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RELATIONSHIPS OF STAND CONDITIONS TO SPRUCE BUDWORM DAMAGE ON LUBRECHT FOREST, MONTANA

By

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INTRODUCTION

I. THE PROBLEM

Outbreaks of the spruce budworm (Choristoneura fumiferana (Clem.)) in the Northern Rocky Mountains have resulted in heavy damage to about five million acres of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) (McComb and Terrell, 1958). Normally, budworm outbreaks are restrained by natural control factors (Whiteside and Carolin, 1960) such as parasites, predators, diseases, stand conditions, and adverse climate. Conditions favorable for budworm survival and regeneration can result in a rapid population buildup, requiring direct control methods to prevent heavy tree mortality and damage. Certain insecticides offer effective direct control of the budworm but are costly, only temporary in effectiveness, and often of potential danger to the survival of other fauna.

More desirable than insecticides in respect to cost, hazard to fauna, and duration of effect is the utilization of natural control. Natural control might be accomplished by introducing host-specific diseases or parasites, or by applying silvicultural practices to the stand that will reduce the vulnerability of the stand to budworm damage.

The purpose of this study is to investigate the relationship of percent Douglas-fir, stand stocking, and site quality to defoliation caused by the spruce budworm on Lubrecht Forest. Knowing these relationships, the feasibility of using silvicultural practices as a means of reducing damage to Douglas-fir can be more easily determined.

II. OBJECTIVES

Specifically, objectives of this study are:

1. To study the relationship of site quality, stand density, crown closure, and percent Douglas-fir to tree defoliation caused by the spruce budworm.
2. To study the feasibility and practicality of reducing defoliation of Douglas-fir through application of forest management practices.
3. To compare various methods of measuring stand stocking and forest composition for predicting budworm defoliation.

CHAPTER II

LITERATURE REVIEW

I. THE SPRUCE BUDWORM

Classification of species.

The spruce budworm (*Choristoneura fumiferana* (Clem.) (Lepidoptera: Tortricidae)) is native only to North America. Classification of the budworm is still unsettled, but it is now believed that there are at least four distinct species, and possibly more. Miller (1963) cites the following classification:

Choristoneura pinus (jack pine budworm) --- most commonly found on jack pine (*Pinus banksiana* Lamb.) in the Lake States.

C. fumiferana (spruce budworm) --- three forms are recognized:

a. eastern one-cycle budworm --- found on balsam fir (*Abies balsamea* (L.) Mill).

b. western one-cycle budworm --- found in the western Montane Forest Region.

c. western two-cycle budworm --- found in western Sub Alpine Forest Region of Canada.

In a recent report, Stehr (1965) stated that the two western forms of budworm are actually distinct species from the eastern spruce budworm, rather than forms or races of the budworm found on balsam fir, such as suggested by Miller. Certain characteristics and feeding habits of spruce budworm found on western larch (*Larix occidentalis* Nutt.) and on ponderosa pine (*Pinus ponderosa* Laws.) suggest that still other species of budworm may occur in the Rocky Mountain Region.[1]

Host trees.

The spruce budworm feeds on many coniferous species, but causes the most extensive damage to Douglas-fir and several species of true fir (Abies) (Bean and Waters, 1961; Whiteside and Carolin, 1961). A partial list of trees that are host to the budworm is found in Table I, page 5.

Damage caused by spruce budworm.

Tree damage results from budworm larvae feeding on new foliage and buds, and occasionally on branch shoots; old needles are fed upon when new foliage has been consumed. Large populations of budworm feeding on both old and new foliage can defoliate and kill young trees in one season. Generally, though, three to five years of continuous, heavy defoliation is required to cause tree mortality (Johnson, 1955; Bean and Waters, 1961).

Spruce budworm characteristically feed heaviest on the top portion of the crown. Terrell (1962) estimates that top kill can be expected when a tree is over fifty percent defoliated. In studying the pattern of spruce budworm defoliation in crowns of Douglas-fir, Silver (1962) found that about sixty-three percent of the needles in the top one-third of the crown were current or one year old needles, and that the greatest portion of new needles of the whole crown were in this top portion.

