1. INTRODUCTION . . . . .	1
PROBLEM STATEMENT . . . . .	4
OBJECTIVES . . . . .	4
2. LITERATURE REVIEW . . . . .	6
PLANT HORMONES . . . . .	6
Anatomical Location of Sprouting Sites . . . . .	6
Sprouting Regulation in Herbaceous Plants . . . . .	7
Apical dominance . . . . .	7
Promotion of dormant bud outgrowth . . . . .	8
Sprouting Regulation in Woody Plants . . . . .	9
Inhibition of sprouting of existing buds . . . . .	9
Control of numbers of sprouts originating from existing buds . . . . .	10
Development of New Bud Primordia . . . . .	11
Initiation of buds in existing tissue . . . . .	11
Initiation of buds in newly formed callus . . . . .	12

Chapter	Page
CARBOHYDRATE RESERVES . . . . .	13
The Photosynthetic Budget . . . . .	13
Cyclical Nature of Carbohydrate Use . . . . .	14
Carbohydrate Use Patterns . . . . .	14
<del>Sprout Carbohydrate Relationships . . . . .</del>	<del>15</del>
<del>Sprouting Model for Woody Plants . . . . .</del>	<del>17</del>
FIRE EFFECTS UPON PLANTS . . . . .	18
Soil Temperature - Soil Moisture Relationships . . . . .	19
Sprouting After Fire . . . . .	21
Observations on Species Response . . . . .	22
3. FIELD METHODS . . . . .	27
STUDY AREA DESCRIPTION . . . . .	27
BACKGROUND . . . . .	28
DATA COLLECTION . . . . .	35
4. ANALYSIS . . . . .	38
COMPARISON OF PLOT MEANS . . . . .	38
MULTIPLE REGRESSION . . . . .	40
Independent Variable Selection . . . . .	42
Equation Development . . . . .	48
5. RESULTS AND DISCUSSION . . . . .	50
CHANGES IN PLANT NUMBER AND DENSITY . . . . .	58
REGRESSION EQUATIONS . . . . .	67
SIGNIFICANT VARIABLES . . . . .	82
HYPOTHESES ABOUT DIFFERENTIAL FIRE EFFECTS . . . . .	86
6. CONCLUSIONS . . . . .	91
7. FUTURE RESEARCH . . . . .	94

	Page
LITERATURE CITED . . . . .	97
APPENDICES . . . . .	105
A. Fuel Inventory Procedures Used for a Cooperative Fire Research Project on the Lubrecht Experimental Forest, Montana, 1972-1973 . . . . .	105
B. Air Temperature, Moisture Conditions, and Duff and Soil Surface Temperatures Attained During Fires . . . . .	113
C. Constants and Variables for Computing Woody Shrub Weight . .	114
D. Plot Summaries . . . . .	115
E. Full Statistics for Regression Equations . . . . .	116

## LIST OF TABLES

Table	Page
1. Mean and Standard Deviation of Measured Variables, Lubrecht Prescribed Fire Study . . . . .	30
2. Range of Measured Variables, Lubrecht Prescribed Fire Study . . . . .	31
3. Simple Linear Correlation Coefficients Between Duff and Soil Moisture Content . . . . .	33
4. Independent Variable Set One . . . . .	44
5. Independent Variable Set Two . . . . .	47
6. Plot Summaries - <u>Vaccinium globulare</u> . . . . .	51
7. Tests of Changes in Number of Shrub Stems Per Plot, Prefire - First Year After Fire, 1973-1974 ( $n_1 = n_2$ ) . .	59
8. Tests of Changes in Numbers of Shrub Stems, First Year After Fire - Second Year After Fire, 1974-1975 ( $n_1 = n_2$ ) . . . . .	61
9. Tests of Changes in Shrub Stem Density, Prefire - 1 Year After Fire, 1973-1974 ( $n_1 \neq n_2$ ) . . . . .	64
10. Tests of Changes in Shrub Stem Density, First Year After Fire - Second Year After Fire, 1974-1975 ( $n_1 \neq n_2$ ) . . .	65
11. Variable Set One: Significance of Variables in Regression Equations . . . . .	83

Table	Page
12. Variable Set Two: Significance of Variables in Regression Equations . . . . .	84
13. Simple Linear Correlation Coefficients Between Mineral Soil Surface Temperature and Forest Floor Moisture Content . . . . .	90

LIST OF FIGURES

Figure	Page
1. Percent of Plots with Changes in Number of <u>Vaccinium globulare</u> . . . . .	52
2. Percent of Plots with Changes in Number of Quadrats in Which <u>Vaccinium globulare</u> Appears . . . . .	52
3. First Year Shoot Development in Plants Pruned Above Ground Level . . . . .	54
4. First Year Shoot Development in Plants Pruned Below Ground Level . . . . .	55
5. Sprouting Sites in Rhizome Network with Deep Lethal Temperature Penetration . . . . .	55
6. Hypothesized Relationship Between Number of Stems and Pruning Depth . . . . .	57
7. Fuel Inventory Scheme . . . . .	109

## CHAPTER 1

### INTRODUCTION

Vegetation is a function of its environment. Topography, soils, organisms, and climate interact to produce a mosaic of plant community types. In the northern Rocky Mountains, fire is an additional, highly significant agent affecting the vegetation. Winters in this region are cold, and summers are warm and dry. Decomposition of organic matter takes place slowly because of a lack of extended periods of warm, wet weather. Summer thunderstorms generate lightning, often unaccompanied by rain. The present climate thus creates an environment conducive to fire occurrence by providing sites with adequate fuel and a random ignition source, lightning.

Plants have adapted to fire through mechanisms such as thick bark, serotinous cones, and vegetative reproduction from buried plant organs. The vegetation of some communities has adapted to a point where it now seems to require periodic fire to persist. Fifty years of efficient fire suppression has significantly reduced the area burned in the western mountains. Changes can now be observed in many ecosystems in which fire was historically important. Ponderosa pine trees, weakened by competition with understory trees for water and nutrients, are dying from mountain pine beetle attack (Sartwell and Stevens, 1975). Overmature aspen clones which have stopped suckering are deteriorating and reverting to rangeland (Schier, 1975). Brushfields are losing value

as wildlife habitat because many plants are becoming woody and unpalatable, and sometimes too tall for animals to browse. The removal of fire as an active ecological force may be largely responsible for such ecosystem alterations.

Fuels continue to accumulate naturally in the forest. It can be hypothesized that fuels have accumulated to greater levels than would occur naturally in some community types adapted to frequent fire. The fuels have been augmented by selective logging practices and extensive bark beetle kill in some areas of the northern Rockies. The possibility of catastrophic fire may thus be increasing.

There is a growing awareness of a need to rectify these conditions. The application of fire under prescribed conditions is considered as a viable alternative by many. Sound land use management requires an understanding of fire effects upon various ecosystem components in order to ensure that prescribed fires achieve management objectives.

The small stature of the understory vegetation places it among the dead fuel. It will directly feel the impact of a fire, and may influence fire spread and intensity (Norum, 1975). Periodic fire has undoubtedly been an important\*selection stress for shrubs and herbaceous vegetation. \*The plants have developed ways to reproduce from<sup>①</sup>underground plant parts,<sup>①</sup>from seeds which survive in the soil, and<sup>②</sup>from wind-disseminated seed. \*Plants propagated by one or more of these mechanisms play an important role after a fire. They absorb nutrients released by the mineralization of organic material and reduce nutrient loss due to leaching. Surviving roots and rhizomes anchor the soil while new vegetative cover prevents splash erosion. Vegetative regrowth provides

a source of nutritious forage, while quick sprouting taller shrubs provide needed cover for wildlife. Vigorous vegetative growth can also offer severe competition to tree seedlings on the burned site. The overall effect of fire on a site is thus closely related to the amount of vegetation present the first few years after burning.

In northern Rocky Mountain forest ecosystems, perennial plants are the dominant component of plant communities. The spring flush of herbaceous growth arises from roots, rhizomes, tubers, bulbs, and corms located within upper layers of the forest floor. Shrubs also vegetatively reproduce by sprouting from rhizomes and root crowns found within the duff and soil layers. The depth of sprouting sites assures them a place among the first species to recolonize an area after fire. Because of their persistence and rapid growth form, shrubs are often the dominant postburn plant cover. These woody plants thus play a key role in maintaining site quality.

A comparison of postfire plant communities shows how fire intensity or time of burn can cause marked differences in vegetative response. Great contrast can be found the first few years after fire. Bare ground, patches of lush new growth, and places untouched by fire may lie within a few meters of each other. The pattern of burned and unburned ground is caused by differences in fire intensity. But what is the reason for the great variation in plant cover on burned areas? Why is growth promoted on some microsites and seemingly impaired on others? The site differences may be a function of the prefire shrub community characteristics, the environmental conditions at fire time, the fuel loading, or may express an interaction of all three of these factors.

## PROBLEM STATEMENT

An increased use of prescribed fire is being considered by forest managers to reduce understory fuels, thin stands and manipulate wildlife habitat. Guidelines which carefully take the shrub community into account are lacking because present knowledge of fire-shrub interactions is limited. Little quantitative information is available that describes the interrelationships between shrubs and fuel components, fuel moisture and environmental parameters. We do not know the effect which fuel complex alterations will have upon the shrub community, nor the duration of any fire-induced changes. Our ability to apply fire wisely requires an identification and quantification of those fire and fire-induced parameters which best explain changes in the shrub community.

## OBJECTIVES

The purpose of this study was to extract and supplement data from a series of understory fires conducted in 1973 and to relate the information to changes in the shrub community. The specific objectives were:

1. Relate the number of shrub stems present after fire to:
  - (a) prefire fuel loadings
  - (b) fuel, duff, and soil moisture
  - (c) atmospheric conditions
  - (d) season of burning
  - (e) fuel consumption
  - (f) fire intensity (Kcal/sec/m<sup>2</sup>)
  - (g) soil temperature achieved during burning
  - (h) prefire numbers of shrub stems

2. Identify factors which may contribute to promotion or inhibition of shrub sprouting.
3. Determine the relative sensitivity of the various shrub species to fire.
4. Determine whether the data gathered in the brush fuel inventory (part of the 1973 prescribed fire study) can also be used to quantify shrub species' response to fire.

## CHAPTER 2

### LITERATURE REVIEW

#### PLANT HORMONES

##### Anatomical Location of Sprouting Sites

Sprouting is a phenomenon commonly observed in many species of woody plants. The buds from which sprouts develop may be newly initiated or preexisting. Dormant root and shoot primordia exist on apple roots (Siegler and Bowman, 1939). Sweetgum sprouts (Liquidamber styraciflua) originate from suppressed buds buried in the root periderm (Kormanik and Brown, 1967). Birch (Betula populifolia) forms basal adventitious buds which eventually are protected at or below the soil surface by soil accumulation processes (Stone and Cornwall, 1968). Stump sprouts in white oak (Quercus alba) arise from suppressed buds (Vogt and Cox, 1970). Rabbitbrush sprouts (Chrysothamnus nauseosus) develop from adventitious buds at the "summit" of the root (Daubenmire, 1975). Blaisdell and Mueggler (1956) reported that sprouts in bitterbrush (Purshia tridentata) originate from a cluster of preexisting dormant root collar buds or, if these buds have been destroyed, from new buds formed in callus tissue (undifferentiated wound tissue) at the site of injury. Adventitious shoots of aspen (Populus tremuloides) develop on the roots from newly initiated buds, preexisting bud primordia, and suppressed short shoots (Schier, 1973b). Eastern lowbush blueberry

(Vaccinium angustifolium) and tall huckleberry (Vaccinium membranaceum), a species common to moist western forests, sprout from existing buds on rhizomes (Minore, 1975). Examination of three shrub species from the Lubrecht site, huckleberry (Vaccinium globulare), spiraea (Spiraea betulifolia), and Oregon grape (Berberis repens), revealed the existence of many dormant rhizomatous buds from which sprouts were observed to have developed.<sup>1</sup>

#### Sprouting Regulation in Herbaceous Plants

Apical dominance. The inhibition of sprouting is probably maintained by hormones translocated from growing plant loci to the budding sites. This inhibition is one of several controls over plant growth and form exerted by the aboveground plant parts, grouped under the phenomenon called apical dominance. Most of the pertinent research concerning hormonal mechanisms of bud inhibition and promotion of bud outgrowth has been done with herbaceous plants.

Auxin is a plant hormone, the presence of which is necessary for plant growth. It is manufactured in growing plant parts, stem and root apices, enlarging leaves, and developing flowers. Concentrations of auxin higher than those optimal for growth will inhibit growth, different plant parts being differentially sensitive (Thimann, 1937). The removal of the terminal bud of pea (Pisum sativum) will result in outgrowth of one or two of the axillary buds (Scott et al., 1967). Auxin applied to decapitated plants will inhibit this outgrowth (Thimann, 1937), possibly by preventing the suppressed bud from synthesizing its

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<sup>1</sup>Bilderback, David. 1974. Personal conversation. University of Montana, Department of Botany.

own auxin (Sachs and Thimann, 1967). Auxin in supra-optimal concentrations has induced the formation of ethylene gas at these inhibited bud sites in pea (Burg and Burg, 1968). Ethylene gas has been shown to be inhibitory to auxin synthesis from its predecessor compound (Valdovinos et al., 1967). An equal concentration of applied auxin and gibberellin (a hormone formed in roots and/or stems (Crozier and Reid, 1971) which promotes internode elongation) applied to decapitated pea will more completely reestablish the inhibition over axillary buds which is maintained by the apical bud in the intact plant (Scott et al., 1967). Gibberellin may augment inhibition by facilitating auxin transport within the stem (Jacobs and Case, 1965).

The growth inhibition maintained by apical dominance seems to be an inhibitory block, which once suddenly released, in some plants may not be reimposed upon growing buds (Danckwardt-Lilliestrom, 1957). The experimentally demonstrated fact that a steady supply of auxin is necessary to maintain apical dominance is consistent with this theory (Thimann and Skoog, 1934, cited by Thimann et al., 1971).

Promotion of dormant bud outgrowth. Applied cytokinin, a hormone promotive of cell division which is synthesized in plant roots, can cause lateral bud outgrowth in pea (Wickson and Thimann, 1958). High light intensities and good soil nitrogen and phosphorus supplies enhance the amount of cytokinin promoted release (Thimann et al., 1971). Cytokinin promoted release of inhibited buds has been shown to coincide with vascular trace differentiation between axillary buds and the plant vascular system. Applied auxin inhibits this differentiation (Sorokin and Thimann, 1964). The effect of auxin in inhibiting lateral bud

outgrowth may be one of the "directing" cytokinins away from the bud, thus preventing vascular trace development (Phillips, 1969). The growth of cytokinin-released buds is enhanced by applied auxin (Sachs and Thimann, 1967). Gibberellin (Panigrahi and Audus, 1966) and cytokinin (Sachs and Thimann, 1967) may also be necessary for continued growth. The effect of gibberellin may be through enhancement of auxin supply, since gibberellin has been shown to enhance rates of tryptophan conversion to auxin (Valdovinos et al., 1967).

Lateral bud release in seedlings of flax (Linum usitatissimum L.) was experimentally induced by increasing concentrations of nitrogen in the nutrient solution (McIntyre and Larmour, 1974). Observations on the sequence of bud development and xylem differentiation led to the conclusion (as opposed to Sorokin and Thimann) that vascular trace differentiation was not a prerequisite for bud development. The investigators also noted a marked increase in nitrogen levels of those buds released from dominance by removal of the apical bud. Thimann et al. (1971) have postulated that nitrogen and phosphorus may be a very important factor in the control of cytokinin synthesis. The experimentally increased nitrogen supply to the roots may have stimulated formation of cytokinin or other growth promotive compounds (McIntyre and Larmour, 1974).

#### Sprouting Regulation in Woody Plants

Inhibition of sprouting of existing buds. Inhibition of lateral bud outgrowth by actively growing shoots of woody plants is probably by a mechanism similar to apical dominance in herbaceous plants (Phillips,

1969). However, the situation is somewhat more complex in shrubs because they are perennials and have a yearly dormancy period. Applied auxin inhibits epicormic sprouting of white oak stumps (Quercus alba) (Bowersox and Ward, 1968), basal stump sprouting in pin oak (Quercus palustris Muench) and white oak (Vogt and Cox, 1970), and root suckering in black locust (Robinia pseudoacacia) (Sterrett and Chappell, 1967). Eliasson (1972a) established that inhibition of shoot formation in European aspen (Populus tremula) roots is due to auxin translocated to the roots from growing shoot parts. A decrease in root auxin supply accompanied the removal of growing shoots. Abscisic acid, a substance inducing autumnal dormancy in woody plants which is formed in the leaves, may also play a role in root sprouting inhibition. Applied abscisic acid inhibited bud outgrowth in excised aspen roots (P. tremuloides), exerting greater inhibition over newly initiated, less developed primordia (early primordia) than over large, readily visible primordia (late primordia) (Schier, 1973c). Applied gibberellin inhibited outgrowth of early primordia but stimulated outgrowth of late primordia in aspen roots. An inhibitor of gibberellic acid inhibited shoot outgrowth (Schier, 1973a).

#### Control of numbers of sprouts originating from existing buds.

The number of suckers initiated depends on hormone levels (Eliasson, 1972a). Two to six buds were usually released in root segments of P. tremula (Eliasson, 1972b). Seventy-two percent of the variation in numbers of suckers produced in P. tremuloides could be explained by amounts of auxin in the roots at the time of collection. Both seasonal and clonal variation in auxin levels was observed (Schier, 1973d).

Elongating shoots formed on excised aspen roots decreased the amount of further sucker development. Decapitation of these suckers significantly increased the amount of suckering (Schier, 1972). A similar situation in which developed shoots inhibited elongation of buds released farther down the stem was observed on an excavated rhizome of Vaccinium globulare.<sup>2</sup>

#### Development of New Bud Primordia

Initiation of buds in existing tissue. It is thought that bud primordia in aspen roots may develop as a result of a temporary reduction in apical dominance caused by injury (Eliasson, 1972a, 1972b; Schier, 1973b). Even a slight disturbance may be sufficient to cause primordia initiation (Schier, 1973b) if hormone levels, particularly that of auxin, are altered. The existence of an auxin oxidizing system in black locust roots was postulated by Sterrett and Chappell (1967). They suggested that this system could be activated by injury to the roots, and result in sprouting. The enzyme peroxidase is an effective auxin oxidant (Thimann, 1969). Since the genes controlling the peroxidase activity are derepressed by injury (Galston and Davies, 1969), this could explain injury deactivation of inhibitory auxin. A decreased auxin level has been shown to induce shoot primordia in isolated root cuttings of Taraxacum (dandelion) and Cichorium (Warmke and Warmke, 1950). It is possible that bud primordia in roots are initiated as a result of an increased root produced cytokinin to auxin ratio, since

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<sup>2</sup>Bilderback, David. 1974. Personal conversation. University of Montana, Department of Botany.

such an increased ratio has produced shoots in isolated root segments of herbaceous plants, Isatis tinctoria (Danckwardt-Lilliestrom, 1957), and Convolvulus arvensis (Torrey, 1958).

Nitrogen levels may play a role in bud initiation, as well as in promotion of existing bud outgrowth. McIntyre and Raju (1967) found that twice as many buds developed on roots of Euphorbia esula (spurge) plants treated with high amounts of nitrogen as on controls. Hieracium (hawkweed) plants in the basal rosette stage initiated and subsequently developed more root buds after nitrogen treatments (Peterson, 1974).<sup>3</sup> Euphorbia esula plants had poor root regenerative capacity even after release from apical dominance if nitrogen was deficient (McIntyre, 1972).

Initiation of buds in newly formed callus. Sprouts have been seen to originate in bitterbrush from buds newly formed in callus tissue after top removal by fire. Plant hormones may also play a role in this process. Naphthalene acetic acid (a synthetic auxin) promoted callus tissue formation in tobacco (Nicotinium tobaccum) stem segments (Skoog and Tsui, 1948). Applied kinetin with auxin caused shoot initiation in tobacco pith callus (Skoog and Miller, 1957), and in aspen callus culture (Wolter, 1968). Gibberellin inhibited organ differentiation in tobacco callus culture (Murashige, 1964, cited in Thorpe and Murashige, 1970). Auxin, kinetin, and gibberellin could all be supplied by the roots of sprouting shrubs.

A histo-chemical analysis of tobacco callus culture revealed that areas which would differentiate into shoot primordia showed

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<sup>3</sup>Peterson, R. L. The initiation and development of root buds. In Cabot Symposium Proc., Harvard Univ., 1974. (Unpublished)

increased amounts of RNA and proteins<sup>4</sup> just before and during the differentiation process, and showed evidence of starch accumulation (Murashige, 1964, cited in Thorpe and Murashige, 1970). The starch seems to be required to provide energy for primordia initiation and later developmental stages. Gibberellin was shown to inhibit this starch accumulation process, a possible explanation for its role in organ formation inhibition in tobacco and the inhibition of the stages in early primordia development in aspen root segments observed by Schier (1973a).

### CARBOHYDRATE RESERVES

As stated previously, there are two aspects to the sprouting process, the initiation of bud development, and subsequent growth. Successful sprouting of a decapitated plant, once growth is initiated, depends upon an adequate supply of carbohydrates from roots or rhizomes for respiration and assimilation until the shoot is capable of manufacturing a self-sustaining amount of photosynthate. Additional energy is required if the sprout is developing from a subsurface organ rather than from a stump because of the additional period of dependency upon carbohydrate reserves until the sprout reaches the soil surface.

#### The Photosynthetic Budget

The breakdown of carbohydrates by the respiration process provides energy for plant metabolic activity and substrate for vegetative and reproductive growth. Carbohydrate production above that

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<sup>4</sup>Increased protein synthesis has been found to be a primary indicator of wound callus differentiation in Coleus internodal stem pieces (Fosket and Miksche, 1966, cited in Thorpe and Murashige, 1970).

required for these processes will determine the net amount of carbohydrate available for storage. A deficit in the photosynthetic budget causes a reduction in carbohydrate reserve supply.

### Cyclical Nature of Carbohydrate Use

The rate of carbohydrate use depends on the rate of processes that require energy from carbohydrates. Hormonal activity and environmental factors interact to control this use rate by controlling respiration, assimilation, and metabolic activity at different stages of growth, development, and rest (Garrison, 1971). Particularly high rates of use occur during periods of shoot elongation, early leaf expansion and flower and fruit development (Kozłowski and Keller, 1966). Since the seasonal pattern of temperate climate imposes a cyclical pattern on plant phenologic events, marked trends in carbohydrate accumulation and depletion occur which are characteristic for each species (Garrison, 1971).

### Carbohydrate Use Patterns

Carbohydrate storage maxima in woody plants generally occur at the end of the growing season. The high energy requiring processes of growth and reproduction have been completed, and the mature leaves have been photosynthesizing at their highest net rate (Kozłowski and Keller, 1966), allowing maximum carbohydrate storage. Reserves will decline over the winter due to respiration. Since respiration rates increase with temperature, a warm winter can weaken young plants through reserve depletion, greatly increasing susceptibility to frost kill and disease (Printz, 1933, cited in Kozłowski and Keller, 1966). The greatest carbohydrate demand is exerted by developing shoots and expanding leaves

In spring. Reserves will then increase after the spring depletion, again reaching a maximum in late summer or early fall.