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[1] Personal communication with David G. Fellin, research entomologist for the U.S. Forest Service, Missoula, Montana.

TABLE I

HOST TREES OF THE SPRUCE BUDWORM

Common Name	Scientific Name
PREFERRED HOSTS	
balsam fir	*Abies balsamea* (L.) Mill.
grand fir	*A. grandis* (Dougl.) Lindl.
white fir	*A. concolor* (Gord. and Glend.) Lindl.
subalpine fir	*A. lasiocarpa* (Hook.) Nutt.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Engelmann spruce	*Picea engelmannii* Parry
COMMON HOSTS	
white spruce	*Picea glauca* (Moench) Voss
red spruce	*P. rubens* Sarg.
black spruce	*P. mariana* (Mill.) B.S.P.
blue spruce	*P. pungens* Engelm.
ponderosa pine	*Pinus ponderosa* Laws.
lodgepole pine	*P. contorta* var. *latifolia* Engelm.
OCCASIONAL HOSTS	
eastern larch	*Larix laricina* (Du Roi) K. Koch
western larch	*L. occidentalis* Nutt.
eastern white pine	*Pinus strobus* L.
western white pine	*P. monticola* Dougl.
limber pine	*P. flexilis* James
western juniper	*Juniperus scopulorum* Sarg.

Source: Whiteside and Carolin, 1961; Bean and Waters, 1961.

Spruce budworm life cycle.

The spruce budworm may have either a one-year or a two-year life cycle. In the one-year cycle, the budworm overwinters in the second-instar larval stage. In the two-year cycle, the larvae feed a second summer in the third instar and overwinter in the fourth-instar stage (Miller, 1963; Shepard, 1961). Shepard stated that cool temperatures and a shorter growing season cause the second diapause.

The budworm completes its life cycle in one year in Montana. Adults emerge from their puparia in July or early August and live about two weeks, during which time they often are carried by wind up to 100 miles (Johnson, 1955; Mott, 1963).

Shortly after emergence, the female moths begin laying eggs on the underside of needles. In about ten days, the eggs hatch and larvae, approximately .5mm long, emerge. These first instar larvae seek a protective place to overwinter, such as under a bark scale, and then spin hibernacula. The larvae molt and overwinter in the second instar (Whiteside and Carolin, 1961).

Budworm larvae break hibernation when warm termperatures return in the spring; this usually occurs in May in Montana and Idaho.

Upon the opening of new buds, the larvae commence feeding on the new foliage, and develop to maturity through six or seven instars; this development period lasts about two months from the time hibernation ends. All of the tree damage caused by the spruce budworm occurs during the larval stage (Johnson, 1955).

The mature larvae pass into the pupal stage, where they rest in puparia for six to fifteen days while the adult features are formed. Emergence of the moth completes the life cycle.

Budworm mortality is dependent on a wide range of environmental conditions. Generally, most mortality can be expected between the time when the egg is deposited and when the first instar larvae enter into hibernation. Miller (1963) indicates that during this period, budworm will suffer about seventy percent mortality, most of this occurring when the larvae drop or disperse to non-host vegetation. Rather heavy losses also occur to the emerging second instar larvae and to the pupae.

II. THE SPRUCE BUDWORM IN BALSAM FIR

In eastern Canada, upper New England and New York, and the Lake States area, considerable research has been done on the spruce budworm and its control. Probably ninety percent of all literature on the budworm stems from studies conducted in these areas. This situation is mostly due to the fact that severe damage has occurred in balsam fir for a much longer time than in western Douglas-fir stands, and that until the past two decades, spruce budworm has had a much more severe economic impact on balsam fir than on Douglas-fir.

There is a long history of outbreaks of budworm in Eastern Canada and New England. Severe outbreaks occurred before 1800 in New Brunswick (Morris, 1963) and as early as 1807 in Maine (Bean and Waters, 1961). The most severe outbreak in the United States occurred from Minnesota to Maine between 1910 and 1926, resulting in the loss of an estimated forty-seven million cords of balsam fir (Bean and Waters, 1961). Budworm populations built up to epidemic proportions again in 1935 and since then have been a problem throughout the balsam fir region.