Bitterbrush reserves decline to an early summer minimum and then accumulate to a maximum at the onset of fall dormancy (Garrison, 1971). Chamise (Adenostema fasciculatum), a species of the California chaparral, shows a rapid early summer decline during its active growth period, and a slow increase to an early spring maximum. The dormant season occurs during the summer (Laude et al., 1961).

Some patterns of carbohydrate use are more complex, with several sharp growing season fluctuations. Donart (1969) found that reserves in rabbitbrush (Chrysothamnus viscidiflorus) declined 60 percent to their seasonal low in one May week while growing from late leaf-bud stage to an early leaf stage with flower buds present. Snowberry (Symphoricarpos vaccinoides) reserves declined 71 percent in that same week. Reserves in both plants began to accumulate and then dropped again about one month later as apical leaves developed. Snowberry showed another sharp decline as flower buds developed about two months after growth had ensued.

#### Sprout Carbohydrate Relationships

Stored carbohydrates in many shrubby plants are not directly affected by crown removal since the bulk of carbohydrate is stored in small diameter roots (Garrison, 1971). Stump sprouts and root suckers in decapitated plants are completely dependent upon these reserves when they commence active growth. Thus the timing of top removal in relation to the level of reserve requirements of the plant will greatly affect the vigor of new sprouts. A relationship between sprout height the

growing season after cutting and amount of carbohydrate reserve at the time of cutting was observed in Ceanothus sanguineas (Hickey, 1971), chamise (Jones and Laude, 1960), and turkey oak (Woods et al., 1959). Dry weight of aspen suckers grown in the dark (a simulation of sucker growth conditions in soil) was highest from root cuttings made at the time of highest carbohydrate content (Zasada and Schier, 1973). The dry weight of suckers per root cutting was a function of the number of suckers and the amount of stored carbohydrate (Schier and Zasada, 1973). Wenger (1953) found no relationship between vigor of stump sprouts in sweetgum and carbohydrate content, attributing observed differences to seasonal hormonal variations. Vogt and Cox (1970) found no relationship between these factors in stumps of oak except when grown in the dark. It may be that total carbohydrates were sufficiently abundant to not be a limiting factor, or that sprouts were able to photosynthesize sufficiently with the available light.

The number of sprouts produced after cutting has been related to levels of carbohydrate reserves. Stoeckeler and Macon (1956) found 74 to 78 percent less sprouting of aspen cut during summer than from aspen cut during the dormant season. Isolated aspen root segments collected during the summer also produced fewer suckers (Tew, 1970). Fewer rabbitbrush sprouts followed cutting during time of lowered reserves (Robertson and Cords, 1957). Schier (1973d), however, found that 72 percent of the variation in sucker numbers from aspen roots collected at different times of the year could be associated with the amount of auxin contained at the time of collection. Carbohydrates were more important in subsequent growth (Schier and Zasada, 1973; Schier and Johnston, 1971). Sterrett et al. (1968) postulate a combined hormone carbohydrate

effect controlling summer suckering in black locust. It is likely that hormone levels and carbohydrate content interact to control the amount of sprouting. Carbohydrates are necessary for initial differentiation but probably seldom become limiting during bud formation. The carbohydrate supply is more likely to limit the number of sprouts initiated from root primordia which will reach the surface.

#### Sprouting Model for Woody Plants

Removing the above-ground portion of many species of woody plants does not greatly affect them, since they have been genetically "primed" for this event if they exist in an environment in which they are periodically subjected to fire or browsing. The sprouts may originate in three ways: from buds newly formed in root tissue, from buds newly formed in callus (wound) tissue which developed at the site of wounding, or from dormant root crown or rhizomatous buds. The site of sprout origin will vary by species.

The major effect of top removal is destruction of the source of the stream of auxin which inhibited sprouting. Sprouting may then be initiated in the following manner. The ratio of hormones present after the removal of the inhibitory auxin stream may be proper to induce bud formation or activate dormant buds, or cytokinin may be translocated from the root apex to provide the initial stimulus. Once cells are actively dividing, the growing bud apex could be its own source of auxin (and possibly gibberellin) necessary for its further growth and development.

If existing dormant buds are destroyed, callus differentiation may be stimulated by residual auxin or auxin translocated from the

growing root tip, with cytokinin then promoting bud differentiation in the tissue. The number of buds initiated may depend on hormone levels. Hormone synthesis is at least partially controlled by the availability of nutrients.

Reserve carbohydrates provide the substrate for these energy requiring processes. The number of initiated sprouts completing the process depends on the supply of carbohydrates available for growth maintenance until the sprout is photosynthetically self-sufficient. The availability of critical nutrients may also affect growth rates. Initiation and growth of additional sprouts would be inhibited by the increasing amount of auxin synthesized by actively growing shoots.

#### FIRE EFFECTS UPON PLANTS

The amount of damage sustained by a plant organ in a fire is a function of the temperature to which it is heated, the initial temperature of the vegetation, and the plant phenological state. A temperature as low as 50 to 60°C can kill plant tissues, possibly by coagulation of protoplasmic proteins (Meyer et al., 1973). Hare (1961) also mentions enzymatic destruction, asphyxiation, intoxication, and lipid liberation as possible causes of plant death. The duration of heating is important, with increasing temperatures killing plant tissue in progressively shorter lengths of time. An additional consideration is the initial temperature of the vegetation, since vegetation at a high temperature would require less heating to reach lethal temperature (Brown and Davis, 1973). Seasonal variation in plant tissue condition may affect fire susceptibility. Tissues higher in water content are more likely to be affected by fire heat (Hare, 1961). Succulent tissues are thus more

heat susceptible than those which have hardened later in the season. —  
Plants with high food reserves are also more heat tolerant (Hare, 1961). —  
Death of dormant buds at or above the soil surface depends on the air  
temperature reached, while subsurface organ damage is sustained only if —  
heat penetrates the soil.

#### Soil Temperature - Soil Moisture Relationships

Critical temperatures rarely penetrate more than a few centi- —  
meters into the soil except during extremely intense fires (Beadle,  
1940; Spurr, 1964; Smith, 1968). Decreased sprouting of bitterbrush  
(Blaisdell, 1953; Blaisdell and Mueggler, 1956) and blueberry (Vaccinium  
angustifolium and V. myrtilloides) (Smith, 1968) on higher intensity  
burns may be due to a greater heat penetration into duff and soil layers  
under these intense fires, thereby increasing the amount of sprouting  
site destruction.

Heat penetration has been related to the amount of moisture  
present in soil and duff layers. Shearer (1975) found that the amount  
of duff reduction, soil heating, and nonconiferous root mortality  
resulting from slashburns was negatively correlated to duff and soil — +  
moisture content. Ninety-five percent of rabbitbrush plants on deep  
heavy soils sprouted after burning; those growing on granitic sandy soil  
were killed (Robertson and Cords, 1957). Driscoll (1963) reported 80  
percent sprouting of bitterbrush on fine-textured, stony soil, and as  
little as 1 percent recovery on soils with coarse materials present on  
or within the surface soil horizon. Coarse-textured soils are usually  
well drained, and therefore have a greater proportion of air in macro-  
pore space than more finely textured soils. Observed differences in

shrub sprouting response may have been due to differing amounts of soil moisture caused by different soil moisture retention properties.

Wijk (1963, in Smith, 1966) has stated that heat is transferred through soil largely by conduction. Wet soil is a better conductor of heat than dry soil. However, much more energy is required to heat wet soil. The energy required for heating a substance can be expressed in terms of specific heat. The specific heat of a soil is the ratio of the amount of heat required to raise its temperature from 15 to 16°C to the amount of heat required to raise the temperature of an equivalent amount of water. The dry weight specific heat of most mineral soils is about 0.2, whereas the specific heat of a soil with 30 percent moisture content is about 0.38 (Buckman and Brady, 1966). The higher the soil moisture content, the more heat would have to be provided by the fire to raise its temperature.

Albini<sup>5</sup> has said that the principal method of heat transfer through a porous medium such as duff or soil is by the mechanism of vapor transfer. Water in surface ground layers is evaporated by fire, absorbing about 540 cal/gram of heat in the process. The vapor moves in all directions in response to the vapor pressure gradient. Some steam will move downward through the profile in macropore spaces, condensing on cool surfaces if the relative humidity is near 100 percent, a saturated condition. The latent heat will be released upon vapor condensation. If duff and soil are dry, this heat will be directly transferred to the particles. If water is present, the latent heat will be expended in heating the water. Only a very small amount of heat

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<sup>5</sup>Albini, Frank A. 1975. Personal conversation. USDA Forest Service, Northern Forest Fire Laboratory, Missoula, Montana.

would be transmitted to duff and soil particles with a film of water about them. Uggle (1958) has described the formation of a "sweating zone" immediately below the fire surface in thick moist humus, the result of condensation of fire evaporated moisture on the cold humus surface. This layer will insulate layers below from further heat penetration until it is completely evaporated by fire heat. Moist soil layers may also retard heat penetration by deflecting additional steam back towards the surface.<sup>6</sup> The amount of deflection may be related to the amount of water in soil macropore space. This vapor mechanism of heat transfer could account for the greater heat penetration into more coarsely textured soils observed by Robertson and Cords (1957) and Driscoll (1965).

#### Sprouting After Fire

Fire can thus exert a more severe effect upon a shrub than does top removal by clipping or grazing because of the increased likelihood of destruction of budding sites. Buds may be killed by fire heating or possibly fire-induced dessication of duff and soil layers. Sprouts must arise from buried, relatively undamaged stems. Sprouts developing from underground organs take longer to appear than those from surface organs, particularly if sprouts arose from root bud primordia which first developed after the fire occurrence, a process requiring additional time and energy. Blaisdell and Mueggler (1956) observed that sprouts originating after a fire from newly formed root collar buds in bitterbrush generally took longer to appear than those developing from existing

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<sup>6</sup>Ibid.

dormant buds. If fire destroyed existing buds, regeneration of new buds could cause greater depletion of carbohydrate reserves. The length of time before self-sustaining photosynthesis occurs would increase. Sprout survival over the following winter could be critically affected. The length of growing season that remains after sprout initiation could also affect winter survival ability by determining the amount of carbohydrate which can be stored for winter respiratory use.

An important factor to consider is the change in available nutrients which often accompanies fire. Prodigious flowering, fruiting, and seed setting in years following fires is often attributed to the fertilizing effect of the ash. The vigorous growth in juvenile stages may increase the percent of sprout success. If the nitrogen and phosphorus supplies are indeed controlling factors in cytokinin synthesis, an increase in these nutrients could increase the number of sprouts initiated from dormant buds and the initiation of bud primordia.

#### Observations on Species Response

Various investigators have made qualitative observations on the response to fire by shrub genus or species found at the Lubrecht site. Investigating a Long Island, New York, wildfire, Brayton and Woodwell (1966) found rhizomes of Vaccinium vacillans successfully sprouting from a depth of 5 cm, and observed rhizomes as deep as 15 cm below the soil surface. There was a statistically significant greater number of stems originating from belowground rhizomes on heavily burned sites ( $138 \pm 24$  stems/m<sup>2</sup>) than originating from root collar buds after a light ground fire ( $117 \pm 27$  stems/m<sup>2</sup>). Vaccinium angustifolium increased in dominance after fire in Minnesota (Ahlgren 1960). Yields of that species increased

a few years after burning in Wisconsin (Vogl, 1970). V. angustifolium and V. myrtilloides quickly resprouted and bore large numbers of berries the second growing season after a northern Minnesota fire (Books, 1972). Sharp reported (1970) that in central Pennsylvania, senescent clones of V. angustifolium and V. myrtilloides achieved an optimum level of increased fruiting 3 years after burning. Yearly burning decreased V. vacillans in New Jersey, while burns every 3 years maintained the same amount of shrub cover (Buell and Cantlon, 1953).

Biweekly burning treatments of lowbush blueberry (Vaccinium angustifolium) were administered from time of snow melt to July and then at monthly intervals to November 1, the treatments replicated on different sites for 3 years (Eaton and White, 1960). Numbers of sprouts, sprout length, and flowering were greatest after spring burns, declining toward an early summer minimum. No sprouts appeared the same year in plants treated after July 1, although plant response the following growing season was similar to that of spring treated plants.

In a northern Ontario experiment, V. angustifolium and V. myrtilloides showed increased density and productivity when burned with a flamethrower at a moderate temperature (362°C 40 sec/m<sup>2</sup> duration) during the dormant season. No change occurred due to the same treatment during the growing season. Decreased productivity resulted from hot treatments (702 to 823°C 80 sec/m<sup>2</sup> duration), probably because of rhizome death (Smith, 1968).

Comparing the effect of heavy and light burning treatments and clipping in mid-May, early July, and late October, Smith and Hilton (1971) found no significant changes in shoot density between treatments

and controls, but found increased dry matter production and percent cover after the spring and fall fire treatments. No statistically significant changes were observed after the summer fires. Clipping generally caused no increase in productivity for either spring or fall treatments. Summer clipping caused decreased productivity. The investigators attributed the different results of clipping and burning to the nutritive effect of the ash and the change in surface albedo after burning.

Regarding western species of huckleberry, Vaccinium membranaceum remained on-site after the Tillamook burn, although it changed from a sprawling forest form to tight separate clumps (Neiland, 1958). Minore (1974) has observed sprouting but no flowering of V. membranaceum two growing seasons after experimental burning for huckleberry regeneration at Mt. Adams, Washington. He believes that rejuvenation of huckleberry with fire is not economical in high-altitude lodgepole pine stands because fire will not carry except under extremely hazardous burning conditions without expensive slashing of standing timber.<sup>7</sup> Mueggler (1965) noted that Vaccinium species which have persisted under a closed canopy will become important on a burned site.

Weaver (1967) reported that Spiraea betulifolia var. lucida in northeastern Washington sprouted vigorously after a fire. S. betulifolia has been observed to return to prefire densities in 1 year in Idaho (Leege and Hickey, 1971). S. lucida could be found on burned sites in the cedar hemlock of northern Idaho (Mueggler, 1965).

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<sup>7</sup>Minore, Don. 1974. Personal communication. USDA Forest Service, Forestry Sciences Laboratory, Corvallis, Oregon.

Rosa woodsii doubled in abundance in Utah 2 years after fire (McKell, 1950, cited in Wright, 1971). R. acicularis on a Minnesota burn was described as being relatively fire intolerant (Ahlgren, 1960). R. spaldingii and R. ultramontana resprouted vigorously (Weaver, 1967). After 1 year, various Rosa species had recovered 60 percent of their former 17 percent cover in 1 year in central Alberta (Doerr et al., 1970), and had recovered prefire densities in Idaho (Leege and Hickey, 1971).

Berberis repens continued to produce increased yields 15 years after fire in southern Idaho (Blaisdell, 1953). Leege and Hickey (1971) reported no change in B. repens density 1 year after burning. It was reduced in numbers after 9 years, but increased to three times prefire density after 18 years (McKell, 1950, cited in Wright, 1971).

Symphoricarpos vaccinoides took 7 years to regain prefire densities (McKell, 1950, cited in Wright, 1971). S. rivularis vigorously resprouted (Weaver, 1967). S. oreophilus had increased in canopy cover by a factor of three, 7 years after a central Idaho experimental burn (Lyon, 1971). S. albus returned in prefire densities the first year (Leege and Hickey, 1971).

Salix scouleriana produced 28 times as many sprouts the year after burning (Leege and Hickey, 1971). Average willow plant volume equalled prefire volume in 4 years (Lyon, 1971).

Amelanchier alnifolia sprouted "prolifically," producing 107 times as many sprouts as controls after a spring fire and 59 times as many after a fall fire (Leege and Hickey, 1971).

It is evident that these species have adaptations which allow them to respond to fire. Those with increased numbers and cover values are benefited by fire pruning. The postfire variability in response within the same species is likely attributable to differential fire intensity, site, and shrub community conditions.

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## CHAPTER 3

### FIELD METHODS

#### STUDY AREA DESCRIPTION

The study area is located within the University of Montana Lubrecht Experimental Forest. Thirty-two 1/3-acre units were located at an elevation of 1,460 meters MSL in the north half of Section #, T13N, R15W, M.P.M., on northwest to northeast aspects with slopes of 15 to 45 percent. The sandy textured soils of the Holloway Series are thin and poorly developed with numerous quartzite argillite rocks of varying sizes (Stark, 1976). The down and dead woody fuel loading on the fire plots ranged from 5 to 50 tons per acre. Very old, partially decomposed slash from light, selective harvests prior to 1930 was supplemented by considerable amounts of naturally accruing fuels.

The area is predominantly in the Pseudotsuga menziesii-Vaccinium globulare habitat type, Arctostaphylos uva-ursi phase, with certain plots transitional to Pseudotsuga menziesii-Xerophyllum tenax habitat type, Arctostaphylos uva-ursi phase. The overstory is a fully stocked stand of all-aged Douglas-fir, (Pseudotsuga menziesii (Mirb.) Franco),<sup>8</sup> western larch (Larix occidentalis Nutt.), and lodgepole pine (Pinus contorta Dougl. ex Loud), with an occasional ponderosa pine (Pinus ponderosa Dougl. ex Loud). The undisturbed shrub understory is

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<sup>8</sup>Taxonomic nomenclature used for Lubrecht species follow C. L. Hitchcock et al., 1955-69.

dominated by low huckleberry (Vaccinium globulare Rydb.) and/or spiraea (Spiraea betulifolia var. lucida (Dougl.) C. L. Hitchc.), or low huckleberry menziesia (Menziesia ferruginea Smith), occasional snowberry (Symphoricarpos albus (L.) Blake), Oregon grape (Berberis repens Lindl.), willow (Salix scouleriana Barratt in Hook.), rose (Rosa spp.), and serviceberry (Amelanchier alnifolia Nutt.).

Small stature woody plants of importance are bearberry (Arctostaphylos uva-ursi (L.) Spreng), twinflower (Linnaea borealis L.), and prince's pine (Chimaphila umbellata var. occidentalis (L.) Blake). The herbaceous plant community is dominated by arnica species (Arnica cordifolia Hook. and Arnica latifolia Bong.) and pinegrass (Calamagrostis rubescens Buckl.), with strawberry (Fragaria virginiana Duchesne), one-sided wintergreen (Pyrola secunda L.), western meadowrue (Thalictrum occidentale Gray), and beargrass (Xerophyllum tenax (Pursh) Nutt.) frequently represented.

#### BACKGROUND

The Lubrecht Cooperative Fire Study was designed to describe criteria by which future prescribed fires could be scheduled to obtain desired levels of understory fuels management (Norum, 1975). Twenty plots were burned during 1973, nine in late spring and early summer, eleven in late summer and early fall. Inventories provided prefire and immediate postfire fuels estimates of fuel loadings by size classes, duff depths and weights, herbaceous biomass, and small tree stem number and location. Large trees were mapped and measured for height, diameter at breast height, height of clear bole, and percent living cambium.

Postfire tree data included the height and percent of crown scorch and bole scorch height. Percent cambium kill was measured one and two summers later. Fuel, duff, and soil moisture content were sampled at fire time; ambient air temperature, wind, and relative humidity were noted. Soil temperatures were measured by inserting 13, grooved 8- by 15-cm asbestos plates into the ground, level with the duff surface. Temperature sensitive paint in each groove provided soil temperature and depth of temperature data. Detailed descriptions of inventory procedures can be found in Appendix A.

Variables which describe preburn fuel weights, fuel, duff and soil moisture, atmospheric conditions, fuel reductions, fire intensity, and duff and soil temperatures attained during burning are listed. Variable means and standard deviations are separately noted for spring and for fall fires in Table 1. Variable ranges are listed in Table 2. Numbers in parentheses in the text refer to the number assigned to each variable listed on the tables. Date of plot ignition, plot moisture content, and soil heating data are listed in Appendix B.

Preburn fuel weight conditions (3, 4, 5, 6) were fairly equivalent between spring and fall except for the weight of sound, 3-inch and larger fuels (7), which averaged 1.7 times higher on spring burned plots. Preburn shrub weight (2) was somewhat greater on these plots as well. Atmospheric conditions (13, 37, 39) and average slope (14) were approximately the same in the spring and the fall.

Moisture conditions at the time of plot ignition often varied widely between spring and fall fires. Understory foliage moisture content (38) was much higher in the spring because of the flush of new

Table 1.--Mean and standard deviation of measured variables, Lubrecht prescribed fire study

Variable	Spring fires		Fall fires	
	Mean	Standard deviation	Mean	Standard deviation
1. Number of Vaccinium globulare stems before fire (1973)	777.33	379.16	670.09	670.51
2. Preburn shrub weight (Kg/m <sup>2</sup> )	.13	.07	.07	.04
3. 0 to 1/4 inch (0 to .635 cm) preburn fuel weight (Kg/m <sup>2</sup> )	.07	.01	.10	.03
4. 1/4 to 1 inch (.635 to 2.54 cm) preburn fuel weight (Kg/m <sup>2</sup> )	.14	.04	.15	.09
5. 1 to 3 inch (2.54 to 7.62 cm) preburn fuel weight (Kg/m <sup>2</sup> )	.43	.21	.57	.31
6. Rotten, 3 inch (7.62 cm) and larger preburn fuel weight (Kg/m <sup>2</sup> )	5.84	3.04	4.10	2.18
7. Sound, 3 inch (7.62 cm) and larger preburn fuel weight (Kg/m <sup>2</sup> )	1.11	1.20	.65	.98
8. Total, 3 inch (7.62 cm) and larger preburn fuel weight (Kg/m <sup>2</sup> )	6.95	2.82	4.75	2.76
9. Total preburn fuel weight (Kg/m <sup>2</sup> )	7.59	2.79	5.57	2.8
10. Preburn duff depth (cm)	7.24	1.20	7.05	1.83
11. Preburn herbaceous vegetation (Kg/m <sup>2</sup> )	.09	.06	.07	.03
12. Preburn dead fuel depth (cm)	16.59	8.68	16.15	8.63
13. Windspeed (mph)	2.56	3.09	2.64	2.66
14. Average slope (percent)	35.00	8.00	37.00	10.00
15. 0 to 1/4 inch (0 to .635 cm) fuel moisture content (percent)	10.74	2.02	20.38	6.33
16. 1/4 to 1 inch (.635 to 2.54 cm) fuel moisture content (percent)	11.46	3.05	23.24	8.22
17. 0 to 1/4 inch (0 to .635 cm) fuel weight reduction (Kg/m <sup>2</sup> )	.02	.02	.04	.03
18. 1/4 to 1 inch (.635 to 2.54 cm) fuel weight reduction (Kg/m <sup>2</sup> )	.06	.05	.08	.09
19. 0 to 1 inch (0 to 2.54 cm) fuel weight reduction (Kg/m <sup>2</sup> )	.09	.05	.12	.11
20. 1 to 3 inch (2.54 to 7.62 cm) fuel weight reduction (Kg/m <sup>2</sup> )	.08	.23	.28	.32
21. Total, 3 inch (7.62 cm) and larger fuel weight reduction (Kg/m <sup>2</sup> )	4.38	3.11	3.35	2.75
22. Total fuel weight reduction (Kg/m <sup>2</sup> )	4.55	3.14	3.83	2.70
23. Mean duff depth reduction (cm)	1.74	.49	3.85	1.74
24. Percent duff depth reduction (percent)	24.41	6.41	53.41	14.51
25. Fire intensity (Kcal/sec/m <sup>2</sup> )	103.07	63.01	71.68	44.64
26. Percent shrub weight reduction (percent)	64.47	20.95	53.92	20.91
27. Average mineral soil surface temperature (°F)	143.56	39.33	232.73	39.36
28. Adjusted soil surface temperature (°F)	60.56	50.98	174.36	56.83
29. Average duff surface temperature (°F)	252.44	62.19	359.27	66.42
30. Adjusted duff surface temperature (°F)	220.00	31.38	338.00	74.89
31. Average temperature at 2.5 cm below duff surface (°F)	191.00	56.39	320.27	76.05
32. Average temperature at 5.0 cm below duff surface (°F)	153.89	48.89	299.27	76.21
33. Average temperature at 7.5 cm below duff surface (°F)	141.78	31.98	263.91	79.25
34. Upper duff moisture content (percent)	40.57	21.45	70.53	28.86
35. Lower duff moisture content (percent)	89.99	42.84	79.11	23.02
36. Soil moisture content (percent)	29.09	11.33	12.51	3.97
37. Relative humidity (percent)	37.44	7.78	39.45	7.98
38. Understory foliage moisture content (percent)	259.00	57.46	128.31	16.67
39. Ambient air temperature (°F)	68.56	6.09	59.91	11.09
40. Number of Vaccinium globulare stems 1 year after fire (1974)	1102.55	319.89	719.36	676.14
41. Number of Vaccinium globulare stems 2 years after fire (1975)	1283.33	452.2709	955.27	826.41

Table 2.--Range of measured variables, Lubrecht prescribed fire study

Variable	Spring fires		Fall fires	
	Low	High	Low	High
1. Number of Vaccinium globulare stems before fire (1973)	87	1288	103	2547
2. Preburn shrub weight (Kg/m <sup>2</sup> )	.07	.27	.03	.18
3. 0 to 1/4 inch (0 to .635 cm) preburn fuel weight (Kg/m <sup>2</sup> )	.05	.09	.05	.15
4. 1/4 to 1 inch (.635 to 2.54 cm) preburn fuel weight (Kg/m <sup>2</sup> )	.08	.20	.05	.36
5. 1 to 3 inch (2.54 to 7.62 cm) preburn fuel weight (Kg/m <sup>2</sup> )	.14	.76	.20	1.24
6. Rotten, 3 inch (7.62 cm) and larger preburn fuel weight (Kg/m <sup>2</sup> )	1.62	10.52	1.01	7.31
7. Sound, 3 inch (7.62 cm) and larger preburn fuel weight (Kg/m <sup>2</sup> )	0.00	3.55	0.00	3.44
8. Total preburn fuel weight (Kg/m <sup>2</sup> )	2.14	10.52	1.08	10.75
9. Total preburn fuel weight (Kg/m <sup>2</sup> )	3.01	11.06	1.41	11.41
10. Preburn duff depth (cm)	5.00	8.40	4.30	10.80
11. Preburn herbaceous vegetation weight (Kg/m <sup>2</sup> )	.04	.25	.03	.14
12. Preburn dead fuel depth (cm)	3.62	28.50	6.97	30.31
13. Windspeed (mph)	0.00	10.00	0.00	7.00
14. Average slope (percent)	21.00	48.00	23.00	50.00
15. 0 to 1/4 inch (0 to .635 cm) fuel moisture content (percent)	8.60	15.46	8.03	35.20
16. 1/4 to 1 inch (.635 to 2.54 cm) fuel moisture content (percent)	8.58	18.92	8.40	42.50
17. 0 to 1/4 inch (0 to .635 cm) fuel weight reduction (Kg/m <sup>2</sup> )	.06	.12	-.02	.03
18. 1/4 to 1 inch (.635 to 2.54 cm) fuel weight reduction (Kg/m <sup>2</sup> )	-.03	.12	-.0002	.31
19. 0 to 1 inch (.635 to 2.54 cm) fuel weight reduction (Kg/m <sup>2</sup> )	.04	.18	-.002	.38
20. 1 to 3 inch (2.54 to 7.62 cm) fuel weight reduction (Kg/m <sup>2</sup> )	-.36	.42	-.02	1.05
21. Total, 3 inch (7.62 cm) and larger fuel weight reduction (Kg/m <sup>2</sup> )	.71	8.84	-1.06	9.21
22. Total fuel weight reduction (Kg/m <sup>2</sup> )	.72	9.01	-1.01	9.27
23. Mean duff depth reduction (cm)	1.20	2.70	1.60	7.60
24. Percent duff depth reduction (percent)	14.30	34.60	23.50	71.80
25. Fine intensity (Kcal/sec/m <sup>2</sup> )	33.66	213.76	34.70	159.57
26. Percent shrub weight reduction (percent)	36.59	95.44	17.91	85.55
27. Average soil surface temperature (°F)	103.00	211.00	175.00	310.00
28. Adjusted soil surface temperature (°F)	8.00	148.00	50.00	262.00
29. Average duff surface temperature (°F)	132.00	346.00	274.00	494.00
30. Adjusted duff surface temperature (°F)	53.00	338.00	238.00	494.00
31. Average temperature at 2.5 cm below duff surface (°F)	107.00	275.00	209.00	466.00
32. Average temperature at 5.0 cm below duff surface (°F)	103.00	243.00	198.00	442.00
33. Average temperature at 7.5 cm below duff surface (°F)	103.00	186.00	191.00	432.00
34. Upper duff moisture content (percent)	12.98	70.30	9.77	115.40
35. Lower duff moisture content (percent)	18.89	145.06	22.78	103.19
36. Soil moisture content (percent)	14.20	43.26	5.74	18.41
37. Relative humidity (percent)	27.00	52.00	28.00	53.00
38. Understory foliage moisture content (percent)	139.88	343.30	91.51	157.67
39. Ambient air temperature (°F)	55.00	75.00	44.00	77.00
40. Ambient air temperature/soil moisture content	1.38	5.14	2.62	13.07
41. Number of Vaccinium globulare stems 1 year after fire (1974)	323	1634	60	2417
42. Number of Vaccinium globulare stems 2 years after fire (1975)	600	2165	54	3056

growth. The moisture content of the 0- to 1/4-inch fuels (15) and 1/4- to 1-inch fuels (16) was much lower in the spring than in the fall. The unusually dry conditions in May (Appendix B) could have been due to the dry winter, since the study area had an unusually low snowpack during the 1972-1973 winter. These fine fuels remained fairly dry throughout the spring and into the early summer. The moisture content of 1- to 3-inch and 3-inch and larger fuels was generally higher in the spring than in the fall<sup>9</sup> although no specific data are available. The upper duff moisture content (34) was generally lower in the spring than in the fall, exhibiting a drying trend throughout the spring and into the early summer. Lower duff moisture content (35) was fairly high at the beginning of the spring burning season, but also tended to dry through the spring. Soil moisture content (36) was much higher than in the fall throughout most of the spring season, although it had dropped sharply on the last two plots burned to within the range of the fall season fires. It may be that the moisture content of the 1- to 3-inch fuels and the sound, 3-inch and larger fuels was also decreasing throughout the spring, since heavy fuel moisture is loosely related to duff moisture content and duff moisture did decrease. The high linear correlation between upper and lower duff and lower duff and soil moisture content in the spring (Table 3) indicates that the drying process was affecting them simultaneously. The drying trend from the initially high spring soil and duff moisture content was promoted by long days and high sun angles, with a consequently more effective daily drying period than in the fall.

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<sup>9</sup>Norum, Rodney A. 1976. Personal conversation. USDA Forest Service, Northern Forest Fire Laboratory, Missoula, Montana.

Duff moisture content slowly increased throughout the fall season. Upper duff (34) and lower duff (35) moisture content were well correlated for fall, but lower duff moisture content was not significantly related to soil moisture content. Apparently, late summer rains had raised duff moisture levels, but had not raised soil moisture content levels proportionately. Soils at the time of the fall prescribed burns may have absorbed a fair amount of water since the summer, but had yet to reach the higher moisture content status which they could attain.

Table 3.--Simple linear correlation coefficients  
between duff and soil moisture content

	: Spring	: Fall	: All fires
Upper duff moisture content - Lower duff moisture content	.7537*	.8389**	.5166*
Upper duff moisture content - Soil moisture content	.6003	.3497	-.1379
Lower duff moisture content - Soil moisture content	.8747**	.4659	.6515**

\* Significant at  $P < .05$

\*\* Significant at  $P < .01$

Fuel weight reduction, the change of the amount of fuel due to fire treatment, was calculated by comparing postburn fuel inventory data with preburn information. Fuel reduction did not necessarily equal fuel consumption. Tree downfall after fire sometimes added considerable fuel to plots. The heavy fuel weight actually increased by 44 percent on Plot 14 after fire because of the death and collapse of a 32-inch d.b.h. western larch which had a rotten center. Consumption of heavy

fuels, 3 inches and larger in diameter was actually much greater in the fall than in the spring, a fact not revealed by fuel reduction figures in this size class (21). Total fuel weight reduction figures (22) are likewise biased because of the great contribution to total fuel weight made by heavy fuels.

Average 1/4- to 1-inch (18) and 0- to 1-inch (19) fuel weight reduction and percent brush weight reduction (26) were fairly equivalent for the two burning seasons. Fires which were conducted in late summer and early fall resulted in greater 0- to 1/4-inch fuel weight reduction (17) and three-and-one-half times as much reduction of 1- to 3-inch fuels (20). Duff reduction (23, 24) and soil heating (27 through 33) were generally higher for fall fires.

Fires conducted in late summer and early fall were hotter than those conducted in late spring and early summer. They caused greater soil heating and led to more complete combustion of fuels and duff than occurred in the earlier burning season. Spring fires were more intense (23) in terms of maximum energy output per unit time, as calculated according to Van Wagner's formula for computing fire intensity from crown scorch height (Norum, 1975). Spring fires resulted in much less fuel reduction in heavier fuel classes and caused much less subsurface heating than occurred in fall fires.

Regression equations were computed that relate fuel amounts, fuel moisture, and environmental parameters to fuel reduction, fire intensity, soil temperatures, small stem mortality, and tree cambial kill (Norum, 1975). Associated studies involved forest fuel moisture determination, a test of fire spread models, smoke production, changes in soil nutrient levels, and plant nutrient uptake.

## DATA COLLECTION

Although shrubs can be an important factor in wildland fires, data for total shrub species biomass and estimation procedures have not previously existed. Regression equations have been developed which predict biomass of certain wildland shrubs on the basis of basal stem diameters (Brown, 1976). The approach involved the systematic selection of samples from three or more distinct stands covering as complete a range of stem basal diameters as possible. Plants were clipped, basal diameter measured, air dried, and separated into stemwood and foliage components. Stemwood size distributions were determined for each species. Regression equations predicting total aboveground weight and leaf weight on the basis of species stem diameters were developed. Distributions of basal diameter classes by species were calculated through systematic sampling of randomly located 1/4-acre plots in various habitat types. Sampling density necessary to predict shrub biomass can be estimated from the coefficient of variation calculated for each habitat type. Constants and variables used for calculating brush weight are given in Appendix C.

The shrub inventory procedures used for the 1973 Lubrecht fire study were intended to provide estimates of woody fuel biomass using the linear regression equations developed by Brown. Thirteen points were systematically located within each 20- by 20-meter sampling plot, each point being 7.071 and/or 10 meters distant from adjacent points. Two 113.2-cm diameter circular quadrats were established at each of the fuel inventory points. A random procedure was used to select an azimuth from the plot center, and a 2-meter-long inventory pole was aligned in that

direction. (Azimuth was not noted.) A second 2-meter pole was laid perpendicular to the first. The centers of the shrub plots were at the ends of the second pole. (See Appendix A for diagram.) The center of each 1.0061 m<sup>2</sup> quadrat was 2 meters from the other sample and 2.236 meters from the sampling point.

Individual shrub stems were tallied by basal diameter size class: 0 to 0.5 cm, 0.5 to 1.0 cm, 1.0 to 1.5 cm, 1.5 to 2.0 cm, 2.0 to 3.0 cm, and 3.0 to 5.0 cm. The inventory was repeated on each site shortly after fire treatment as part of the postburn fuels inventory. The same location was not reinventoried because of possible destructive sampling of herbaceous vegetation which may have occurred during the prefire inventory. If the inventory was made after autumn leaf fall, and in cases where leaves were burned from a live stem, species identification was sometimes difficult. Spiraea betulifolia and Vaccinium globulare were tallied together, since they were in the same class for biomass estimation. Accurate immediate postfire information is thus not available for these two species.

Various methods of assessing fire effect upon the shrub understory were considered when planning the shrub inventory 1 year after fire treatment. Because no comparable prefire inventory was carried out, the use of transects or other methods of sampling would have required comparison with adjacent unburned areas to determine changes in speciation or species density. Species composition differences due to site variability could have precluded the discovery of fire modified vegetative patterns. It was therefore decided that the most viable means of assessing fire impact upon the shrub understory would be by

comparing the prefire shrub inventory to a duplicate inventory conducted one full growing season after burning.

Inventories were conducted in the summers of 1974 and 1975. A fire-pruned stem was considered to be one plant if it was alive at ground level. Sprouts originating from below the duff or soil level were each considered as a separate plant. In order to determine if these regenerated stems originated from one or several pruned stems, excessive disturbance of the duff and/or soil would sometimes have been necessary. They were thus tallied separately to prevent possible bias of future measurements. Quadrats tallied in 1974 were not duplicates of the prefire inventory; 1974 and 1975 quadrats were identical. Plot percent cover and average plant height were not noted in the 1975 inventory.

## CHAPTER 4

### ANALYSIS

Two distinct sets of statistical operations were used in the analysis. Comparisons of plot mean values were made to determine relative species sensitivity to fire. Regression analysis was used to determine relationships between fire and fire time environmental characteristics, resultant fire effects, and the postfire shrub community.

#### COMPARISON OF PLOT MEANS

Prefire to postfire plant numbers (1973 to 1974) were compared using t-tests of plot mean values and the nonparametric Mann-Whitney-Wilcoxon Rank Sum Test of median values. It was hoped that the median test would reveal differences which the t-test could not because of the nonnormality of the sample distributions and the random nature of observation collection. The Mann-Whitney comparison is a distribution-free test, but it does assume that the two populations being compared possess essentially the same distribution.

Plot mean values were compared, based on the assumption that the number of quadrats on which rhizomes were present was the same before and after burning. If prefire sample size did not equal postfire sample size, it could be due to nonmanifestation of existing rhizomes. Increases in number of quadrats on which plants appeared after fire may

be due to stimulation of sprouting. Decreases may be attributable to some effect of fire, whether it be rhizome kill or a depth of pruning from which sprouts had not yet appeared. Means and variances were calculated for each plot before and after fire for each species, averaging in zero for unrepresented quadrats to make prefire and postfire sample size equivalent. The variance estimate was a pooled value of prefire and first year after fire plot variances. Variances were compared using the Maximum F-test to determine if significant changes in plot variance had occurred. These tests evaluated changes in average number of plants manifesting from existing rhizomes.

A comparison of average number of aboveground stems per sample quadrat before and 1 year after fire was a test for changes in average density of plants where aboveground stems did occur. Means and variances were calculated with sample size equal to the actual number of sample quadrats on which stems of each species were tallied at the time of each inventory. Average values were compared with the two sample t-test and Mann-Whitney-Wilcoxon Rank Sum Test. The Maximum F-test of variance was conducted to determine significant changes in the variance of aboveground stem density.

Data collected at the end of the first and second full growing seasons after fire treatment, 1974 and 1975, were compared to determine whether increases in numbers of shrubby plants which occurred on most plots could be attributed to the appearance of additional sprouts the second year after fire. Since the same quadrats were inventoried in the 2 subsequent postfire years, a paired sample t-test could be used to test for changes in the number of stems appearing in association with

existing rhizomes. The variance estimate was based upon differences in plant numbers observed on each quadrat. Since comparison of paired data by a t-test is a much more powerful comparison than the Mann-Whitney-Wilcoxon Rank Sum Test, this latter test was not used to analyze changes in plot mean values occurring between 1974 and 1975. Maximum F-tests of variance were also conducted.

The average number of aboveground stems per sample quadrat was also compared to determine whether the density of plants continued to change from 1974 to 1975. Three statistical tests were performed, the two sample t-test, the Mann-Whitney-Wilcoxon Rank Sum Test, and the Maximum F-test of variance. Values for plot variance were obtained by pooling variances estimated for 1974 and 1975 data.

A basic difficulty in applying standard statistical techniques of comparison was the inherent variability in the plant community, greatly enhanced by fire treatment. Plant occurrence did not conform to a standard normal distribution in many instances. The ability to make prefire-postfire comparisons was further limited because it was impossible to resample in the 1974 inventory the same quadrats as were inventoried before fire. Tests could not be run for many species on many plots because they were not present in sufficient numbers or on sufficient data points.

#### MULTIPLE REGRESSION

The data were subjected to a multiple regression analysis to determine if a significant part of the variation in postfire numbers of shrubs could be explained by fuel loadings, fuel moisture, environmental conditions at the time of plot ignition, or fire effects. The data were

.

scatter plotted to detect possible relationships between independent and dependent variables. Data used were gathered before fire or 1 year after fire. Thirty-five independent variables were plotted against the following:

- change in plot total percent shrub cover,
- percent change in plot total percent shrub cover,
- prefire number of Vaccinium stems tallied per plot,
- number of Vaccinium stems tallied per plot 1 year after fire,
- change in number of Vaccinium stems per plot,
- percent change in number of Vaccinium stems per plot,
- plot residual values (predicted minus observed) of the

equations

$$y = a + bx$$

$$y = bx$$

where  $x$  = prefire number of Vaccinium stems tallied per plot  
and  $y$  = postfire number of Vaccinium stems tallied per plot  
1 year after fire.

Variables were plotted for all 20 fires, and for spring and fall fires separately. No relationships were apparent.

Computer program REX (Grosebaugh, 1967) was used to develop regression equations. The program determines regression equations for all combinations of independent variables and prints the ratio mean square for each. The coefficient of multiple determination ( $R^2$ ) was calculated for low ratio mean square values. Variable sets which explained a large amount of the variation in  $Y$  were selected and additional statistics computed by another section of the REX program.

The significance level of the entire regression equation was determined by an analysis of variance F-test. Individual regression coefficients were tested with a t-test, dividing the Beta-coefficient value by the variance of that coefficient. Residual analysis of error terms consisted of dividing each error term by the standard error of the regression, obtaining a Z-statistic for each error term. These Z-statistics were examined for nonnormality of distribution. Simple correlation coefficients between all independent variables within each equation and between the independent and dependent variables were also available.

#### Independent Variable Selection

Equations were developed in the regression screening process from two different sets of independent variables. Variables had all been logically or statistically related to fire or to fire effects. The first set contained variables which described conditions on each plot at the time the prescribed fires were ignited. Variables which described fire effects and temperatures at and below the ground surface were included in the second set of independent variables. The same expression of the postfire Vaccinium community was used throughout the analysis,  $Y = \text{total number of } \underline{\text{Vaccinium}} \underline{\text{globulare}} \text{ stems tallied on each individual burn plot}$ . No other shrub species was present in sufficient numbers on enough plots to be used as an independent variable in the regression analysis.

Hare (1961) suggested that the temperature of a plant during a fire depends on its distance from the flames, and the intensity and duration of the fire. He attributed fire intensity and duration to

fuel, slope, and atmospheric conditions. It is reasonable to assume that the temperature reached by an underground plant part will be additionally a function of the moisture condition of the duff and/or soil which separates it from the fire. Independent Variable Set One (Table 4) thus contained variables which would establish burning conditions, resultant fire characteristics, and variables which might logically interact with fire to control the heat regime within the duff and soil.

Plot fuel loadings were included because fuels are the factor contributing most to the characteristics which the fire will assume (Brown and Davis, 1973). Fuels were entered individually, by size class, because of the various roles that fuels of different sizes play. Small fuels tend to act as kindling for larger fuels which, in turn, contribute to soil heating (Brown and Davis, 1973).

Fuel moisture content will affect the ease of fuel ignition and fire spread (Countryman, 1971). High fuel moisture can interfere with combustion. The moisture which is evaporated by fire heat tends to accumulate around a fuel particle, inhibiting the amount of fuel contact with oxygen necessary for combustion (Brown and Davis, 1973). Combustion occurs much more quickly if fuel moisture is low. Energy is released over a much shorter period of time. The intensity of energy release per unit of time would thus be higher in dry than in wet fuels. Dry fuels are very responsive to changes in atmospheric relative humidity, and thus also to ambient air temperature, since it controls the total amount of moisture which the air can hold. Very fine fuels, with large surface-to-volume ratios, such as twigs less than 1/8 inch in size, cone scales, dry needles, and dead herbaceous material respond most quickly to

Table 4.--Independent Variable Set One


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$x_1$	= preburn number of huckleberry stems tallied per plot
$x_2$	= preburn shrub weight (Kg/m <sup>2</sup> )
$x_3$	= 0 to 1/4 inch (0 to .635 cm) preburn fuel weight (Kg/m <sup>2</sup> )
$x_4$	= 1/4 to 1 inch (.635 to 2.54 cm) preburn fuel weight (Kg/m <sup>2</sup> )
$x_5$	= 1 to 3 inch (2.54 to 7.62 cm) preburn fuel weight (Kg/m <sup>2</sup> )
$x_6$	= rotten, 3 inch (7.62 cm) and larger preburn fuel weight (Kg/m <sup>2</sup> )
$x_7$	= sound, 3 inch (7.62 cm) and larger preburn fuel weight (Kg/m <sup>2</sup> )
$x_8$	= total, 3 inch (7.62 cm) and larger preburn fuel weight (Kg/m <sup>2</sup> )
$x_9$	= total preburn fuel weight (Kg/m <sup>2</sup> )
$x_{10}$	= preburn duff depth (cm)
$x_{11}$	= preburn herbaceous vegetation weight (Kg/m <sup>2</sup> )
$x_{12}$	= preburn dead fuel depth (cm)
$x_{13}$	= windspeed (mph)
$x_{14}$	= slope (percent)
$x_{15}$	= 0 to 1/4 inch (0 to .635 cm) fuel moisture content (percent)
$x_{16}$	= 1/4 to 1 inch (.635 to 2.54 cm) fuel moisture content (percent)
$x_{34}$	= upper duff moisture content (percent)
$x_{35}$	= lower duff moisture content (percent)
$x_{36}$	= moisture content of the top 5.0 cm of soil (percent)
$x_{37}$	= relative humidity (percent)
$x_{38}$	= understory foliage moisture content (percent)
$x_{39}$	= ambient air temperature (°F)
$x_{40}$	= ambient air temperature/moisture content of the top 5.0 cm of soil

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changes in atmospheric moisture content (Steen, 1963). Smith and Sparling (1966) found some evidence that the heat front moved more slowly when relative humidity was higher in July surface fires conducted in a Pinus banksiana (jack pine) - Vaccinium community.