In 1945, the Department of Forestry in Canada initiated a program known as the "Green River Project" to study intensively the spruce budworm in Eastern Canada. In his introduction to a monograph on this research project, R. F. Morris (1963) outlined the need and scope for such a study:

> It was commonly observed after earlier outbreaks of the spruce budworm that the degree of tree mortality was related to certain edaphic features of the forest, the term edaphic being used very broadly to cover such factors as topography,

> forest continuity or isolation, stand type, composition and age, and the condition of the trees with respect to flower production. As some of these factors are susceptible to modification by man it was clear that a joint project involving research on insect population, silviculture, and forest management was needed to investigate the feasibility of reducing the frequency of outbreaks or the degree of damage through cultural methods. ...the problem might be defined simply as one of elucidating the relationships between tree defoliation or mortality as the dependent variable and all relevant edaphic factors as the independent variables. ...By itself, however, this approach would be inadequate because population density is not determined by edaphic factors alone. ...The entomological problem was therefore defined very broadly as one of ascertaining, and modelling mathematically if possible, the effect of all important factors on the survival rate of the spruce budworm. This included both the factors that determine changes in population from generation to generation in each stand and those that determine population differences from stand to stand.

The results of this intensive study confirmed earlier findings by Balch (1946), Blais (1957, 1961), Craighead (1924), Graham (1939), Graham and Orr (1940), deGryse (1944), McLintock (1947, 1948, 1949), McLintock and Westveld (1946), Turner (1952), and Westveld (1945, 1946) that highly susceptible conditions in balsam fir are represented by: (1) extensive, unbroken spruce-fir forests, (2) mature balsam fir, and (3) forests in which balsam fir is the predominant species. Steps recommended by these investigators to reduce budworm hazard generally aim at keeping the balsam fir young and vigorous, and preventing accumulation of fir over wide areas by utilizing the shortest rotation and smallest stem diameter possible. The most important of these recommendations are reviewed and summarized by Turner (1952).

Recognizing the importance of species composition, density, and age, several of the authors cited above have also presented methods for rating the estimated vulnerability of balsam fir stands, based on some combination of these stand characteristics and tree vigor. Most of these methods rely on ground surveys or cruise data (Balch, 1946; McLintock, 1949; Westveld, 1945). Morris and Bishop (1951) presented a method that fully utilizes aerial photographs and maps, and requires a small amount of field checking.

The success of classifying balsam fir stands for vulnerability to budworm attack is largely due to the uniformity in composition of the timber type over large areas, and to the stands being mostly evenaged. Equal success in Douglas-fir stands in the Northern Rocky Mountains might prove difficult due to the irregularity of timber types and frequency of mixed-aged stands.

III. THE SPRUCE BUDWORM IN DOUGLAS-FIR

Populations of spruce budworm probably have always existed in Douglas-fir stands (Terrell and Keefe, 1964), but no serious outbreaks were noted prior to one on Vancouver Island in 1909. The first serious recorded epidemic outbreak in the Western United States occurred in Northern Idaho in 1922. Since that time, budworm outbreaks have occurred in Douglas-fir stands, true fir stands, and occasionally in other timber types, throughout the Rocky Mountains (Whiteside and Carolin, 1961).

In 1923, an extensive stand of Douglas-fir was reputedly destroyed by spruce budworm in Yellowstone National Park. From 1932 to 1942, seventy-six infestations of budworm were reported in Montana and Northern Idaho forests. All of these subsided naturally without special control measures being applied (Johnson, 1955). In contrast to outbreaks in balsam fir, these infestations resulted in only slight tree mortality. Most damage was confined to the killing of tops and twig terminals.

Renewed outbreaks of budworm in Montana developed to economically important proportions in 1948, affecting over 400,000 acres of timber (Johnson, 1955). Extensive aerial spraying with DDT began in 1949, but did not prevent the infested area from increasing to over two million acres by 1953, and over five million acres by 1957 (McComb and Terrell, 1958).

The years of 1960 and 1961 were unusually warm and dry, favoring an abnormally high percentage survival of spruce budworm. The effect of the dry weather was especially notable in Douglas-fir stands east of the Continental Divide in Montana, where whole townships of timber were killed (Terrell, 1963). This was one of the first incidents of widespread mortality in Douglas-fir.