Understory foliage moisture content was included in the analysis because lush herbaceous vegetation may tend to smother a fire, although it will burn if sufficiently preheated (Lawson, 1972). Smith and Sparling (1966) found that greater temperatures were attained when understory biomass was greater. A positive correlation between amounts of grassy fuel and fire temperatures was recorded on Texas prairies by Stinson and Wright (1969). Herbaceous and shrub biomass were thus included as variables in the regression analysis as measures of the amount of vegetation present on each site which could influence the fire.

An effect of wind, said to be equivalent to that of slope, is the preheating of fuel because of flame bending into closer contact with fuel particles (Murphy et al., in Stinson and Wright, 1969). Wind is also said to affect fire by introducing more oxygen. Simple dispersal of accumulated water vapor about fuel particles could increase the amount of available oxygen. Moderate windspeeds enhanced fire temperature in dense heath communities, but greater windspeeds tended to cool fires (Whittaker, 1961). Sparling and Smith (1966) found that moderate windspeeds (greater than 4.5 mph) cooled fires in clumpy Vaccinium communities. They concluded that wind's role of increasing the oxygen supply would only be important on sites with dense, uniform vegetation.

Huckleberry rhizomes are distributed throughout the duff (partially decomposed organic matter) and upper soil layers. Heat released

by the fire would interact with duff and soil moisture and govern the amount of heating which rhizomes received. Because of the differences in duff and soil moisture content and probably differences in insulating properties, prefire duff depth was included as an independent variable.

Transformed variables were also combined with variables in Set One. Ambient air temperature divided by soil moisture content was thought to integrate air temperature with the amount of insulation afforded rhizomes from that temperature. Two transformations were combined with variables in Set One, but did not significantly improve equation fit. These transformations were reciprocal values for fuel, duff, soil and understory vegetation moisture content, and effective windspeed. This latter variable integrated the effect of slope and wind. Values for effective windspeed were derived from the terrain slope tangent table for "timber with litter and understory fuel" model at low windspeeds.<sup>10</sup>

Henry Wright<sup>11</sup> has suggested that wind and relative humidity had been the most important variables in his work on mesquite (Prosopis glandulosa) burning in Texas. He said that these two variables plus 0 to 1/4 inch and total preburn fuel weight, 1/4 to 1 inch fuel moisture content, and ambient air temperature would be the most important variables to consider in this study.

The variables in Independent Set Two (Table 5) were used in order to determine whether any of the measured fire effects could be

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<sup>10</sup>Albini, Frank A. 1976. Estimating wildfire behavior and effects. (In preparation). USDA Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report.

<sup>11</sup>Wright, Henry A. May 13, 1975, personal communication to W. C. Fischer.

Table 5.--Independent Variable Set Two


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$x_1$	= preburn number of huckleberry stems tallied per plot
$x_{17}$	= 0 to 1/4 inch (0 to .635 cm) fuel weight reduction (Kg/m <sup>2</sup> )
$x_{18}$	= 1/4 to 1 inch (.635 to 2.54 cm) fuel weight reduction (Kg/m <sup>2</sup> )
$x_{19}$	= 0 to 1 inch (0 to 2.54 cm) fuel weight reduction (Kg/m <sup>2</sup> )
$x_{20}$	= 1 to 3 inch (2.54 to 7.62 cm) fuel weight reduction (Kg/m <sup>2</sup> )
$x_{21}$	= total, 3 inch (7.62 cm) and larger fuel weight reduction (Kg/m <sup>2</sup> )
$x_{22}$	= total fuel weight reduction (Kg/m <sup>2</sup> )
$x_{23}$	= mean duff depth reduction (cm)
$x_{24}$	= percent duff depth reduction (percent)
$x_{25}$	= fire intensity (Kcal/sec/m <sup>2</sup> )
$x_{26}$	= percent shrub weight reduction (percent)
$x_{27}$	= average temperature reached at mineral soil surface (°F)
$x_{28}$	= adjusted temperature reached at mineral soil surface (°F)
$x_{29}$	= average temperature reached at duff surface (°F)
$x_{30}$	= adjusted temperature reached at duff surface (°F)
$x_{31}$	= average temperature reached at 2.5 cm below duff surface (°F)
$x_{32}$	= average temperature reached at 5.0 cm below duff surface (°F)
$x_{33}$	= average temperature reached at 7.5 cm below duff surface (°F)
$x_{34}$	= upper duff moisture content (percent)
$x_{35}$	= lower duff moisture content (percent)
$x_{36}$	= moisture content of the top 5.0 cm of soil (percent)
$x_{37}$	= relative humidity (percent)

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closely related to the postfire shrub community. Variables measured the degree of heating of the site directly, by indicating soil and duff temperatures attained during burning, or indirectly, by measuring fuel, brush, and duff reduction, factors which related to the amount of heat released during the fire. Soil surface and duff temperatures attained during burning were average values at different depths obtained from the 13 soil temperature plates inserted in each plot. One hundred and three degrees was averaged in for all points not heated by the fire when calculating temperatures attained at each particular depth. Average duff and soil surface temperatures were also calculated using ambient air temperature rather than  $103^{\circ}$  for points not heated by the fire. No significant difference in equation fit resulted from use of these variables.

Adjusted soil and duff surface temperature were transformations obtained by multiplying the average soil and duff temperatures calculated by the percentage of the 13 data points which did register a temperature during burning. This adjusted plot averages for those data points which were heated to less than  $103^{\circ}$  but were considered to have reached  $103^{\circ}$  when calculating average figures. This transformation also adjusted for missing data on three plots.

#### Equation Development

The REX screening process is capable of developing regression equations for all combinations of 17 independent variables taken 5 at a time. Since all possible sets of variables could not be screened at one time, groups of independent variables were chosen. These lists were modified for additional regression screens by eliminating variables or

variable transformations which did not appear significant and by adding variables not previously included in the screening process.

Equations from both variable sets were developed using data on postfire numbers of Vaccinium globulare plants in 1974 and in 1975, one and two full growing seasons after fire treatment. The first equations developed were for all 20 fires. Equations were developed for spring and fall fires separately. The equations which were examined contained a maximum of 4 independent variables for the 9 spring fires, and 5 independent variables for the 11 fall fires.

The selection of "best" final equations was made from those containing three independent variables for spring fires, giving three degrees of freedom for the regression and five degrees of freedom for error. Fall equations were selected from those containing four independent variables, giving four and six degrees of freedom. Best equations were selected on the basis of the following criteria: significance of the regression equation, equations being ranked by the F-test, significance of each independent variable according to the t-test, and normality of error distribution. If the sign of a Beta-coefficient was illogical in an otherwise statistically good equation, the simple linear correlation coefficient was checked for significance. If nonsignificant, the difference in coefficient sign was attributed to the least squares fitting process. If significant, the possibility of experimental bias exists. However, at no time was a variable illogically fitted which was significantly related to the dependent variable.

## CHAPTER 5

### RESULTS AND DISCUSSION

A comparison of shrub inventory data collected before and after fire shows that plant numbers and distributions did change after treatment. Table 6 presents inventory data for Vaccinium globulare. Data for other species are in Appendix D. The total number of huckleberry plants found on the 26 brush inventory quadrats and the number of quadrats on which huckleberry stems appeared are listed for each plot. Data are listed for three inventories: before fire (1973), 1 year after fire (1974), and 2 years after fire (1975). Figures 1 and 2 compare the results of spring and fall fires and document the changes in plant numbers and distributions following fire. Figure 1 shows the percent of plots in which the numbers of Vaccinium increased or decreased. Figure 2 shows the percent of plots on which there was a change in the number of quadrats with plants. Spring and fall data are listed separately. Spring fires were those ignited between May 11 and June 29, 1973. Fall fires were ignited between September 11 and October 11, 1973.

After spring fires, the total number of Vaccinium stems found on the inventory quadrats increased by the end of the first full growing season. Plants usually appeared on the same number or a slightly greater number of quadrats. After fall fires, the total number of stems often decreased. In all but three cases, plants were found on fewer quadrats.

Table 6.--Plot summaries - Vaccinium globulare

Plot	Prefire - 1973		Postfire - 1974		Postfire - 1975	
	: Total number of plants	: Number of quadrats with plants	: Total number of plants	: Number of quadrats with plants	: Total number of plants	: Number of quadrats with plants
2	87	11	923	18	600	16
5	712	24	1,014	25	1,237	21
6	482	21	836	22	1,058	24
9	600	21	748	25	1,016	25
25	1,120	25	1,213	24	1,400	25
26	1,190	26	1,634	26	2,165	26
28	785	26	922	18	1,037	19
29	1,288	26	1,602	26	1,722	26
30	732	25	1,031	26	1,315	26
SPRING FIRES						
1	103	8	60	4	54	7
3	195	6	135	7	217	7
10	901	26	990	22	1,231	23
11	427	23	621	23	821	24
14	2,547	26	2,417	26	3,056	26
18	863	23	776	15	879	19
21	438	22	148	7	373	17
22	323	21	118	9	298	13
23	409	25	988	16	1,100	19
27	487	25	976	18	1,186	20
31	678	25	684	23	1,293	24
FALL FIRES						

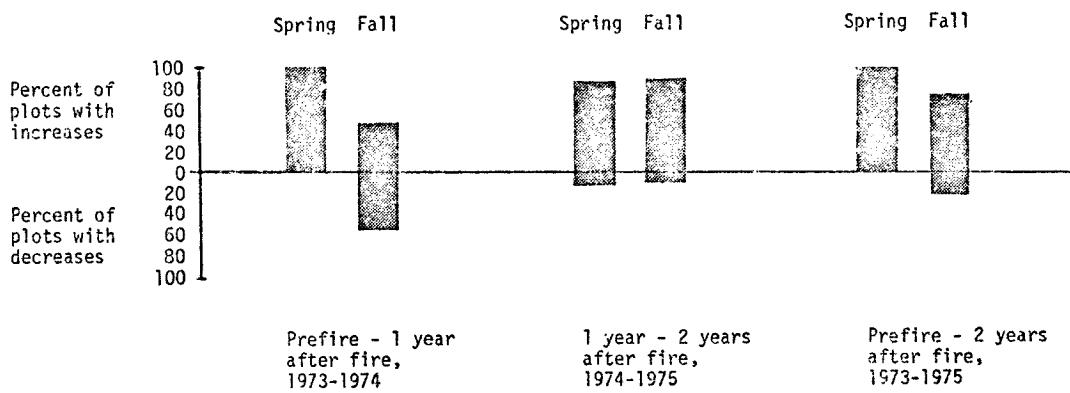


Figure 1.--Percent of plots with changes in the number of Vaccinium globulare

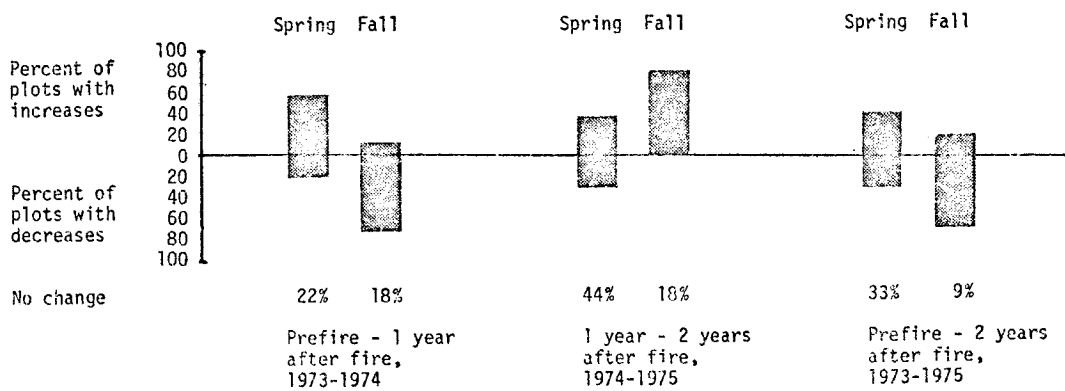


Figure 2.--Percent of plots with changes in number of quadrats in which Vaccinium globulare appeared.

Between the first and second years after fire treatment, plant numbers usually increased on both spring and fall burned plots. During this time period, plants reappeared on about half of the more severely burned fall quadrats.

By the end of the second year, the number of plants on all spring plots and on most fall plots was greater than before fire treatment. However, increases in plant numbers on fall burned plots were usually not as great as the increases on spring plots. In addition, the number of quadrats with plants had decreased on 8 of the 11 fall burned plots. These data support field observations that the effect of fall fires on the Vaccinium community was often more severe than the effect of spring fires. While plant numbers did increase on some areas within fall burned plots, large decreases on other areas of the same plots indicate that rhizome mortality occurred.

What could account for these changes? Why do plant numbers increase? Are observed decreases in plant number from prefire to postfire always due to plant mortality?

Huckleberry rhizomes are distributed somewhat uniformly in duff and surface soil layers beneath clones, with decreasing density at greater depths. Rhizomes also exist in areas which, because of microsite or past fire history, contain only a few aboveground shoots. When the stems or rhizomes of Vaccinium globulare are severed, the source of apical inhibition over dormant bud outgrowth is removed. An average of three to five buds nearest the pruning site are released from inhibition. These buds may elongate the same year if pruned early enough in the

season, or may not grow until the following spring. The growing sprout will draw upon stored carbohydrate reserves until it is photosynthetically self-sufficient.

The number of Vaccinium plants on a site 1 year after fire is apparently a function of the location of the lethal isotherm during the fire, whether above the ground surface or at various depths within or below the rhizome network. A single pruned stem will appear as one or several plants depending on where the stem is pruned. If pruned above ground level, the shoots which develop will appear as branches on a single plant (Figure 3). If the stem is pruned below ground level; each shoot will appear at the ground surface as a separate plant. In Figure 3, 4 stems are supporting aboveground biomass, while in Figure 4, 14 aboveground stems originate from 4 original stems. Greatly increased numbers of aboveground stems after fire may be attributed to stem killing slightly below the ground surface.

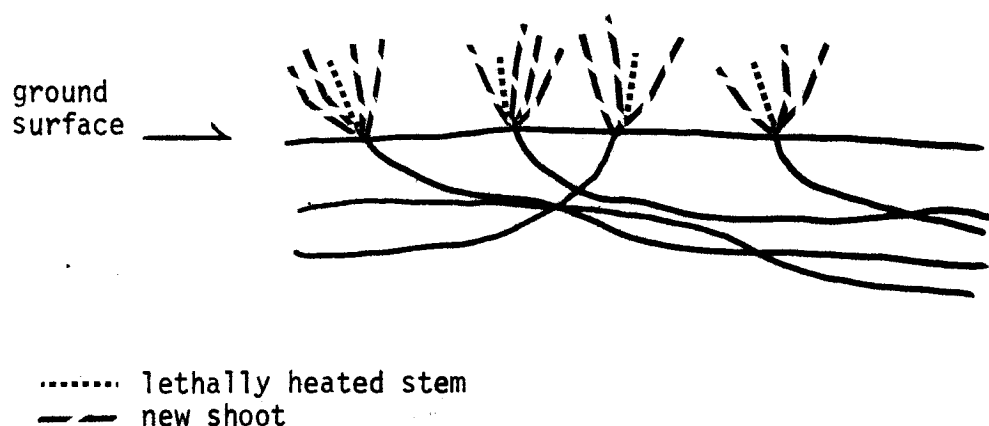


Figure 3.--First-year shoot development in plants pruned above ground level.

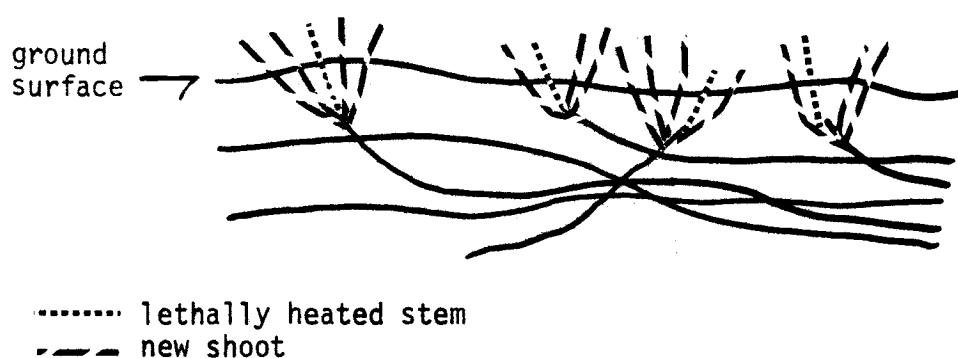


Figure 4.--First-year shoot development in plants pruned below ground level.

The depth of killing in relation to rhizome and stem density will determine the number of sites pruned and the distance which shoots must grow before reaching the ground surface. Figure 5 illustrates that heat penetration to a zone of lesser rhizome density will decrease the number of sites at which buds will be stimulated to grow. Buds would be induced to elongate from sites A and B. Elongating shoots were found on

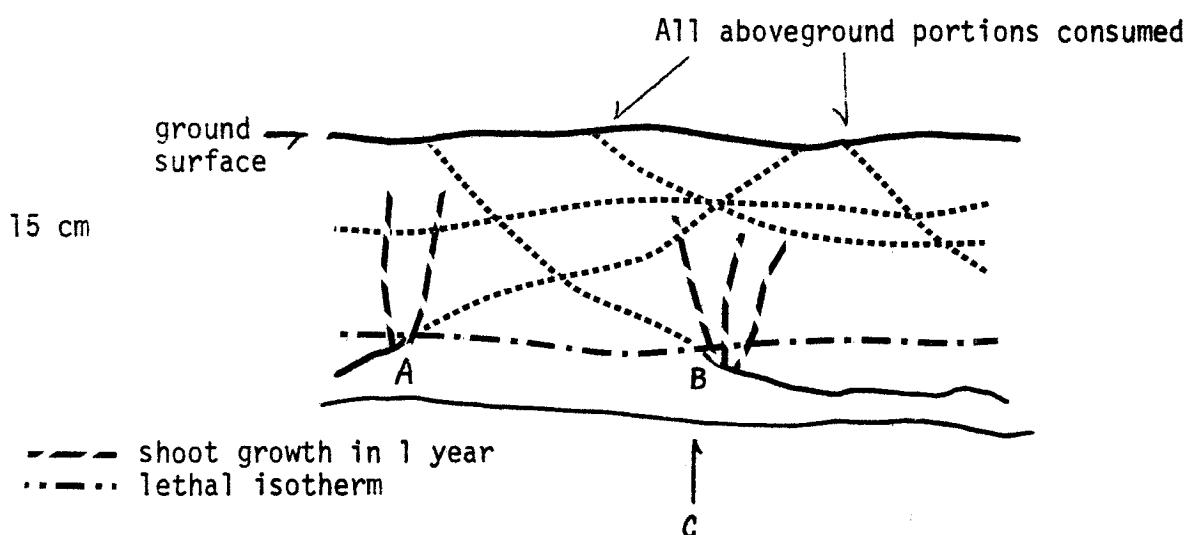


Figure 5.--Sprouting sites in rhizome network with deep lethal temperature penetration.

the site of a late June fire which originated from depths greater than 22 cm below the soil surface. These sprouts had not yet reached the surface by the end of the second summer after burning. If the lethal temperature penetrated below the depth of all rhizomes on a particular site, or did not intersect any rhizomes (such as Rhizome C on Figure 5), sprouts may not appear at all on that site.

Excavation in 1975 of a plot burned in the fall of 1972 revealed that new rhizome growth can be induced after fire. New rhizomes up to 25 cm in length were found growing from sites a few centimeters down the rhizome from new shoots. None of these new rhizomes supported above-ground stems or gave any indication of turning toward the surface. Rhizomes in eastern blueberry (Vaccinium angustifolium) have been reported to form in response to new aerial growth (Kender, 1967). The new, vigorous Vaccinium growth after fire treatment may have stimulated rhizome development. Possibly some new shoots form from newly initiated rhizomes.

An increased density of sprouts may result from fire pruning of rhizomes which formerly supported few or no aboveground shoots. Shoots may have died back because of senescence. Rhizomes which form in response to fire treatment or sporadically from other causes may rarely be stimulated to turn toward the surface and support aboveground stems. They may first produce shoots after fire pruning or other injury. Severing of rhizomes supporting little aboveground biomass could account for some of the greatly increased number of plants and number of sites supporting plants observed after the spring fire on Plot 2.

Lethal temperature penetration to various soil depths can thus cause greatly increased numbers of plants, little change in plant

numbers, or substantial decreases. Pruning a plant above ground level will tend to cause replacement by one plant. Pruning plants below ground level where rhizome density is fairly high will greatly increase plant numbers by causing several separate shoots to originate from each pruning site. Heating of soil to greater depths will cause decreases in numbers of plants because of the decreased rhizome density with a resultant decrease in number of available pruning sites.

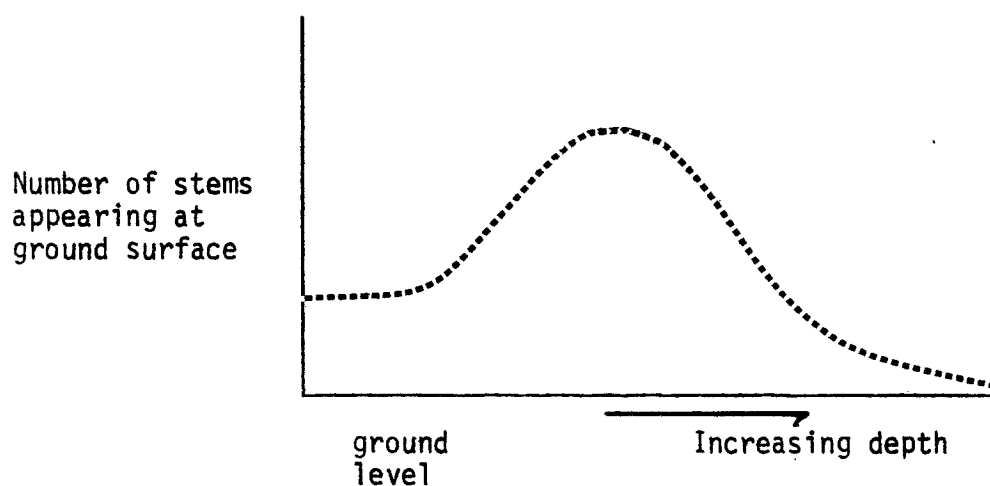


Figure 6.--Hypothesized relationship between number of stems and pruning depth.

In summary, the Vaccinium globulare plants present on a site 2 years after a fire may be

1. residual plants which were not killed by fire
2. plants originating from lateral bud elongation on stems pruned above ground level
3. shoots elongating from stems pruned below ground level
4. shoots developing from rhizomes which had not supported aboveground stems at the time of fire treatment.

The percent of huckleberry plants which fall into each class is determined by the interaction of the fire, environmental, and duff and soil moisture factors which control the temperature regime above and below the ground level during a fire.

#### CHANGES IN PLANT NUMBER AND DENSITY

Statistical tests of changes in numbers of plants per plot were carried out to determine whether species were differentially sensitive to fire, that is, whether certain species tended to increase or decrease in numbers or in average density after fire treatment. A plot was tested for a specific species change if the number of quadrats on which plants appeared was greater than or equal to five in the two samples which could be compared. Testing with smaller sample sizes would greatly increase the possibility of statistically rejecting a change that actually occurred.

A plot standard deviation greater than the plot mean would make any calculated t-value small, and hence insignificant. T-tests were thus conducted if the plot mean for a particular species was greater than the standard deviation in each of the two samples, and if the sample sizes to be compared were each greater than five. Mann-Whitney-Wilcoxon Rank Sum tests and Maximum F-tests were performed for all comparisons for which  $n_1$  and  $n_2$  were greater than or equal to five. Therefore, statistical tests were not performed for many species on many plots.

The results of the unpaired t-tests of changes in numbers of plants before and 1 year after fire are summarized in Table 7. Results for spring and fall fires are listed separately for each species. The

Table 7.--Tests of changes in number of shrub stems ( $n_1 = n_2$ ), prefire - first year after fire, 1973-1974

Species	Season	T-test of mean		Mann-Whitney-Uilcoxon		F-test of variance		
		No. of plots : tested : .1 : .05 : .01	Significance level	No. of plots : tested : .1 : .05 : .01	Significance level	No. of plots : tested : .1 : .05 : .01	Significance level	
Huckleberry ( <u>Veccinium globulare</u> )	Spring	6	1	9	1	2	1	4
	Fall	5		11	2*	11	2	6
Menziesia ( <u>Menziesia ferruginea</u> )	Spring	0		1		1		1
	Fall	0		1		1		1
Serviceberry ( <u>Amaianchier alnifolia</u> )	Spring	2		4	1,1*	4	1	1
	Fall	0		4	1	4	1	1,2*
Rose ( <u>Rosa</u> spp.)	Spring	0		1	1	1		1
	Fall	1		3		3	1,1*	
Oregon grape ( <u>Barberis rrpens</u> )	Spring	0		2	1,1*	2		1
	Fall	1		2		2	1*	
Spiraea ( <u>Spiraea betulifolia</u> )	Spring	3		9	1	9	1	5
	Fall	4	1	9	1	9	1	2
Snowberry ( <u>Symphoricarpos albus</u> )	Spring	1		1		1		1
	Fall	0		2		2		2

\* Decrease.

number of plots tested for each species are listed to the left beneath each test. The number of tests significant at each level are listed accordingly. Values which represent significant decreases are asterisked.

Although the raw numbers indicated rather great changes in numbers of plants, the t-tests only verified the most highly significant changes in plant numbers. Of the 11 plots tested for changes in Vaccinium, only 1 plot showed a statistically significant increase. Four plots showed significant increases in spiraea (Spiraea betulifolia) from prefire to postfire. Mann-Whitney-Wilcoxon tests were performed on a greater number of plots. More significant prefire to postfire changes were verified by this median test. There were significant increases in Vaccinium numbers in four spring fire plots, and significant decreases in two fall fire plots. Serviceberry (Amelanchier alnifolia) numbers increased from prefire to postfire in one of four plots tested. Oregon grape (Berberis repens) increased in one of four plots tested, and decreased in two of the four plots. Spiraea increased in 8 of the 18 plots tested. No real differences in numbers or in direction of change between spring and fall fires seemed to be indicated for any species.

The third section of Table 7 gives the results of the test for difference in variance from prefire to the first year after fire. The variance of Vaccinium distribution increased on 7 of 9 spring fires and 6 of 11 fall fires. All other major species showed significant increases in variance. Twenty-six of the 39 other tests showed increased variances and variances decreased 3 times.

The paired sample t-test of changes in plant numbers from 1974 to 1975 (Table 8) verified that significant increases in numbers of

Table 8.--Tests of changes in numbers of shrub stems, first year after fire - second year after fire, 1974-1975 ( $n_1 = n_2$ )

Species	Season	T-test of mean		Mann-Whitney-Uilcoxon		F-test of variance	
		No. of plots tested	Significance level	No. of plots tested	Significance level	No. of plots tested	Significance level
Huckleberry ( <i>Vaccinium globulare</i> )	Spring	9	1	3.1*		9	2
	Fall	11	2	2		11	1
Menziesia ( <i>Menziesia ferruginea</i> )	Spring	1				1	
	Fall	1				1	
Serviceberry ( <i>Amelanchier alnifolia</i> )	Spring	3				3	1
	Fall	1				1	
Rose ( <i>Rosa</i> spp.)	Spring	1				1	1
	Fall	1	1			1	1
Oregon grape ( <i>Berberis repens</i> )	Spring	1				1	
	Fall	2	1			2	1
Spiraea ( <i>Spiraea betulifolia</i> )	Spring	9				9	1
	Fall	11	1			11	4
Snowberry ( <i>Symphoricarpos albus</i> )	Spring	1				1	
	Fall	2				2	

TESTS WERE  
NOT MADE

\* Decrease.

Vaccinium were still occurring on 8 of the 20 plots from the first to second year after fire. Rose (Rosa spp.) increased on one of the two plots tested, oregon grape on one of four plots tested, and spiraea continued to increase on 1 plot out of 13.

The maximum F-test (Table 8) showed that variability of plant distribution continued to increase from the first to the second year after fire. Huckleberry variance continued to increase in 4 of the 9 spring fire plots, and in 4 of the 11 plots burned in the fall. Continued increases in plot variance were also indicated for service-berry, rose, oregon grape, and spiraea. Increases were not as highly significant as for the first year after fire. This increased variance would not have prevented statistical verification of changes when paired samples were compared, since differences between paired means will be normally distributed.

The first year response to fire of almost all shrub species analyzed was an increase in numbers of plants on some plots and decreases on other plots. Spiraea was the only species which never decreased in number the first year after fire. About two-thirds of all changes were increases. Far fewer changes occurred from the first to the second year. Huckleberry accounted for 9 of the 12 observed changes. The variability in plant distribution was greatly changed by fire treatment. Seventy percent of the 56 plots tested showed significant changes in variance from prefire to the first year after fire, only three of which were decreases. Variances continued to increase from the first to the second year after fire, with significant increases on 23 of the 54 plots tested. Increases in variance from before fire to 1974 were more highly significant than from 1974 to 1975.

Tests of changes in average plant density per quadrat from before fire to the first year after fire verified that density of aboveground stems sometimes increased after fire (Table 9). The two sample t-tests indicated that average density increased for Vaccinium on 2 of 17 plots tested, in the 1 plot tested for menziesia (Menziesia ferruginea), and in 3 of the 11 spiraea tests made. The Mann-Whitney-Wilcoxon median test indicated significant changes in average density for additional plots and species. Huckleberry density increased from 1973 to 1974 on 6 of 19 plots. Menziesia increased in density on the one plot tested. Oregon grape decreased in average density on one of three plots. Spiraea increased on 2 of 13 plots, and snowberry (Symphoricarpos albus) increased on 1 of 3 plots. The variance of the average density increased for huckleberry and for spiraea from before fire to the first year after fire on more than half of the plots tested. Variability almost always increased for menziesia, serviceberry, and rose during this period.

Average plant density rarely increased from the first to the second year after fire (Table 10). The unpaired t-test showed increases in average density of huckleberry on 2 of 17 plots tested and on 1 of 12 plots for spiraea. The Mann-Whitney-Wilcoxon median test showed significant increases in density of spiraea on two additional plots. Variance continued to increase the second year in some instances for huckleberry, serviceberry, rose, and oregon grape. The variance in spiraea distribution decreased on 1 plot.

Thirty-nine percent of all plots tested increased in variance between the time of the first to the second postfire inventories, compared to the 67 percent of all plots tested which increased in

Table 9.--Tests of changes in shrub stem density, prefire - 1 year after fire, 1973-1974 ( $n_1 \neq n_2$ )

Species	Season	T-test of mean		Mann-Whitney-Wilcoxon		F-test of variance	
		No. of plots tested	Significance level	No. of plots tested	Significance level	No. of plots tested	Significance level
Huckleberry ( <i>Vaccinium globulare</i> )	Spring	7	.1	9	.1	9	.1
	Fall	10	1	10	1	10	6
Menziesia ( <i>Menziesia ferruginea</i> )	Spring	1	1	1	1	1	1
	Fall	0		0		0	
Serviceberry ( <i>Amelanchier alnifolia</i> )	Spring	3		3		3	1
	Fall	0		0		0	
Rose ( <i>Rosa</i> spp.)	Spring	0		0		0	
	Fall	1		1		1	1
Oregon grape ( <i>Berberis repens</i> )	Spring	1		1		1	
	Fall	2		2	1*	2	
Spiraea ( <i>Spiraea betulifolia</i> )	Spring	7	1	7	1	7	2
	Fall	4	1	5	1	5	2
Snowberry ( <i>Symphoricarpos albus</i> )	Spring	1		1		1	1
	Fall	0		2	1	2	2

\* Decrease.

Table 10.---Tests of changes in shrub stem density, first year after fire - second year after fire, 1974-1975 ( $n_1 \neq n_2$ )

Species	Season	T-test of mean		Mann-Whitney-Wilcoxon		F-test of variance	
		No. of plots tested	Significance level	No. of plots tested	Significance level	No. of plots tested	Significance level
Huckleberry ( <u>Vaccinium globulare</u> )	Spring	7	.1	9	.1	9	.1
	Fall	10	.1	11	1*	11	.3
Menziesia ( <u>Menziesia ferruginea</u> )	Spring	0		1		1	
	Fall	1		1		1	
Serviceberry ( <u>Amelanchier alnifolia</u> )	Spring	2		3		3	.1
	Fall	1		1		1	
Rose ( <u>Rosa spp.</u> )	Spring	0		1		1	.1
	Fall	1		1		1	.1
Oregon grape ( <u>Berberis repens</u> )	Spring	1		1		1	.1
	Fall	1		2		2	.1
Spiraea ( <u>Spiraea betulifolia</u> )	Spring	6	.1	8	.2	9	1,1*
	Fall	6		8		8	.1
Snowberry ( <u>Symphoricarpos albus</u> )	Spring	0		1		1	
	Fall	0		2		2	

\* Decrease.

variance from before fire to 1974. Variance increased on fewer plots, and variance changes were generally less significant in the second time period than the changes which occurred from before fire to the first year after fire.

About half as many plots showed changes in density of above-ground stems as showed significant changes in numbers of plants found on quadrats where rhizomes or root crowns existed before fire. This was true for both comparisons made, prefire to the first year after fire, and between year 1 and year 2 after fire. Plant density rarely increased after the first year. Variability in density increased from before fire to the end of the first full growing season after fire and for somewhat fewer plots and species from the first to the second year.

Comparisons between species cannot be made for most species because of the small number of plots which had sufficient numbers of plants for testing. Huckleberry and spiraea were the only species tested on fairly equivalent numbers of plots. However, spiraea was abundant on only 5 of the 20 plots prior to fire. Spiraea often appeared on sites which were not optimal for this species, so its rhizome distribution and sprouting response might not be typical for the species in these plots. Huckleberry and spiraea were therefore not compared. Generalizations about differential species sensitivity to fire should not be made on the basis of this study.

One generalization which can be made is that fire will greatly increase the variability of plant distribution in a shrub community. This variability may continue to increase if new sprouts continue to appear. A plot burned on May 24 (Plot 30) was observed for almost three full growing seasons after fire treatment. Numbers and variance of

huckleberry were still increasing at the end of the third season after fire. The duration of significant changes in numbers of plants and variance due to fire treatment in a Vaccinium community of the type studied is not known, but the results show that increases can continue for at least 3 years after fire.

#### REGRESSION EQUATIONS

The intent of the regression analysis portion of this study was to determine whether the postfire shrub community was functionally related to fuel loadings, environmental conditions at the time of plot ignition, and fire effects, and to identify any factors which might directly contribute to the promotion or inhibition of shrub sprouting. Many significant regression equations were developed which explained variation in postfire numbers of Vaccinium globulare stems. The equations contained many different significant independent variables.

Only slight differences existed in  $R^2$  values of many equations, indicating that there was little variation among equations in their ability to describe postfire plant numbers. No particular equation could be selected as a superior way of explaining postfire plants in terms of the logic of the variables which it contained, since all variables included in the regression screening process were selected as likely factors which could directly or indirectly affect the heat regime of the fire. Because of the study design and the limited number of fires conducted, there is no way of assessing whether certain equations contain more valuable information than others. It was therefore decided to present the regression equations which were the most significant according to F-test value. These were selected from groups of equations

developed for a particular season and year and had all independent variables significant to at least the .05 probability level. Equations developed from each independent variable set are presented for 1 and 2 years after fire for each burning season, spring and fall. Equations developed from Independent Variable Set One (page 43), those equations which explain postfire Vaccinium numbers in terms of fuel loadings, fuel moisture, and environmental conditions will be discussed first.

The equations which explain numbers of plants the first and second year after late spring and early summer fires (Equations 1 and 2) are mathematically logical. Two of the three independent variables,  $x_6$ , rotten 3-inch and larger preburn fuel weight, and  $x_{37}$ , relative humidity, appear in both equations. Relative humidity is a more significant variable in the 1975 equation (.01 compared to .001). The second-year equation has a higher R-square and F-value than the equation which describes plant numbers at the end of the first year after fire, 1974. This could be due to chance, or it could be that some of the variance in 1974 data was removed by the appearance of additional huckleberry sprouts. It was noted during the analysis that variable  $x_{40}$  of Equation 1, ambient air temperature/moisture content of the top 5.0 cm of soil, was negatively and very significantly correlated to lower duff moisture content,  $-.9174$  for spring fires and  $-.7884$  for fall fires. Both correlations are significant to at least the .01 level. This variable was intended to integrate ambient air temperature and soil moisture content, but could be significant because it is a different way of expressing lower duff moisture content at the time of the spring fires. These two equations suggest that plant response to fire may be related to moisture conditions at the time of plot ignition.

## Equation 1: Spring 1974

Number of huckleberries 1 year after late spring and early summer fires:

$$\hat{Y} = 1104.2278 - 172.7340 x_6 + 5619.8914 x_{37} - 392.1480 x_{40}$$

where:

$\hat{Y}$  = Number of Vaccinium globulare stems appearing in all shrub inventory quadrats 1 year after late spring and early summer fires

$\bar{Y}$  = 1102.56      Range: 923-1634

$x_6$  = Rotten, 3-inch (7.62 cm) and larger preburn fuel weight (Kg/m<sup>2</sup>)

$x_{37}$  = Relative humidity (percent)

$x_{40}$  = Ambient air temperature/moisture content of the top 5.0 cm of soil (percent)

$R^2 = .8700$        $F = 11.1544$ ; significant at the .01 level

Standard error of estimate = 145.8893

## Equation 2: Spring 1975

Number of huckleberries 2 years after late spring and early summer fires:

$$\hat{Y} = -2403.5965 - 219.0046 x_6 + 66.7587 x_{36} + 8116.4752 x_{37}$$

where:

$\hat{Y}$  = number of Vaccinium globulare stems appearing in all shrub inventory quadrats 2 years after late spring and early summer fires

$\bar{Y}$  = 1283.33      Range: 600-2165

$x_6$  = Rotten, 3-inch and larger (7.62 cm) preburn fuel weight (Kg/m<sup>2</sup>)

$x_{36}$  = Moisture content of the top 5.0 cm of soil (percent)

$x_{37}$  = Relative humidity (percent)

$R^2 = .9170$        $F = 18.4145$ ; significant at the .005 level

Standard error of estimate = 171.7840

The equations which are most significant for 1 and 2 years after fall fires (Equations 3 and 4) are alike only in that they both contain prefire number of Vaccinium globulare stems, variable  $x_7$ . These equations express postfire plant numbers as some function of the number of plants on the site before fire.

Two of the variables in Equation 3 have intuitively illogical coefficients. The positive coefficients for  $x_3$ , 0- to 1/4-inch preburn fuel weight, and  $x_8$ , total 3-inch and larger preburn fuel weight, suggest a positive correlation between the amount of fire heat and postfire plant numbers. Since the negative, simple linear correlation coefficients between these variables and  $Y$  are not significant, the sign of the coefficients can be attributed to the least squares fitting process. The negative coefficient of variable  $x_{15}$  in Equation 4, 0- to 1/4-inch preburn fuel moisture content, indicates that plots with lower fine fuel moisture content would tend to have more plants after fire. Since the simple linear correlation coefficient between this variable and 1975 Vaccinium numbers is positive, .1670, the coefficient assigned to this variable is likely also due to the least squares fitting process. The appearance of lower duff moisture content,  $x_{35}$ , as a significant variable in Equation 4 identifies this variable as an important descriptor of postfire plants for fires conducted in the fall. No cause and effect can be inferred from the regression fitting process, but the significance of this variable does agree with the conclusions of others that duff moisture is an important regulator of heat penetration during a fire. Lower duff moisture content and 0- to 1/4-inch fuel moisture content, which both appear in Equation 4, are correlated at the .05 level of significance. Since both variables are significant within the

## Equation 3: Fall 1974

Number of huckleberries 1 year after late summer and early fall fires:

$$\hat{Y} = -498.3475 + 1.0430 x_1 + 6754.6459 x_3 + 70.3139 x_8 - 28.5512 x_{12}$$

where:

$\hat{Y}$  = Number of Vaccinium globulare stems appearing in all shrub inventory quadrats 1 year after late summer and early fall fires

$\bar{Y}$  = 719.36      Range: 60-2417

$x_1$  = Preburn number of Vaccinium globulare stems in all shrub inventory quadrats

$x_3$  = 0- to 1/4-inch (0 to .635 cm) preburn fuel weight (Kg/m<sup>2</sup>)

$x_8$  = Total 3-inch (7.62 cm) and larger preburn fuel weight (Kg/m<sup>2</sup>)

$x_{12}$  = Preburn dead fuel depth (cm)

$R^2 = .9812$        $F = 78.4659$ ; significant at the .001 level

Standard error of estimate = 119.5520

## Equation 4: Fall 1975

Number of huckleberries 2 years after late summer and early fall fires:

$$\hat{Y} = 442.0076 + 1.0742 x_1 - 1520.2378 x_{14} - 31.5622 x_{15} \\ + 12.7059 x_{35}$$

where:

$\hat{Y}$  = Number of Vaccinium globulare stems appearing in all shrub inventory quadrats 2 years after late summer and early fall fires

$\bar{Y}$  = 955.27      Range: 54-3056

$x_1$  = Preburn number of Vaccinium globulare stems in all shrub inventory quadrats

$x_{14}$  = Average slope (percent)

$x_{15}$  = 0- to 1/4-inch (0 to .635 cm) fuel moisture content (percent)

$x_{35}$  = Lower duff moisture content (percent)

$R^2 = .9821$        $F = 82.4340$ ; significant at the .001 level

Standard error of estimate = 142.6204

context of the equation, it is implied that distinct information is conveyed by each one. The data suggests that the relationships established in the equation hold true, but one must be careful about drawing conclusions because of the small sample size.

The set of regression equations developed from the second set of independent variables (page 46) explains variation in postfire plant numbers using independent variables which quantified fire effects resulting from the prescribed fires. Equations which explain plant numbers appearing one and two seasons after late spring and early summer fires, Equations 5 and 6, contain two of the same variables:  $x_1$ , prefire number of Vaccinium stems, and  $x_{25}$ , fire intensity. All regression coefficient signs are logical but for  $x_{25}$ , fire intensity. The positive sign of this coefficient suggests that the more intense the fire, the more plants will appear afterwards. Fire intensity is negatively, but not significantly, related to Vaccinium numbers after spring fires in 1974 (-.3172) and in 1975 (-.1598). The positive sign of the Beta-coefficient may be a result of the least squares fitting process. However, the positive coefficient sign may reflect the fact that heating to depths below ground level but still within the bulk of the rhizome network may increase huckleberry numbers over what they had been before fire. Lethal temperatures usually did not penetrate to levels below the rhizome network during spring fires, evidenced by the fact that only one plot had plants represented on fewer quadrats than before fire. Percent shrub weight reduction,  $x_{26}$ , the third variable in Equation 6, is negatively fit in the equation. The simple linear

## Equation 5: Spring 1974

Number of huckleberries 1 year after late spring and early summer fires:

$$\hat{Y} = 1173.3210 + .6756 x_1 - 451.6954 x_{23} + 1.8632 x_{25}$$

where:

$\hat{Y}$  = Number of Vaccinium globulare stems appearing in all shrub inventory quadrats 1 year after late spring and early summer fires

$\bar{Y}$  = 1102.56      Range: 923-1634

$x_1$  = Preburn number of Vaccinium globulare stems in all shrub inventory quadrats

$x_{23}$  = Mean duff depth reduction (cm)

$x_{25}$  = Average fire intensity (Kcal/sec/m<sup>2</sup>)

$R^2 = .9474$        $F = 30.0186$ ; significant at the .005 level

Standard error of estimate = 92.8019

## Equation 6: Spring 1975

Number of huckleberries 2 years after late spring and early summer fires:

$$\hat{Y} = 555.6506 + 1.4142 x_1 + 3.6020 x_{25} - 11.2802 x_{26}$$

where:

$\hat{Y}$  = Number of Vaccinium globulare stems appearing in all shrub inventory quadrats 2 years after late spring and early summer fires

$\bar{Y}$  = 1283.33      Range = 600-2165

$x_1$  = Preburn number of Vaccinium globulare stems in all shrub inventory quadrats

$x_{25}$  = Average fire intensity (Kcal/sec/m<sup>2</sup>)

$x_{26}$  = Percent shrub weight reduction

$R^2 = .9535$        $F = 34.1478$ ; significant at the .001 level

Standard error of estimate = 128.2812

correlation coefficient between this variable and Y,  $-.0160$ , indicates that no linear relationship exists between this variable and Vaccinium numbers in 1975. Removal of aboveground shrub biomass could be accompanied by a range of effects on associated rhizomes, from great increases in plant numbers to death of all plant parts. It may be that large amounts of brush reduction indicate a greater likelihood of destruction of rhizomatous sprouting sites on some of the plot area.