These two dry years apparently influenced the outbreak of budworm on the north half of the University of Montana's Lubrecht Experimental Forest, thirty miles east of Missoula. A static population of budworm existed on the south portion of Lubrecht Forest and extended into the Garnet Mountains. Another small area was infested four miles west of the Forest. During 1960 and 1961, budworm presumably spread from these areas into the portion of Lubrecht Forest north of Montana Route 20. (see Figure 2, page 15). By 1964, much of this area, including the study area for this investigation, was classed from Forest Service aerial survey as being heavily infested. Although many areas in Western Montana showed some decline from budworm outbreaks in 1965, the outbreak on Lubrecht Forest had increased somewhat in severity.[2]

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[2] Personal communication with T.T. Terrell, U.S. Forest Service, Missoula, Montana.

Evidence of the duration of the outbreak on Lubrecht Forest was obtained from personal observations and from examination of damage to Douglas-fir branches. Reduction in radial growth was not evident in 1965, due to the short duration of the outbreak at that time.

The process of spruce budworm dispersal is rather complex and not fully understood. Greenbank (1963), Mott (1963), and Morris (1963) discuss the effect of the environment and of foliage depletion in dispersing the population of insects. In some stands, prevailing winds or timber type may exert the most influence on the dispersal pattern of the budworm, while in other stands or even in the same stands at a different time, competition for food may be the primary cause forcing the budworm population to spread from the epicenter of the outbreak.

Research on the Rocky Mountain form of the spruce budworm has been and is still being conducted primarily by federal agencies in both Canada and the United States. In the United States, most of the research has been done by personnel of the U.S. Forest Service experiment stations. Until quite recently, these Forest Service researchers devoted most of the time spent on the budworm to making damage surveys and studying methods of direct control of outbreaks with insecticides. Government entomologists, however, are now making intensive investigations into the biology of the western spruce budworm, and into host-predator and predator-parasite relationships.

From the damage surveys and population studies has come some useful guidelines and observations. Terrell (1959) reported that populations of budworm was higher on ridges than in creek bottoms in Montana, but that there was no difference between south and north slopes.

In other reports, Terrell suggested that damage is less along creek bottoms because of higher site quality and soil moisture (Terrell, 1965; Terrell and Keefe, 1965).

These observations may prove correct. A cursory examination of spruce budworm damage-survey maps prepared by the U. S. Forest Service for Region One shows most of the worst outbreaks to have occurred in southwestern, central, and southern Montana forests. The Douglas-fir forests in northwestern Montana and northern Idaho have not had nearly as severe or widespread infestations; a fact perhaps attributable to the better site quality and cooler, moister climate of this area.

The most severely defoliated size of Douglas-fir are those that are less than twenty feet tall (Whiteside and Carolin, 1961). Terrell and Keefe (1965) have made the observation that mortality is very high in the understory on all but the very best quality sites. No statistical evidence was presented to support this observation, however.

In a study of the budworm in Eastern Oregon, Williams (1963) attempted to determine if spruce budworm damage could be adequately estimated from ground observation for damage survey purposes. Four damage classes were established, with trees being classified on general appearance of the crown, extent of adventitious branching, health of the top, and amount of new foliage being grown. Analysis showed that if the observer used binoculars and observed the tree from the sunny side on a clear day, that these criteria could be used to classify tree damage as light, medium, or heavy.

The usefulness of this type of damage rating system is questionable. The U. S. Forest Service has been mapping budworm damage with similar accuracy from aerial reconnaisance flights and at a per acre cost that is much lower than could be achieved using ground surveys.

A review of the literature indicates that no research has been done to determine quantitatively the effect that crown closure, stand stocking, percent Douglas-fir, or site quality has on spruce budworm damage or mortality in Douglas-fir stands. This investigation will approach this problem.

FIGURE 1

AREA OF HEAVY DEFOLIATION ON LUBRECHT FOREST

CHAPTER III

STUDY AREA DESCRIPTION AND SELECTION

I. DESCRIPTION

The investigation was conducted on an area encompassing 2,500 acres of mixed second-growth ponderosa pine and Douglas-fir stands. This area is located approximately twenty-six miles east of Missoula, Montana in sections 4, 5, 6, 7, and 8 in Township 13 North and Range 15 West. About 2,200 of these acres lie within the boundaries of the Lubrecht Experimental Forest. The remaining 300 acres are on adjacent private land. The study area location is shown in Figure 2, page 15.