The equations which describe numbers of huckleberries 1 and 2 years after fall fires, Equations 7 and 8, are almost identical in the variables which they contain, and are both significant at the  $.001$  level. Since  $x_{28}$ , adjusted soil surface temperature which appears in Equation 8 is a transformation of  $x_{27}$ , average soil surface temperature, of Equation 7, it can be said that the equations which best explain postfire plant numbers in these subsequent years are based upon essentially the same information. Adjusted soil surface temperature was a somewhat better descriptor of postfire plant numbers in 1975 ( $.01$  significance level) than soil surface temperature was for 1974 ( $.05$  significance level). The decrease in standard error of the 1975 equation over the 1974 equation may be due to the appearance of additional sprouts in the second year after fire which had been initiated by fire pruning. One- to 3-inch fuel weight reduction was a significant variable in both equations. It is possible that this variable is related to postfire Vaccinium numbers because fuel consumption in this size class contributed directly to rhizome heating. It may also be that heat released by burning of 1- to 3-inch fuels indirectly affected the plants by sustaining combustion of larger fuels or promoting duff

## Equation 7: Fall 1974

Number of huckleberries 1 year after late summer and early fall fires:

$$\hat{Y} = 807.9676 + .7183 x_1 - 885.4242 x_{20} - 4.8737 x_{27} + 67.7194 x_{36}$$

where:

$\hat{Y}$  = Number of Vaccinium globulare stems appearing in all shrub inventory quadrats 1 year after late summer and early fall fires

$\bar{Y}$  = 719.36      Range: 60-2417

$x_1$  = Preburn number of Vaccinium globulare stems in all shrub inventory quadrats

$x_{20}$  = 1- to 3-inch (2.54 to 7.62 cm) fuel weight reduction (Kg/m<sup>2</sup>)

$x_{27}$  = Average temperature reached at mineral soil surface (°F)

$x_{36}$  = Moisture content of the top 5.0 cm of soil (percent)

$R^2 = .9602$        $F = 47.2760$ ; significant at the .001 level

Standard error of estimate = 153.0757

## Equation 8: Fall 1975

Number of huckleberries 2 years after late summer and early fall fires:

$$\hat{Y} = 605.4407 + .9297 x_1 - 774.6745 x_{20} - 4.6911 x_{28} + 60.7141 x_{36}$$

where:

$\hat{Y}$  = Number of Vaccinium globulare stems appearing in all shrub inventory quadrats 2 years after late summer and early fall fires

$\bar{Y}$  = 955.27      Range: 54-3056

$x_1$  = Preburn number of Vaccinium globulare stems in all shrub inventory quadrats

$x_{20}$  = 1- to 3-inch (2.54 to 7.62 cm) fuel weight reduction (Kg/m<sup>2</sup>)

$x_{28}$  = Adjusted temperature reached at mineral soil surface (°F)

$x_{36}$  = Moisture content of the top 5.0 cm of soil (percent)

$R^2 = .9817$        $F = 80.2725$ ; significant at the .001 level

Standard error of estimate = 144.4982

consumption. It is also possible that no direct relationship exists between this variable and postfire Vaccinium numbers, but that factors which contributed to 1-to 3-inch fuel weight reduction also affected the huckleberry plants. The two equations for fall fires support the contention that forest-floor moisture is extremely important in determining the ultimate effect which fire has upon Vaccinium, and possibly upon other rhizomatous shrubs.

It can be hypothesized that these regression equations directly or indirectly described aspects of the heat regime to which Vaccinium globulare stems and rhizomes were subjected. Equations developed from Independent Variable Set One, Equations 1 through 4, may have assessed the potential for forest floor heating, since they contain measures of fuel, fuel moisture, and other factors which may have affected fire characteristics, and the amount of insulation which is afforded rhizomes by duff and soil moisture. The equations developed from Independent Variable Set Two, Equations 5 through 8, support this hypothesis, since they contain direct or indirect measures of heat release during the prescribed fires, such as duff and soil temperatures attained during burning, fuel reductions, and shrub and duff reduction. Consumption in different fuel classes could have differentially contributed to fire intensity because of the different roles which fuels play in ignition and duration of heat release. Measures of duff and soil heating and duff reduction more directly describe heat which could have affected aboveground stems and rhizomes. The appearance in most equations of duff or soil moisture or factors which have been directly related to duff moisture, such as duff and shrub reduction (Norum, 1975), indicate

that an interaction of fire-created heat with forest floor moisture will determine the amount and duration of rhizome heating.

One must be cautious in applying these regression equation results because of the small sample size of this study. The many interactions which occur between microsite variations in fuels and environmental conditions lead to variability in fire effects. The total stem number on a site in years after a fire may be composed of stems with new shoots which were pruned above ground level, multiple shoots originating from one site pruned below ground level, and plants which were not burned by the fire. The temperature regime created by fire probably determines how many stems fall into each of these classes.

Certain similarities existed in plot conditions and fire effects which affected the nature of the postfire huckleberry community. It is possible that relationships in the equations and the hypotheses based upon these relationships and field observations would not hold true for a larger sample size or on other sites. However, the fact that the equations are so highly significant does suggest that Vaccinium globulare plants systematically respond to fires of varying intensity.

The number of huckleberry plants which appear on plots after late spring and early summer fires was described by equations which did not contain prefire numbers of Vaccinium. This implies that fires were acting upon a relatively homogeneous community. Since aboveground stem numbers varied widely at the time of plot ignition, it may well be that rhizome density was fairly consistent among plots. The sprouting potential of the huckleberry plants on the plots may have been fairly uniform at the time of the prescribed fires. These results substantiate

the observation that differences in plant response were probably caused by different temperature regimes created at ground level and within the rhizome network.

Equations were also developed for plants appearing after late summer and early fall fires which did not contain prefire Vaccinium numbers. The equations contained a minimum of five independent variables, so were not presented although highly significant. The nonuniformity of plant response after fall fires, with increases and decreases in plant numbers, may account for the additional variables required to describe plant numbers after fall fires. A single variable may have been less likely to be related to plant response in the same manner over a spectrum as broad as that of fall fires. The mode of variable interaction may vary considerably during fires of very different intensities and may account for the wide range of plant response observed after fall fires.

#### SIGNIFICANT VARIABLES

Regression equations presented do not contain all variables which were significantly related to postfire plants. Spring-fall differences were not revealed. Therefore, lists of all significant variables which appeared in regression equations were compiled. Lists were prepared for each time period and set of independent variables for which equations were generated. Lists for subsequent years within the same season were quite similar, so were combined. Tables 11 and 12 list levels of statistical significance of variables in regression equations tested for spring and fall fires from each independent variable set.

Independent variables used in the regression screening process were selected because they bore some known or postulated relationship to

Table 11. ---Variable Set One: Significance of variables in regression equations

Variable	Spring		Fall	
	: : > .05 : > .01 : > .001 :	: : > .05 : > .01 : > .001 :	: : > .05 : > .01 : > .001 :	: : > .05 : > .01 : > .001 :
x <sub>1</sub> - preburn number Vaccinium globulare stems	X	X	X	X
x <sub>2</sub> - preburn shrub weight	X	X	X	X
x <sub>3</sub> - 0 to 1/4 inch (0 to .635 cm) preburn fuel weight			X	X
x <sub>4</sub> - 1/4 to 1 inch (.635 to 2.54 cm) preburn fuel weight	X	X	X	X
x <sub>5</sub> - 1 to 3 inch (2.54 to 7.62 cm) preburn fuel weight	X	X	X	X
x <sub>6</sub> - rotten, 3-inch (7.62 cm) and larger fuel weight	X	X	X	X
x <sub>7</sub> - sound, 3 inch (7.62 cm) and larger fuel weight	X	X	X	X
x <sub>8</sub> - total, 3 inch (7.62 cm) and larger fuel weight	X	X	X	X
x <sub>9</sub> - total preburn fuel weight	X	X	X	X
x <sub>10</sub> - preburn duff depth			X	
x <sub>11</sub> - preburn herbaceous vegetation weight	X	X	X	X
x <sub>12</sub> - preburn dead fuel depth	X	X	X	X
x <sub>13</sub> - windspeed	X	X	X	X
x <sub>14</sub> - average slope			X	X
x <sub>15</sub> - 0 to 1/4 inch fuel moisture content	X	X	X	X
x <sub>16</sub> - 1/4 to 1 inch fuel moisture content	X	X	X	X
x <sub>34</sub> - upper duff moisture content	X	X	X	X
x <sub>35</sub> - lower duff moisture content			X	X
x <sub>36</sub> - moisture content of the top 5 cm of soil	X	X	X	X
x <sub>37</sub> - relative humidity	X	X	X	X
x <sub>38</sub> - understory foliage moisture content	X	X	X	X
x <sub>39</sub> - ambient air temperature	X	X	X	X
x <sub>40</sub> - ambient air temperature/soil moisture content	X	X	X	X

Table 12.--Variable Set Two: Significance of variables in regression equations

Variable	Spring		Fall	
	: : > .05 : > .01 : > .001 :	: : > .05 : > .01 : > .001 :	: : > .05 : > .01 : > .001 :	: : > .05 : > .01 : > .001 :
x <sub>1</sub> - prefire number <u>Vaccinium globulare</u> stems	X	X	X	X
x <sub>17</sub> - 0 to 1/4 inch (0 to .635 cm) fuel weight reduction	X	X		
x <sub>18</sub> - 1/4 to 1 inch (.635 to 2.54 cm) fuel weight reduction				
x <sub>19</sub> - 0 to 1 inch (0 to 2.54 cm) fuel weight reduction				
x <sub>20</sub> - 1 to 3 inch (2.54 to 7.62 cm) fuel weight reduction			X	X
x <sub>21</sub> - total, 3 inch (7.62 cm) and larger fuel weight reduction	X	X	X	X
x <sub>22</sub> - total fuel weight reduction	X	X	X	X
x <sub>23</sub> - mean duff depth reduction	X	X	X	X
x <sub>24</sub> - percent duff depth reduction	X	X		
x <sub>25</sub> - fire intensity	X	X	X	
x <sub>26</sub> - percent shrub weight reduction	X	X	X	X
x <sub>27</sub> - average mineral soil surface temperature	X	X	X	X
x <sub>28</sub> - adjusted mineral soil surface temperature			X	X
x <sub>29</sub> - average duff surface temperature	X	X	X	X
x <sub>30</sub> - adjusted duff surface temperature			X	X
x <sub>31</sub> - average temperature at 2.5 cm below duff surface	X	X	X	X
x <sub>32</sub> - average temperature at 5.0 cm below duff surface	X	X	X	X
x <sub>33</sub> - average temperature at 7.5 cm below duff surface	X	X	X	X
x <sub>34</sub> - upper duff moisture content	X	X	X	X
x <sub>35</sub> - lower duff moisture content	X	X	X	X
x <sub>36</sub> - soil moisture content	X	X	X	X
x <sub>37</sub> - relative humidity	X	X	X	X

fire or to fire effects. It was therefore not surprising to find that almost all of the variables appeared significantly in an equation at some time. However, the probability of inclusion of some variables if no true relationship existed was only 1-in-100 or 1-in-1,000 times. It is thus felt that some degree of relationship may well exist between the postfire Vaccinium community and these highly significant variables.

Many more variables (Table 11) appear significant at the .001 level in spring than in the fall. Lower duff moisture content,  $x_{35}$ , is the only variable aside from prefire number of Vaccinium stems which was significant at this highest probability level for fall fires. It may be that lower duff moisture content is a good descriptor of the general moisture regime of the plot. The role of forest floor moisture in determining fire effects is further supported by the high significance of upper duff moisture content,  $x_{34}$ , and soil moisture content,  $x_{36}$ , for spring fires. The high significance of herbaceous biomass,  $x_{11}$ , and understory foliage moisture content,  $x_{38}$  (Table 11), substantiate hypotheses regarding the effect of vegetative moisture on fire. Zero- to 1/4-inch and 1/4- to 1-inch fuel moisture content and relative humidity ( $x_{15}$ ,  $x_{16}$ ,  $x_{37}$ ) as it affects very fine fuel moisture are known to be related to fire characteristics.

An important contribution of heavy fuels to the fires which affected the postburn Vaccinium community is suggested by the high significance of rotten, 3-inch and larger preburn fuel weight,  $x_6$ , for spring fires and total 3-inch and larger fuel weight reduction,  $x_{21}$ , for fall fires (Table 12). Fuel weight reduction in other classes is also deemed important by the .001 significance of 0- to 1/4-inch fuel weight

reduction,  $x_{17}$ , for spring fires and 1- to 3-inch fuel weight reduction,  $x_{20}$ , for fall fires.

The high significance of spring fire intensity,  $x_{25}$ , and the high significance of percent shrub weight reduction,  $x_{26}$ , in fall fires, may indicate that these factors directly contribute to the heat regime which affected the Vaccinium plants. Since a very high correlation exists (.8227) between preburn shrub weight and preburn numbers of Vaccinium stems for fall burned plots, figures for shrub reduction are probably closely related to the amount of Vaccinium biomass removed by fires. Mean duff depth reduction,  $x_{23}$ , is highly significant in equations developed for both burning seasons. Duff reduction can be logically related to the heat regime within the forest floor during burning. Heat from burning duff could cause lethal heating of rhizomes in soil and duff layers beneath the fire zone.

Average mineral soil surface temperature,  $x_{27}$ , was important in equations for both spring and fall fires. The temperature attained by the mineral soil surface reflects the heat regime to which rhizomes were exposed. The higher the soil surface temperature, the more likely the destruction of rhizomes located in duff layers above, and the greater the probability of rhizome death within soil layers. The importance of duff and soil moisture content is again emphasized in equations presented from Variable Set Two.

#### HYPOTHESES ABOUT DIFFERENTIAL FIRE EFFECTS

Field observations revealed the nature of differences between most spring and fall fires. Fall fires were hotter, since much more mineral soil was exposed and far less vegetation appeared in the first

growing season after fire. The greater Vaccinium mortality on fall fire sites is logically related to the greater heating of the sites. Average duff surface temperatures reached during fall fires indicate that much more heat was present at the forest floor surface than in spring fires. Much more heat would therefore be available for forest-floor heating. Much greater mean duff depth reduction and soil surface heating in fall fires shows that the heat created by these fires was very effective in penetrating the forest floor. Explanations based upon study results and the literature were developed to account for the more intense ground heating during fall fires and the differences in significant variables between spring and fall.

The moisture content of woody fuels in the 0- to 1/4-inch and 1/4-to 1-inch size class was much lower in the spring than in the fall, indicating that other fine fuels such as needles and cured, herbaceous material were also rather dry. The dry moisture regime would have made these fuels much more sensitive to changes in relative humidity and ambient air temperature than they would have been if more moist. This may explain the significant appearance of ambient air temperature and relative humidity in many equations developed for spring fires. Burning of smaller fuels may have contributed much to the heating received by Vaccinium plants in spring fires which ultimately controlled their sprouting. Zero- to 1/4-inch fuel weight reduction was significant at the .001 level in equations describing postfire huckleberry numbers for spring fires. Additionally, Norum (1975) found that 0- to 1/4-inch preburn fuel weight was a significant descriptor of percent brush weight reduction for spring fires.

Larger fuels were not as completely consumed in spring as they were in fall fires. One- to 3-inch fuel weight reduction was 3.5 times lower than in fall fires. Combustion in heavy fuels, larger than 3 inches in diameter, was also much less in spring fires, although possibly biased fuel reduction figures in the total 3-inch and larger fuel class do not show this. Lesser spring consumption in these fuel classes may have been due to their higher fuel moisture content, and to less effective heating of these fuels because of understory foliage.

Understory foliage is said to "smother" fires in spring because of its high moisture content. A high significance of understory foliage moisture content and herbaceous biomass, with a generally positive relationship to postfire plant numbers was indicated in many spring regression equations. Much of the energy released by burning of smaller fuel classes may have been expended in evaporating understory foliage moisture, especially on those plots burned at times of particularly high foliage moisture content. Much less heat would have been available for preheating of larger fuels and heating of duff. The high spring foliage moisture content may have interacted with the higher heavy fuel moisture content and resulted in low consumption of large fuels on many spring burned plots. Heat sources of long duration may thus not have been often present in the early burning season.

Forest floor moisture seems to have played a rather important role in spring fires. It is reasonable to hypothesize that high moisture levels in lower duff were sufficient to retard heat penetration into duff, limiting the amount of rhizome mortality. Average soil surface temperature is significantly and negatively correlated at the .05 level (-.7220) to lower duff moisture content for spring fires. The typically

moist subsurface conditions in spring may also have inhibited heat penetration into mineral soil layers. The only spring burned plot (Plot 28) which had sufficient subsurface heating to produce mortality on many quadrats was ignited at a time of very low duff and soil moisture.

In the fall burning season, vegetative moisture content was lower and larger fuels were much drier than in the spring. Ignition and burning of these fuels was probably more often promoted by consumption of fuels in smaller size classes. The lack of significance of small fuel reduction could be caused by their small contribution to the heating which ultimately controlled huckleberry sprouting after fall fires. Heat released by burning of heavier fuels would have contributed to the sustained heating of duff and soil layers which resulted in deep lethal temperature penetration.

Lower duff moisture content was not significantly related to the average soil surface temperature reached during fall fires, as it was for spring fires. This is logical when one considers that a much greater amount of duff was often removed in fall fires, and most duff moisture would have to have been evaporated prior to duff ignition. Lower duff moisture was a significant descriptor of postfire plant numbers in fall equations, so it most likely did inhibit heat penetration for some period of time during fires.

Soil moisture content was often significantly related to plant response after both spring and fall fires. Percent duff depth reduction and soil moisture was significantly related ( $-.6156$ ) at the .01 level for all 20 fires. Soil moisture content was also significantly related (Table 13) to the average soil surface temperature attained. The soil moisture regime was thus quite closely related to subsurface heating

in this study. Soil moisture is particularly important in controlling soil and associated rhizome heating once duff layers had been dried, thinned, or completely removed by fire. Although the sample size is small, the data suggest that soil moisture content plays an important role in determining the effects of fire upon Vaccinium globulare in forests with thin duff layers.

Table 13.--Simple linear correlation coefficients between mineral soil surface temperatures and forest floor moisture content

	: Spring : fires	: Fall : fires	: All 20 : fires
Average mineral soil surface temperature - Upper duff moisture content	-.4431	.0845	.3364
Average mineral soil surface temperature - Lower duff moisture content	-.7220*	-.2346	-.4482*
Average mineral soil surface temperature - Soil moisture content	-.3793	.4114	-.6137**

\* Significant at  $P < .05$

\*\* Significant at  $P < .01$

## CHAPTER 6

### CONCLUSIONS

Great increases in shrub community diversity occurred after fire treatment. However, postfire number of Vaccinium globulare was more closely related to prefire plant numbers than to any other factor. No seasonal variability was evident in Vaccinium ability to produce sprouts from dormant buds.

It is likely that the intensity and duration of duff and soil heating accounted for the differences in plant response between fires. The essential differences in fire characteristics were probably related to plot moisture conditions, since average fuel loadings did not differ very much between the two seasons.

Rhizome mortality occurred when large amounts of heat were released and penetrated deeply into the forest floor. Long-term heating of duff and soil layers on many fall fire plots likely resulted from the consumption of heavy fuels which were dry during that season. After the heat dried the duff, the relatively dry soil probably did little to curtail heat penetration. Two years after fire, six plots still had plants on at least four fewer quadrats than before fire treatment. At the time of ignition, soil moisture content on each of these plots was 18 percent or less. Soil and lower duff moisture content were 19 percent and 14 percent respectively on Plot 28, the only one of these

six plots which was burned in spring. Lower duff moisture content was greater than 62 percent on each of the 5 fall plots with Vaccinium present on at least 4 fewer quadrats than before fire.

Other rhizomatous species in fire adapted communities, such as Spiraea betulifolia and Symphoricarpos albus may respond to fire in a manner similar to Vaccinium. These species have extensive rhizome networks and produce many sprouts from dormant buds after fire pruning. The rate of response may differ considerably from that of Vaccinium because of physiological differences between species. No comparison should be made between the response of huckleberry and that of Menziesia ferruginea and Amelanchier alnifolia which sprout from root crowns. The heat tolerance of sprouting sites may be quite different from that of rhizomatous shrubs because of differences in form, size, and location of these sites. In addition, it is not known if these species possess dormant buds or initiate new buds in response to fire treatment. It is quite likely, however, that a relationship exists between the sprouting response of these woody plants and fire intensity.

The sample size of this study was small, 9 spring fires and 11 fall fires. Therefore, conclusions should be used with caution. The form of the relationships and nature of variable interaction could differ significantly if the study were expanded to a larger sample or to another area. However, the high statistical significance of many equations and certain independent variables does suggest that a strong relationship exists between burning conditions, fire effects, and the range of Vaccinium globulare response to fire. It is recommended that these results be verified by application to other mesic sites with huckleberry communities.

### Conclusions

1. Fire greatly increases the diversity present in the shrub community.
2. The postfire Vaccinium globulare community is a function of prefire community characteristics and fire effects.
3. Interactions between the fire-created heat regime and forest-floor moisture controlled the number and distribution of pruned sites from which sprouts originated.
4. Great seasonal variation in the physiological ability of Vaccinium to produce sprouts does not exist.

## CHAPTER 7

### FUTURE RESEARCH

This study gathered baseline data concerning the short-term response of Vaccinium globulare to fire. A modified study design could result in a clearer delineation of the relationship between the fuel complex, fuel and forest-floor moisture, environmental conditions, and the heat which affected plants. Suggestions will be made with regard to additional studies of huckleberry, but could apply to the study of other rhizomatous shrubs.

The best single improvement in the study design would be to conduct more fires. Mean comparison tests and regression equations based on at least 30 fires would be much more reliable. The postburn inventory should sample the same shrub quadrats as were inventoried before fire treatment. Other fuels data could still be collected from a randomly oriented quadrat. Marking of shrub quadrat centers would reduce sampling error. Herbaceous vegetation or litter samples were collected from one of four herbaceous quadrats. Since one of these quadrats overlapped the area of the brush quadrat (Figure 7, Appendix A), relocation of this herbaceous quadrat could eliminate a possible source of error.

The scheme for collection of duff and soil temperatures attained during fires could be improved. Soil temperature plates used were of insufficient length to monitor heat penetration in many cases. Lethal

temperatures penetrated to depths greater than the 15-cm plate length on 24 percent of all plates located within fall burned plots. Longer plates or other measurement devices should be considered. Soil temperature monitoring devices should be placed adjacent to or within brush quadrats, depending upon the degree of disturbance which would result from installation. Sampling of duff and soil moisture should also be done within the vicinity of brush quadrats. Soil moisture should be determined for surface and deeper soil layers to improve understanding of the role of soil moisture in deep soil heating.

The nature of the rhizome network should be investigated to further clarify the relationship between Vaccinium sprouting and the duff and soil temperature regime. Rhizome density at different depths and rhizome distribution within duff and soil layers should be sampled. Additionally, areas within plots which do not support aboveground stems should be examined for the presence of rhizomes, and the density compared to that beneath clones.

The immediate postfire shrub inventory could provide additional data which could be tested against fuel and soil temperature data. Stems could be classified as residual unburned stems or living, partially burned stems. The distinction between living and dead stems can be difficult. Stems outside the quadrat area could be tested for living tissue, using a 1 percent orthotolodine and methanol solution and hydrogen peroxide. Stems could then be more easily classified as living or dead by appearance and flexibility.