The topography is characterized by low-relief mountains and very small intermittent streams. The ridges shown in the photograph of the study area (Figure 3) rise about 500 to 800 feet above the stream beds. Gradients are generally less than five percent (two degrees) along the creeks and thirty to sixty percent (thirteen to twenty-seven degrees) on the hillsides. Elevations range from about 3,000 feet to 5,100 feet above sea level.

Soils in the stream beds consist mainly of alluvial deposits that are moist, deep, fine-textured, but fairly well drained. The adjacent stream terraces are also alluvial, but are coarse-textured and well drained. On the steeper ridges, soils are shallow, often poorly developed, and rocky (Brenner, 1964).

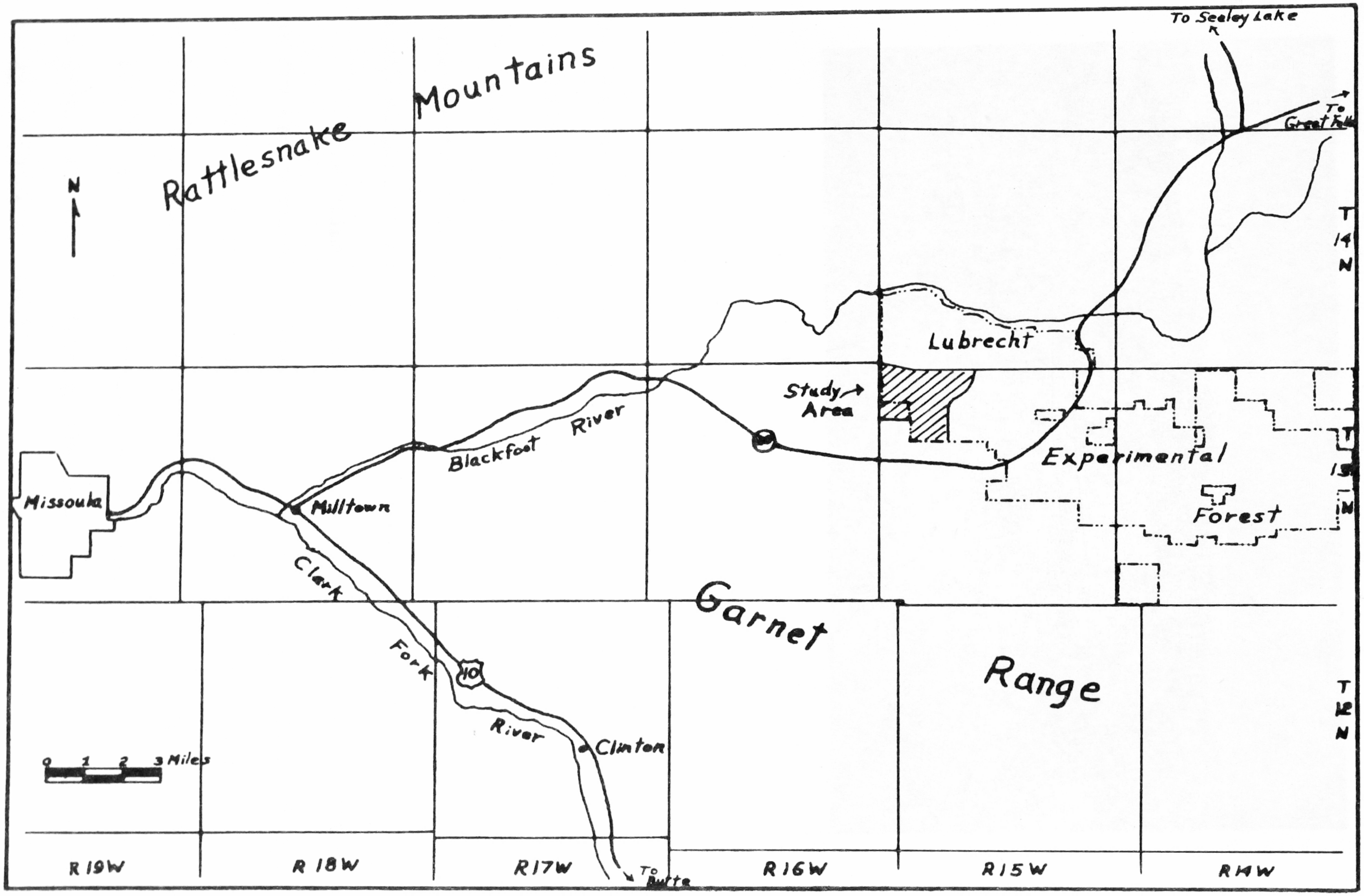


FIGURE 2

MAP OF STUDY AREA LOCATION

FIGURE 3

GENERAL VIEW OF STUDY AREA, LOOKING SOUTHWEST

The best sites are found along the creek bottoms (lower center in Figure 3), while the poorest sites occur on the ridges where soil moisture is low (upper right in Figure 3). Site indexes, based on the height of Douglas-fir at an age of fifty years, range from about forty on steep south slopes, to seventy along the lower stream beds.

The climate of most of Lubrecht Forest might be best described as dry and temperate. Weather records kept at the Greenough Post Office, four miles east of the study area, show an average annual temperature of 39.2°F., ranging from a mean monthly temperature of 16.9°F in January, to 62.9°F. in July. Precipitation averages 17.64 inches annually. It is evenly distributed through the year, falling as snow from November to April (Steele, 1965).

Greenbank (1963) found that the best relationship between the daily catch of adult budworm in flight and weather was provided by minimum relative humidity. At Lubrecht Forest, a low day time relative humidity prevails from May through September. The average daily minimum relative humidity for these months is 31.4 percent, dropping below thirty percent on 89 of the 153 days (Steele, 1965)

Wind at the Greenough Post Office averages only 1.2 miles per hour (Steele, 1965). Occasional gusty winds associated with passing storms are about the only disturbance of otherwise calm summer days.

II. STAND DESCRIPTION AND HISTORY