The first year inventory should list stems as either unburned or new growth. New growth could be classified as originating at or above ground level or from a belowground sprouting point. Plots burned in the

spring should be inventoried that fall. Subsequent inventories would have to count stem number only, since branching of stems in the second year would make it difficult to distinguish these stems from unburned stems. These inventories could provide information about the duration of fire-induced changes in plant number and distribution.

Results of this study suggest that the number of sprouts induced is a function of depth of pruning by fire. It is recommended that future studies clarify the relationship between fire intensity and plant productivity, in terms of number of new stems per unit area and biomass production per stem. Changes in stem productivity could result from alteration of the nutrient regime or other microenvironmental changes, such as an improved temperature or moisture regime. With particular regard to Vaccinium, the relationship between fruit productivity and fire intensity should be thoroughly investigated. Knowledge of postfire shrub-environmental interactions could strengthen any assessment of long-term effects of prescribed fire application upon a sprouting shrub community.

## LITERATURE CITED

- Ahlgren, C. E. 1960. Some effects of fire on reproduction and growth of vegetation in northeastern Minnesota. *Ecology* 41:431-445.
- Ahlgren, I. F., and C. E. Ahlgren. 1960. Ecological effects of forest fires. *Bot. Rev.* 26:483-533.
- Beadle, N. C. W. 1940. Soil temperatures during forest fires and their effect on the survival of vegetation. *J. Ecol.* 28:180-192.
- Blaisdell, J. P. 1953. Ecological effects of planned burning of sagebrush grass range on the Upper Snake River Plains. USDA Tech. Bull. 1075, 39 p.
- \_\_\_\_\_, and Walter F. Mueggler. 1956. Sprouting of bitterbrush following burning. *Ecology* 37(2):365-370.
- Books, David J. 1972. Little Sioux burn: year two. *Naturalist* 23(3&4):2-7.
- Bowersox, T. W., and W. W. Ward. 1968. Auxin inhibition of epicormic sprouts in white oak. *For. Sci.* 14:192-196.
- Brayton, R. D., and G. M. Woodwell. 1966. Effects of ionizing radiation and fire on Gaylussacia baccata and Vaccinium vacillans. *Amer. J. Bot.* 53(8):816-820.
- Britton, Carlton M., and Henry A. Wright. 1971. Correlation of weather and fuel variables to mesquite damage by fire. *J. Range Manage.* 24(2):136-141.
- Brown, Arthur A., and Kenneth P. Davis. 1973. *Forest fire: control and use.* 686 p. McGraw-Hill Book Co.: New York.
- Brown, James K. 1976. Estimating shrub biomass from basal stem diameters. Accepted for publication in *Can. J. For. Res.*, April 1976.
- Buckman, Harry O., and Nyle C. Brady. 1966. *The nature and properties of soils.* 567 p. The MacMillan Co.: New York.
- Buell, M. F., and J. E. Cantlon. 1953. Effects of prescribed burning on ground cover in the New Jersey pine region. *Ecology* 34:520-528.

- Burg, S. P., and E. A. Burg. 1968. Ethylene formation in pea seedlings; its relation to the inhibition of bud growth caused by indole-3-acetic acid. *Plant Physiol.* 43:1069-1074.
- Crozier, A., and D. M. Reid. 1971. Do roots synthesize gibberellins? *Can. J. Bot.* 49:967-975.
- Danckwardt-Lilliestrom, C. 1957. Kinetin induced shoot formation from isolated roots of Isatis tinctoria. *Physiol. Planta* 10:794-797.
- Daubenmire, R. 1975. Plant succession on abandoned fields, and fire influences in a steppe area in southeastern Washington. *Northw. Sci.* 49(1):36-48.
- Doerr, P. D., L. B. Keith, and D. H. Rusch. 1970. Effects of fire on a ruffed grouse population. In Annual Tall Timbers Fire Ecol. Conf.: proceedings. 10:25-46.
- Donart, Gary B. 1969. Carbohydrate reserves of six mountain range plants as related to growth. *J. Range Manage.* 22(6):411-415.
- Driscoll, Richard S. 1963. Sprouting bitterbrush in central Oregon. *Ecology* 44(4):820-821.
- Eaton, E. L., and R. G. White. 1960. The relation between burning dates and the development of sprouts and flower buds in the lowbush blueberry. *Amer. Soc. Hort. Sci.* 76:338-342.
- Eliasson, E. 1972a. Growth regulators in Populus tremula. III. Variation of auxin and inhibitor level in roots in relation to root sucker formation. *Physiol. Planta* 25:118-121.
- \_\_\_\_\_. 1972b. Growth regulators in Populus tremula. IV. Apical dominance and suckering in young plants. *Physiol. Planta* 25:263-267.
- Galston, A. W., and P. J. Davies. 1969. Hormonal regulation in higher plants. *Science* 163:1288-1297.
- Garrison, George A. 1971. Carbohydrate reserves and response to use. In Wildland shrubs - their biology and utilization: symposium proceedings, July 1971, Logan Utah. USDA For. Serv., Gen. Tech. Rep. INT-1, p. 271-278. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Grosebaugh, L. R. 1967. REX - Fortran 4 - system for combinatorial screening or conventional analysis of multivariate regressions. USDA For. Serv., Res. Pap. PSW-44, 47 p. Pacific Southw. For. and Range Exp. Stn., Berkeley, California.
- Hare, Robert C. 1961. Heat effects on living plants. USDA For. Serv., Occasional Pap. 183, 32 p. Southern For. Exp. Stn., Asheville, N.C.

- Hickey, William O. 1971. Response of *Ceanothus sanguineus* to cutting and burning at various stages of phenology. Unpublished M.S. thesis. Univ. Idaho, Moscow. 39 p.
- Hitchcock, E. Leo, Arthur Cronquist, Marion Ownby, and J. W. Thompson. 1955. Vascular plants of the Pacific Northwest. Part 1: Vascular cryptograms, gymnosperms and monocotyledons. 914 p. Univ. Washington Press: Seattle.
- \_\_\_\_\_. 1964. Vascular plants of the Pacific Northwest. Part 2: Salicaceae to Saxifragaceae. 597 p. Univ. Washington Press: Seattle.
- \_\_\_\_\_. 1961. Vascular plants of the Northwest. Part 3: Saxifragaceae to Ericaceae. 614 p. Univ. Washington Press: Seattle.
- \_\_\_\_\_. 1959. Vascular plants of the Pacific Northwest. Part 4: Ericaceae through Campanulaceae. 510 p. Univ. Washington Press: Seattle.
- \_\_\_\_\_. 1955. Vascular plants of the Pacific Northwest. Part 5: Compositae. 343 p. Univ. Washington Press: Seattle.
- Jacobs, W. P., and D. B. Case. 1965. Auxin transport, gibberellin and apical dominance. *Science* 148:1729-1731.
- Jones, M. B., and H. M. Laude. 1960. Relationships between sprouting in chamise and the physiological condition of the plant. *J. Range Manage.* 13(4):210-214.
- Kender, Walter J. 1967. Rhizome development in the lowbush blueberry as influenced by temperature and photoperiod. *Amer. Soc. Hort. Sci.* 90:144-148.
- Kormanik, P. P., and C. L. Brown. 1967. Root buds and the development of root suckers in sweetgum. *For. Sci.* 13:338-345.
- Kozłowski, Theodore T., and Theodore Keller. 1966. Food relations of woody plants. *Bot. Rev.* 32(4):293-382.
- Laude, H. M., M. B. Jones, and W. E. Moon. 1961. Annual variability in indicators of sprouting potential in chamise. *J. Range Manage.* 14:323-326.
- Lawson, Bruce D. 1972. Fire spread in lodgepole pine stands. B.C. Internal Report BC-36, 119 p. Pacific For. Res. Centre, Can. Forestry Serv., Victoria, B.C.
- Leege, T. A., and W. O. Hickey. 1971. Sprouting of northern Idaho shrubs after prescribed burning. *J. Wildlife Manage.* 35(3):508-515.

- Lyon, L. Jack. 1971. Vegetal development following prescribed burning of Douglas-fir in south-central Idaho. USDA For. Serv., Res. Pap. INT-105, 30 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- McIntyre, Gordon I. 1972. Developmental studies on Euphorbia esula. The influence of the nitrogen supply on the correlative inhibition of root bud activity. Can. J. Bot. 50:949-956.
- \_\_\_\_\_, and Shirley D. Larmour. 1974. The correlative inhibition of bud and shoot growth in flax. Anatomical changes associated with the release of lateral buds from inhibition. Can. J. Bot. 52:2269-2275.
- \_\_\_\_\_, and M. V. S. Raju. 1967. Developmental studies on Euphorbia esula L. Some effects of the nitrogen supply on the growth and development of the seedling. Can. J. Bot. 45:975-984.
- Meyer, Bernard S., Donald B. Anderson, Richard H. Bohning, and Douglas G. Fratianne. 1973. Introduction to plant physiology. 565 p. D. Van Nostrand Co.: New York.
- Minore, Don. 1972. The wild huckleberries of Oregon and Washington-- a dwindling resource. USDA For. Serv., PNW-143, 20 p. Pacific Northw. For. and Range Exp. Stn., Portland, Oregon.
- \_\_\_\_\_. 1975. Observations on the rhizomes and roots of Vaccinium membranaceum. USDA For. Serv., Res. Note PNW-261, 5 p. Pacific Northw. For. and Range Exp. Stn., Portland, Oregon.
- Mueggler, Walter F. 1965. Ecology of seral shrub communities in the cedar/hemlock zone of northern Idaho. Ecol. Monogr. 35(2):165-185.
- Neiland, B. J. 1958. Forest and adjacent burn in the Tillamook burn area of northwestern Oregon. Ecology 39:660-671.
- Norum, Rodney A. 1975. Characteristics and effects of understory fires in western larch/Douglas-fir stands. Unpublished Ph.D. thesis, Univ. Montana, Missoula. 157 p.
- Panigrahi, B. M., and L. J. Audus. 1966. Apical dominance in Vicia faba. Ann. Bot. NS 30:457-473.
- Phillips, I. D. J. 1969. Apical dominance. In Physiology of Plant Growth and Development. p. 163-202. M. B. Wilkins (ed.). McGraw-Hill: London.
- Robertson, J. H., and H. P. Cords. 1957. Survival of rabbitbrush (Chrysothamnus spp.) following chemical burning and mechanical treatments. J. Range Manage. 10:83-89.
- Sachs, T., and K. V. Thimann. 1967. The role of auxins and cytokinins in the release of buds from dominance. Amer. J. Bot. 54:136-144.

- Sartwell, Charles, and Robert E. Stevens. 1975. Mountain pine beetle in ponderosa pine. *J. For.* 73(3):136-140.
- Schier, G. A. 1972. Apical dominance in multishoot culture from aspen roots. *For. Sci.* 18:147-149.
- \_\_\_\_\_. 1973a. Effect of gibberellic acid and an inhibitor of gibberellin action on suckering from aspen root cuttings. *Can. J. For. Res.* 3(1):39-44.
- \_\_\_\_\_. 1973b. Origin and development of aspen root suckers. *Can. J. For. Res.* 3(1):45-53.
- \_\_\_\_\_. 1973c. Effect of abscisic acid on sucker development and callus formation on excised roots of Populus tremuloides. *Physiol. Planta* 28:143-145.
- \_\_\_\_\_. 1973d. Seasonal variation in sucker production from excised roots of Populus tremuloides and the role of endogenous auxin. *Can. J. For. Res.* 3(3):459-461.
- \_\_\_\_\_. 1975. Deterioration of aspen clones in the middle Rocky Mountains. USDA For. Serv., Res. Pap. INT-170, 14 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- \_\_\_\_\_, and R. S. Johnston. 1971. Clonal variation in total nonstructural carbohydrates of trembling aspen roots in three Utah areas. *Can. J. For. Res.* 1(4):252-255.
- \_\_\_\_\_, and John C. Zasada. 1973. Role of carbohydrate reserves in the development of root suckers in Populus tremuloides. *Can. J. For. Res.* 3(2):243-250.
- Scott, T. K., D. B. Case, and W. P. Jacobs. 1967. Auxin-gibberellin interaction in apical dominance. *Plant Physiol.* 43:1329-1333.
- Sharp, W. M. 1970. The role of fire in ruffed grouse habitat management. In *Annual Tall Timbers Fire Ecol. Conf.: proceedings.* 10:47-61.
- Shearer, Raymond C. 1975. Seedbed characteristics in western larch forests after prescribed burning. USDA For. Serv., Res. Pap. INT-167, 26 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Siegler, E. A., and J. J. Bowman. 1939. Anatomical studies of root and shoot primordia in one-year apple roots. *J. Agric. Res.* 58(11):795-803.
- Skoog, F., and C. O. Miller. 1957. Chemical regulation of growth and organ formation in plant tissues cultured in vitro. *Symp. Soc. Exp. Biol.* 11:118-131.

- \_\_\_\_\_, and C. Tsui. 1948. Chemical control of growth and bud formation in tobacco stem segments and callus cultured in vitro. Amer. J. Bot. 35:782-787.
- Smith, D. W. 1966. Studies in the taxonomy and ecology of blueberries (Vaccinium, subgenus Cyanococcus) in Ontario. Part II. Ecological study with special reference to the effects of fire on the soil and vegetation. Unpublished Ph.D. thesis, Univ. Toronto. 276 p.
- \_\_\_\_\_. 1968. Surface fires in northern Ontario. In Annual Tall Timbers Fire Ecol. Conf.: proceedings. 8:41-54.
- \_\_\_\_\_, and J. R. Hilton. 1971. The comparative effects of pruning by burning or clipping on lowbush blueberries in northeastern Ontario. J. Appl. Ecol. 8(3):781-789.
- \_\_\_\_\_, and J. H. Sparling. 1966. The temperature of surface fires in jackpine barren. I. The variation in temperature with time. Can. J. Bot. 44(10):1285-1292.
- Sorokin, Helen, and K. V. Thimann. 1964. The histological basis for inhibition of axillary buds in Pisum sativum and the effects of auxins and kinetin on xylem development. Protoplasma 59:326-350.
- Sparling, J. H., and D. W. Smith. 1966. The temperature of surface fires in jackpine-Pinus banksiana-barren. II. The effects of vegetation cover, windspeed, and relative humidity on fire temperatures. Can. J. Bot. 44(10):1293-1298.
- Spurr, Stephen H. 1964. Forest ecology. 352 p. Ronald Press Co.: New York.
- Stark, Nellie. 1976. Fuel reduction - nutrient status and cycling relationships associated with understory burning in larch/Douglas-fir stands. In Fire and land management: symposium proceedings, October 1974, Missoula, Montana. Tall Timbers Res. Stn. and Intermt. Fire Res. Council (in press).
- Steen, Harold K. 1963. Relation between moisture content of fine fuels and relative humidity. USDA For. Serv., Res. Note PNW-4, 6 p. Pacific Northw. For. and Range Exp. Stn., Portland, Oregon.
- Sterrett, J. P., and W. E. Chappell. 1967. The effect of auxin on suckering in black locust. Weed Sci. 15:323-326.
- \_\_\_\_\_, W. E. Chappell, and G. M. Shear. 1968. Temperature and annual growth cycle effects on root suckering in black locust. Weed Sci. 16:250-251.
- Stinson, Kenneth J., and Henry A. Wright. 1969. Temperatures of head-fires in the southern mixed prairies of Texas. J. Range Manage. 22(3):169-174.

- Stoeckler, Joseph H., and John W. Macon. 1956. Regeneration of aspen cutover areas in northern Wisconsin. *J. For.* 54:13-16.
- Stone, E. L., and S. M. Cornwall. 1968. Basal bud burls in Betula populifolia. *For. Sci.* 14:64-65.
- Tew, R. K. 1970. Root carbohydrate reserves in vegetative reproduction of aspen. *For. Sci.* 16(3):318-320.
- Thimann, K. V. 1937. On the nature of inhibitions caused by auxin. *Amer. J. Bot.* 24:407-412.
- \_\_\_\_\_. 1969. The auxins. In *Physiology of plant growth and development*. p. 2-45. M. B. Wilkins (ed.): London.
- \_\_\_\_\_, Tsvi Sachs, and K. N. Mathur. 1971. The mechanism of apical dominance in Coleus. *Physiol. Planta* 24:68-72.
- Thorpe, T. A., and T. Murashige. 1970. Some histo-chemical changes underlying shoot initiation in tobacco callus cultures. *Can. J. Bot.* 48:277-285.
- Torrey, J. G. 1958. Endogenous bud and root formation by isolated roots of Convolvulus grown in vitro. *Plant Physiol.* 33:258-263.
- Uggla, Evald. 1973. Fire ecology in Swedish forests. In *Tall Timbers Fire Ecol. Conf.: proceedings*. 13:171-190.
- Valdovinos, Jack G., Leland C. Ernest, and Egbert W. Henry. 1967. Effect of ethylene and gibberellic acid on auxin synthesis in plant tissues. *Plant Physiol.* 43:1803-1806.
- Vogl, R. J. 1970. Fire and the northern Wisconsin pine barrens. In *Annual Tall Timbers Fire Ecol. Conf.: proceedings*. 10:175-209.
- Vogt, A. R., and G. S. Cox. 1970. Evidence for the hormonal control of stump sprouting by oak. *For. Sci.* 16:165-171.
- Warmke, H. E., and G. L. Warmke. 1950. The role of auxin in the differentiation of root and shoot primordia from root cuttings of Taraxacum and Cichorium. *Amer. J. Bot.* 37:272-280.
- Weaver, H. 1967. Fire and its relation to ponderosa pine. In *Annual Tall Timbers Fire Ecol. Conf.: proceedings*. 7:127-149.
- Wenger, K. F. 1953. The sprouting of sweetgum in relation to season of cutting and carbohydrate content. *Plant Physiol.* 28:35-49.
- Whittaker, E. 1961. Temperatures in heath fires. *J. Ecol.* 49:709-715.
- Wickson, M., and K. V. Thimann. 1958. The antagonism of auxin and kinetin in apical dominance. *Physiol. Planta* 11:62-74.

- Wolter, K. E. 1958. Root and shoot initiation in aspen callus cultures. *Nature* 219:509-510.
- Woods, F. S., H. C. Harris, and R. E. Caldwell. 1959. Monthly variation of carbohydrates and nitrogen in roots of sandhill oaks and wiregrass. *Ecology* 40:292-295.
- Wright, Henry A. 1971. Shrub response to fire. *In* Wildland shrubs - their biology and utilization: symposium proceedings, July 1971, Logan, Utah. USDA For. Serv., Gen. Tech. Rep. INT-1, p. 204-217. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Zasada, John C., and George A. Schier. 1973. Aspen root suckering in Alaska; effect of clone, collection date, and temperature. *Northw. Sci.* 47(2):100-104.

APPENDIX A

FUEL INVENTORY PROCEDURES USED FOR A  
COOPERATIVE FIRE RESEARCH PROJECT ON THE LUBRECHT  
EXPERIMENTAL FOREST, MONTANA, 1972-73

by

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(Office Report)  
August 13, 1975

## APPENDIX A

### INTRODUCTION

The fuel inventory procedures followed on this research project utilize the planer intersect technique to assess the quantity of downed fuel, duff depth, fuel height, slope, brush, litter, and rotten wood.

The inventory is taken at 13 points in thirty-two 1/3-acre plots and at 50 points in two 1-acre plots. On odd-numbered lines, odd-numbered points are inventoried and on even-numbered lines, even-numbered points are inventoried.

An experienced two-man team can inventory one point in 9 minutes on the average.

#### Equipment Needed

1. Two light, aluminum poles (ours are 1.6 cm in diameter) 2 meters in length. The poles should be painted white and the midpoint on each pole should be marked with a black stripe 1 cm wide.
2. One aluminum pole 56.6 cm long. This pole should be painted black the first decimeter, white the second decimeter, and alternating black and white each decimeter thereafter.
3. One Silva Type 2 compass.
4. One pointed bricklayer's trowel.

5. One foot-long wooden ruler with both inches and centimeter scales.
6. Clipboard.
7. Porta-punch board, cards, and stylus.
8. Two retractable tape measures with centimeter scales.
9. Four wire quadrats 50 by 20 cm. These are rectangular and should be painted white. It is helpful if each side of the quadrat has a black stripe painted at the midpoint.
10. Topographic Abney level.
11. One knife (or a small pair of scissors).
12. Small hand stapler and staples.
13. Paper bags (approximately size 8).

A multipocket cruiser's vest is a convenient way of storing and carrying sacks, compass, rulers, abney, pencils, etc.

### Inventory Procedures

Step 1 - Initial Data. Upon arriving at an inventory point the number-1 man first determines the direction the slope is facing using the Silva compass. This azimuth is determined to the nearest 10 degrees. Then using the Abney level he measures the degree of slope. A 2-meter pole should be placed on the ground and oriented directly downslope. The Abney is placed on the pole and leveled. The percent slope is then read from the scale to the nearest point.

At the same time, the number-2 man prepares the new porta-punch card. A clear acetate precoded template is inserted into the porta-punch card holder. Beneath this template a blank porta-punch card is inserted. Unit, line and point, and plot information is punched. As soon as azimuth and slope percent is determined this information is announced and punched in the appropriate columns. The number-2 man does all punching on the porta-punch card.

After the slope percent is determined the number-1 man turns the dial on the compass several times to obtain a random direction reading. This azimuth is used to orient a 2-meter pole for Step 2. After the dial is rotated randomly, the entire compass is rotated until the needle points to north. The 2-meter transect is oriented in the direction the arrow is pointing when the needle is on north.

Step 2 - Transect Measurements. As soon as the transect is established the number-1 man begins counting all intercepts in the 0- to 1/4-, 1/4- to 1-, 1- to 3-inch size classes that pass through an imaginary vertical plane both above and below the 2-meter pole. All dead intercepts are counted unless a tree is still standing in a vertical or near-vertical position. Any dead branches or whole stems in a horizontal or near-horizontal position would be counted if its twigs and branches intersect the sampling plane above or below the 2-meter pole.

While the number-1 man counts intercepts, the number-2 man does three things. First, he estimates the percent organic cover along the 2-meter transect. Percent cover is normally a 9 (90 to 100 percent) but if rocks or mineral soil are present along the transect the percent cover could be less than a 9. It simply refers to the amount of lineal

surface area along the transect covered by duff, moss, dead fuel, etc. Only the presence of rocks or mineral soil would reduce the percentage cover.

Next, the number-2 man measures duff depth at each end and at the midpoint of the transect. The duff is parted with the trowel until mineral soil is found. The duff depth is then measured by inserting the wooden ruler in the hole until it contacts the mineral soil surface. The duff depth is read to the nearest centimeter.

Next the number-2 man measures the fuel depth along the transect, again at each end and at the midpoint. To do this he imagines that a vertical cylinder exists on each of the three locations. It has a radius of 6 inches and centers on the ends and midpoint of the 2-meter pole. The fuel height is measured from the highest intercept in this cylinder to the surface of the litter. It is normally done with the tape measure but sometimes the wooden ruler is more convenient to use. This information is read to the nearest centimeter and is punched using 3 columns for each point.

As soon as the number-1 man finishes counting intercepts he announces his three totals to the number-2 man so it can be punched. This completes Step 2.

Step 3 - Herbs, Grasses, Forbs, and Brush Subplots. The number-1 man determines percentages of herbs, forbs, and grasses by using the relative estimate technique. Four wire quadrats are oriented on the ground as shown in the following diagram:

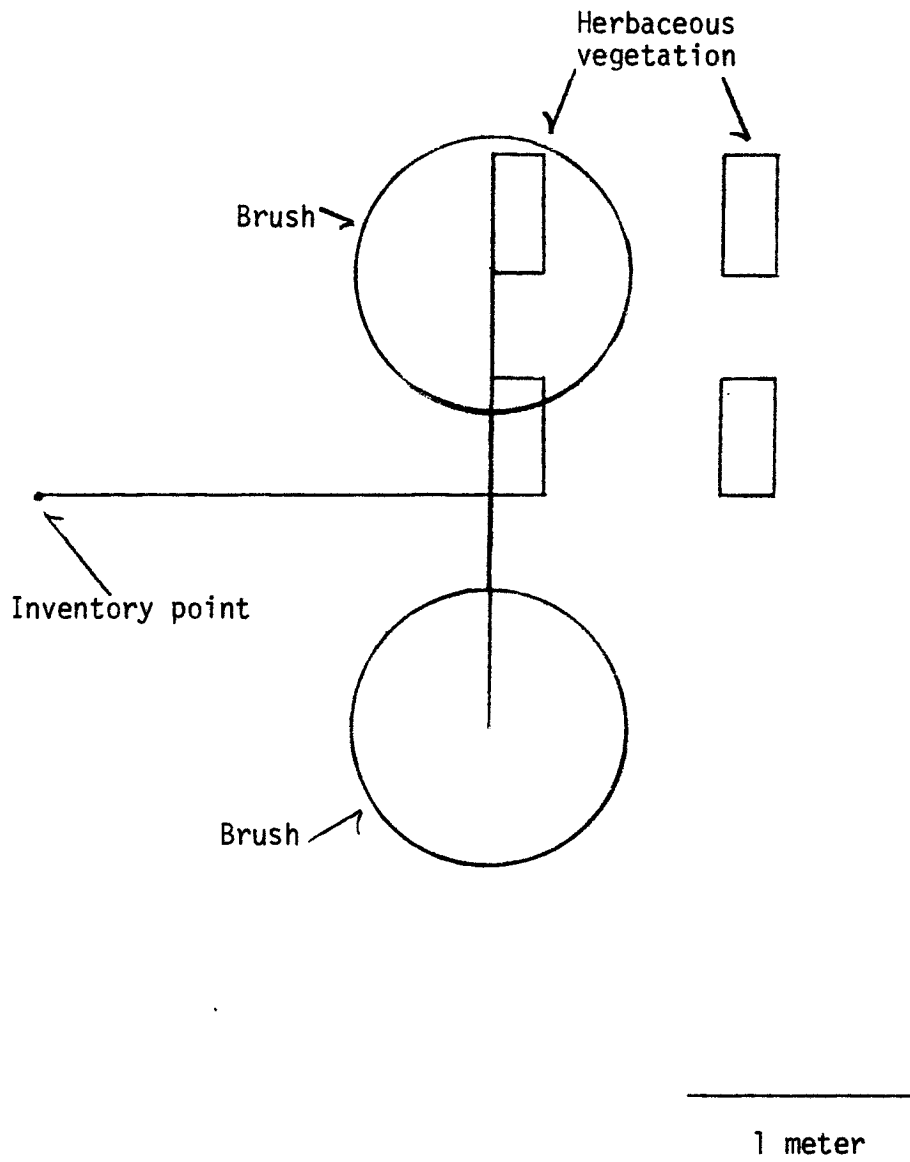


Figure 7.--Fuel inventory scheme.

Each wire should have one corner which is not welded. This enables the user to fit the quadrat around small trees and other obstacles which lie within the area that the quadrat is to be placed. The observer visually determines which of the four quadrats has the greatest volume of grasses, forbs, and herbs within it. He then estimates this percent cover to the nearest 10 percent. Next, he estimates the volume in each of the other three quadrats that is covered in relation to the heaviest loaded quadrat. For example, suppose one quadrat was completely full of arnica and beargrass. Two others had exactly one-half the amount that the first did, and the fourth was empty. The percentages announced would be 90, 50, 50, 0 and would be punched as 9, 5, 5, 0.

After the percentages are determined the number-1 man "clips" the heaviest loaded plot. All green grasses, herbs, and forbs are cut off at the litter surface and collected in a paper bag (which has been labeled as to plot, line, and point). No dead stems or leaves are collected in the bag; only green material. When all material has been clipped and inserted in the bag, the bag is stapled shut.

While the number-1 man is estimating percentages and clipping, the number-2 man is tallying brush.

The tally location is determined by placing the second 2-meter pole perpendicular to the transect pole already in place, thus forming a "T." Each end of this second pole is considered the center of a circle with the 56.6-cm pole being the radius. The short pole is used to help estimate the percent brush cover within the circle. Often times it is helpful to mentally divide the circle into quarters and determine the percent cover of a quarter of the circle at a time. A quarter circle

completely covered by brush would be 25 percent. Adding the percents for each quarter section would give the total percent coverage for the subplot.

The mean height of the brush is determined to the nearest decimeter by standing the short pole upright at several different locations within the circle. The height of the brush is determined by counting the black and white decimeter stripes on the pole to the highest stem. An average is taken. For example, if half the brush within the circle measured 6 decimeters in height and the other half measured 2 decimeters, the average would be 4 decimeters. This would then be punched along with the corresponding percentage cover for that subplot.

After determining the volume and mean height, all brush stems within the 1/4-milacre subplot are tallied by species and size class. Size classes are 0 to .5 cm, .5 to 1, 1 to 1.5, 1.5 to 2, 2 to 3, and 3 to 5. This information is recorded on the fuel inventory tally sheet on the clipboard. This procedure is repeated for the second circular subplot. This completes Step 3.

Step 4 - 3"+ Intercepts and Rotten Wood. To count the intercepts greater than 3 inches, the second 2-meter pole is placed at the end of the first 2-meter pole on the same azimuth. This forms a transect 4 meters long. The diameter of all dead material greater than 3 inches that intersects this 4-meter plane is measured at the point that it crosses the plane. This diameter is determined to the nearest centimeter and is recorded in the appropriate column on the tally sheet. Each intercept is inspected to determine if it is sound or rotten. This information is recorded next to the diameter for that intercept.

The last item in this inventory involves assessing the percent cover of rotten wood which lies beneath the 4-meter transect. This percent cover of rotten wood is estimated to the nearest percent and recorded on the tally sheet.

The first man to complete Step 3 does Step 4. This completes the inventory.

## APPENDIX B

APPENDIX B

Air temperature, moisture conditions, and duff and soil surface temperatures attained during fires

Plot	Burning date	Ambient air		Relative humidity		0-1/4 inch fuel moisture		1/4-1 inch fuel moisture		Upper duff moisture		Lower duff moisture		Soil moisture		Understory foliage moisture		Avg. duff surface temp.		Avg. soil surface temp.	
		temp.	temp.	content	content	content	content	content	content	content	content	content	content	content	content	content	content	content	content	content	content
LATE SPRING AND EARLY SUMMER FIRES																					
29	5-11-73	55	36	15.5	18.9	66.8	145.1	39.9	139.9	220	103										
30	5-24-73	65	48	9.4	8.5	39.2	112.1	32.5	269.4	132	103										
9	5-30-73	75	35	11.2	11.7	57.7	134.2	42.2	225.0	296	132										
26	6-06-73	67	34	9.9	10.5	25.9	102.7	43.3	343.3	299	168										
25	6-12-73	72	36	11.2	11.4	28.3	90.3	20.5	248.1	213	108										
2	6-20-73	70	32	9.1	11.4	48.3	57.4	24.0	252.1	345	211										
6	6-21-73	73	27	10.6	11.4	70.3	109.6	30.3	265.6	237	118										
5	6-26-73	67	52	11.2	10.9	15.5	39.6	14.8	269.2	280	177										
23	6-29-73	73	37	8.5	8.5	13.0	18.9	14.2	318.5	249	172										
LATE SUMMER AND EARLY FALL FIRES																					
21	9-10-73	77	46	16.7	17.7	53.7	66.1	18.4	133.1	494	263										
1	9-11-73	75	30	8.0	8.4	9.8	22.8	5.7	91.5	422	245										
18	9-17-73	61	35	20.3	25.2	70.1	69.7	12.0	129.3	353	237										
3	9-26-73	53	50	35.2	42.5	115.4	89.3	10.5	117.1	345	268										
27	9-28-73	67	42	21.2	24.0	76.3	82.6	10.0	115.5	277	216										
10	9-29-73	70	34	21.9	20.8	95.8	88.3	11.8	138.2	420	310										
14	10-04-73	55	28	22.7	27.3	75.1	94.9	11.0	127.9	274	179										
31	10-05-73	56	35	18.6	25.9	98.9	103.2	11.8	137.8	302	175										
11	10-06-73	55	41	20.7	22.7	64.9	89.0	11.8	136.0	350	235										
22	10-09-73	44	45	18.7	18.7	42.2	63.1	10.6	157.7	376	208										
23	10-10-73	46	53	20.1	22.6	73.6	101.2	17.5	127.3	339	224										

## APPENDIX C

APPENDIX C

Constants and variables for computing woody shrub weight

Species	Mean diameters (cm)					
	a	b	0 to .5	.5 to 1.0	1.0 to 1.5 : 1.5 to 2	
<i>Vaccinium globulare</i>	3.388	3.150	.160	.648	1.120	1.721
<i>Menziesia ferruginea</i>	3.073	3.150	.194	.681	1.203	1.647
<i>Amelanchier alnifolia</i>	3.607	2.887	.220	.675	1.208	1.692
<i>Rosa</i> spp.	3.628	2.779	.196	.585	--	--
<i>Berberis repens</i>	2.976	2.092	.337	.630	--	--
<i>Spiraea betulifolia</i>	3.604	2.604	.142	.500	--	--
<i>Symphoricarpos albus</i>	3.490	2.285	.111	.595	--	--

The weight of a woody shrub is computed from the equation:

$$\ln Y = a + b \ln x$$

where  $Y$  = shrub weight (grams)  $b$  = regression coefficient for the species  
 $x$  = mean base diameter of shrub stem  $a$  = regression constant for the species  
the the size class and species in  
question (cm)

## APPENDIX D

## APPENDIX D

## Plot summaries

Plot	Prefire 1973		Postfire 1974		Postfire 1975	
	no. of plants	with plants	no. of plants	with plants	no. of plants	with plants
<u>MENZIESIA (Menziesia ferruginea)</u>						
9 (S)*	370	14	505	6	617	9
10 (F)	100	4	380	5	241	5
<u>SERVICEBERRY (Amelanchier alnifolia)</u>						
2 (S)	66	11	25	5	37	5
5 (S)	32	10	36	5	30	7
6 (S)	52	11	23	6	71	10
28 (S)	11	5	12	3	6	4
1 (F)	75	5	1	1	33	4
10 (F)	8	7	12	3	4	3
14 (F)	10	3	29	8	29	5
31 (F)	35	7	3	2	12	2
<u>ROSE (Rosa spp.)</u>						
6 (S)	8	4	39	11	48	8
1 (F)	17	6	7	5	8	3
21 (F)	14	5	5	1	5	2
31 (F)	17	10	11	6	26	9
<u>OREGON GRAPE (Berberis repens)</u>						
2 (S)	73	10	109	3	130	5
30 (S)	39	10	80	14	86	13
1 (F)	135	21	56	10	77	11
3 (F)	110	6	127	8	180	10
31 (F)	6	2	2	2	23	5
<u>SNOWBERRY (Symphoricarpos albus)</u>						
30 (S)	21	6	24	6	38	7
1 (F)	31	6	73	9	79	9
3 (F)	96	13	252	11	263	13
<u>SPIRAEA (Spiraea betulifolia)</u>						
2 (S)	523	25	1829	24	1699	26
5 (S)	162	15	316	20	397	24
6 (S)	108	16	166	23	199	22
9 (S)	15	5	17	5	21	7
25 (S)	48	11	51	9	49	8
26 (S)	25	7	30	6	30	6
28 (S)	1	1	167	9	193	16
29 (S)	28	8	43	11	37	8
30 (S)	11	11	37	6	53	8
1 (F)	653	24	1055	24	1424	23
3 (F)	488	22	961	22	983	21
10 (F)	15	5	45	5	32	11
11 (F)	--	--	9	6	24	6
14 (F)	15	4	16	8	45	11
18 (F)	36	1	2	2	12	5
21 (F)	19	4	8	5	42	8
23 (F)	39	8	79	11	101	9
27 (F)	4	2	23	5	11	4
31 (F)	48	8	71	15	122	12

\* (S) and (F) indicate spring or fall burn

## APPENDIX E

APPENDIX E

FULL STATISTICS FOR REGRESSION EQUATIONS

INDEPENDENT VARIABLE SET ONE: EQUATION 1

Number of Vaccinium globulare stems 1 year after spring fires (1974):

Source of variation	df	SS	MS	F
Due to regression	3	712221.740	237407.247	11.1544
Error	5	106418.480	21283.696	
Total	8	818640.220		

Since  $F_{.025}$  with 3/5 df is 7.76, the regression is deemed significant at the .025 level.

$$\text{RMSQR} = .2080$$

$$1 - R^2 = .0830$$

$$R^2 = .8700$$

The standard error of estimate is 145.8893.

Simple linear correlation coefficients between number of Vaccinium stands 1 year after spring fires and independent variables are:

$$x_6 \quad -.1329 \quad (\text{rotten, 3-inch and larger preburn fuel weight})$$

$$x_{37} \quad -.0024 \quad (\text{relative humidity})$$

$$x_{40} \quad -.3988 \quad (\text{ambient air temperature/moisture content of top 5 cm of soil})$$

The maximum correlation between independent variables is:

.5127 between  $x_6$  and  $x_{37}$

A "t" test of regression coefficients yields the following probabilities of getting values as high as achieved if the values were in truth zero.

$b_6$	$b_{37}$	$b_{40}$
.01	.01	.01

## INDEPENDENT VARIABLE SET ONE: EQUATION 2

Number of Vaccinium globulare stems 2 years after spring fires (1975):

Source of variation	df	SS	MS	F
Due to regression	3	1630219.200	543406.400	18.4145
Error	5	147548.770	29509.755	
Total	8	1777768.990		

Since  $F_{.005}$  with 3/5 df is 16.53, the regression is deemed significant at the .005 level.

$$\text{RMSQR} = .1328$$

$$1 - R^2 = .0830$$

$$R^2 = .9170$$

The standard error of estimate is 171.7840.

Simple linear correlation coefficients between number of Vaccinium stems 2 years after spring fires and independent variables are:

$$x_6 \quad .0122 \quad (\text{rotten, 3-inch and larger preburn fuel weight})$$

$$x_{36} \quad .5124 \quad (\text{moisture content of the top 5.0 cm of soil})$$

$$x_{37} \quad .0836 \quad (\text{relative humidity})$$

The maximum correlation between independent variables is:

$$.5127 \text{ between } x_6 \text{ and } x_{37}$$

A "t" test of regression coefficients yields the following probabilities of getting values as high as achieved if the values were in truth zero.

$b_6$	$b_{36}$	$b_{37}$
.01	.001	.01

## INDEPENDENT VARIABLE SET ONE: EQUATION 3

Number of Vaccinium globulare stems 1 year after fall fires (1974):

Source of variation	df	SS	MS	F
Due to regression	4	4485954.500	1121488.625	78.4659
Error	6	85756.090	14292.682	
Total	10	4571710.590		

Since  $F_{.001}$  with 4/6 df is 21.92, the regression is deemed significant at the .001 level.

$$\text{RMSQR} = .0313$$

$$1 - R^2 = .0188$$

$$R^2 = .9812$$

The standard error of estimate is 119.5520.

Simple linear correlation coefficients between number of Vaccinium stems 1 year after fall fires and independent variables are:

$$x_1 \quad .9169 \quad (\text{preburn number of huckleberries})$$

$$x_3 \quad -.2448 \quad (0\text{- to }1/4\text{-inch preburn fuel weight})$$

$$x_8 \quad .0978 \quad (\text{total, 3-inch and larger preburn fuel weight})$$

$$x_{12} \quad -.2321 \quad (\text{preburn dead fuel depth})$$

The maximum correlation between independent variables is:

$$.6105 \text{ between } x_3 \text{ and } x_{12}$$

A "t" test of regression coefficients yields the following probabilities of getting values as high as achieved if the values were in truth zero.

$b_1$	$b_3$	$b_8$	$b_{12}$
.001	.01	.01	.01

## EQUATION 4

Number of Vaccinium globulare stems 2 years after fall fires (1975):

Source of variation	df	SS	MS	F
Due to regression	4	6707512.600	1676878.150	82.4400
Error	6	122043.540	20340.591	
Total	10	6829556.140		

Since  $F_{.001}$  with 4/6 df is 21.92, the regression is deemed significant at the .001 level.

$$\text{RMSQR} = .0298$$

$$1 - R^2 = .0179$$

$$R^2 = .9821$$

The standard error of estimate is 142.6204.

Simple linear correlation coefficients between number of Vaccinium stems 2 years after fall fires and independent variables are:

$$x_1 \quad .9330 \quad (\text{preburn number of huckleberries})$$

$$x_{14} \quad -.0289 \quad (\text{average slope})$$

$$x_{15} \quad .1585 \quad (0\text{- to }1/4\text{-inch fuel moisture content})$$

$$x_{35} \quad .5706 \quad (\text{lower duff moisture content})$$

The maximum correlation between independent variables is:

$$.6385 \text{ between } x_{15} \text{ and } x_{35} \quad (\text{correlation significant at } .05 \text{ level})$$

A "t" test of regression coefficients yields the following probabilities of getting values as high as achieved if the values were in truth zero.

$b_1$	$b_{14}$	$b_{15}$	$b_{35}$
.001	.05	.02	.01

## EQUATION 5

Number of Vaccinium globulare stems 1 year after spring fires (1974):

Source of variation	df	SS	MS	F
Due to regression	3	775579.230	258526.410	30.0186
Error	5	43060.990	8612.198	
Total	8	818640.220		

Since  $F_{.005}$  with 3/5 df is 16.53, the regression is deemed significant at the .005 level.

$$\text{RMSQR} = .0842$$

$$1 - R^2 = .0526$$

$$R^2 = .9474$$

The standard error of estimate is 92.8019.

The simple linear correlation coefficients between number of Vaccinium stems 1 year after spring fires and independent variables are:

$$x_1 \quad .8094 \quad (\text{preburn number of huckleberries})$$

$$x_{23} \quad -.6005 \quad (\text{mean duff depth reduction})$$

$$x_{25} \quad -.3172 \quad (\text{fire intensity})$$

The maximum correlation between independent variables is:

$$.6327 \text{ between } x_{23} \text{ and } x_{25}$$

A "t" test of regression coefficients yields the following probabilities of getting values as high as achieved if the values were in truth zero.

$b_1$	$b_{23}$	$b_{25}$
.001	.01	.05

## INDEPENDENT VARIABLE SET TWO: EQUATION 6

Number of Vaccinium globulare stems 2 years after spring fires (1975):

Source of variation	df	SS	MS	F
Due to regression	3	1695037.600	565012.533	34.1478
Error	5	82730.384	16546.077	
Total	8	1777767.984		

Since  $F_{.001}$  with 3/5 df is 33.20, the regression is deemed significant at the .001 level.

$$\text{RMSQR} = .0745$$

$$1 - R^2 = .0465$$

$$R^2 = .9535$$

The standard error of estimate is 128.2812.

The simple linear correlation coefficients between number of Vaccinium stems 2 years after spring fires and independent variables are:

$$x_1 \quad .8988 \quad (\text{preburn number huckleberries})$$

$$x_{25} \quad -.1598 \quad (\text{fire intensity})$$

$$x_{26} \quad -.0160 \quad (\text{percent brush weight reduction})$$

The maximum correlation between independent variables is:

$$.5813 \text{ between } x_{25} \text{ and } x_{26}$$

A "t" test of regression coefficients yields the following probabilities of getting values as high as achieved if the values were in truth zero.

$b_1$	$b_{25}$	$b_{26}$
.001	.02	.02

## EQUATION 7

Number of Vaccinium globulare stems 1 year after fall fires (1974):

Source of variation	df	SS	MS	F
Due to regression	4	4431117.500	1107779.375	47.2760
Error	6	140593.080	23432.181	
Total	10	4571710.580		

Since  $F_{.001}$  with 4/6 df is 21.92, the regression is deemed significant at the .001 level.

$$\text{RMSQR} = .0513$$

$$1 - R^2 = .0308$$

$$R^2 = .9692$$

The standard error of estimate is 153.0757.

The simple linear correlation coefficients between number of Vaccinium stems 1 year after fall fires and independent variables are:

$$x_1 \quad .9170 \quad (\text{preburn number of huckleberries})$$

$$x_{20} \quad -.3730 \quad (1\text{- to }3\text{-inch fuel weight reduction})$$

$$x_{27} \quad -.3983 \quad (\text{average temperature at soil surface})$$

$$x_{36} \quad .1176 \quad (\text{moisture content of the top } 5.0 \text{ cm of soil})$$

The maximum correlation between independent variables is:

$$.4547 \text{ between } x_{20} \text{ and } x_{36}$$

A "t" test of regression coefficients yields the following probabilities of getting values as high as achieved if the values were in truth zero.

$b_1$	$b_{20}$	$b_{27}$	$b_{36}$
.001	.01	.05	.01

## EQUATION 8

Number of Vaccinium globulare stems 2 years after fall fires (1975):

Source of variation	df	SS	MS	F
Due to regression	4	6704277.800	1676069.450	80.2725
Error	6	125278.410	20879.734	
Total	10	6829556.210		

Since  $F_{.001}$  with 4/6 df is 31.09, the regression is deemed significant at the .001 level.

$$\text{RMSQR} = .0306$$

$$1 - R^2 = .0813$$

$$R^2 = .9817$$

The standard error of estimate is 144.4982.

The simple linear correlation coefficients between number of Vaccinium stems 2 years after fall fires and independent variables are:

$$x_1 \quad .9330 \quad (\text{preburn number of huckleberries})$$

$$x_{20} \quad -.2877 \quad (1\text{- to 3-inch fuel weight loss})$$

$$x_{28} \quad -.4851 \quad (\text{adjusted soil surface temperature})$$

$$x_{36} \quad .1163 \quad (\text{moisture content of the top 5.0 cm of soil})$$

The maximum correlation between independent variables is:

$$.4547 \quad \text{between } x_{20} \text{ and } x_{36}$$

A "t" test of regression coefficients yields the following probabilities of getting values as high as achieved if the values were in truth zero.

$b_1$	$b_{20}$	$b_{28}$	$b_{36}$
.001	.01	.01	.01