Logging operations by the Anaconda Mining Company in 1904 and 1905 removed almost all of the old-growth Douglas-fir and ponderosa pine from the western portion of Lubrecht Forest (Cauvin, 1961). Skidding was done by horses, and slash was scattered, rather than burned, thus apparently permitting survival of much of the regeneration that had become established under the old-growth trees. Annual ring counts on many dominant and codominant trees in the present stand suggest that establishment began five to fifteen years prior to the 1905 logging operations. The present stand is best described as even-aged; most overstory trees are now fifty to seventy years old.

The area is well stocked, except in section five, where most of the south facing slope is poorly stocked. Throughout the study area, there are numerous thickets of both ponderosa pine and Douglas-fir that consist of suppressed saplings. These patches of trees are frequently interspersed with openings, one-fifth to one-half acre in size. Tree reproduction is light, averaging roughly fifty seedlings per acre, two-thirds of which is Douglas-fir. Brush cover is light.

III. SELECTION OF THE STUDY AREA

The selection of the western portion of Lubrecht Forest as the study area was based on the following criteria:

1. A wide variety of stand composition and densities were available within a small area on nearly even-aged timber.
2. The site quality and timber age and type were typical of many budworm-infested areas of Montana.
3. The outbreak of spruce budworm had continued for at least three years, giving opportunity for all Douglas-fir in the area to become infested.
4. No aerial spraying of insecticides had been done to reduce the budworm population on Lubrecht Forest.
5. No previous infestation of the stand by the budworm is known to have occurred.
6. The area was readily accessible and in close proximity to Missoula.

In analysis of the data, it was assumed that all Douglas-fir studied were equally exposed to the impact of the budworm outbreak, and that the damage to a tree varied from that of other trees because of factors other than proximity to the outbreak center. By selecting an area that was small and where the budworm population build-up was essentially uniform, it is hoped that the magnitude of the error in these assumptions has been minimal. Noting the pattern of outbreak and observing the duration of defoliation in the study area, these assumptions seem realistic.

CHAPTER IV

EXPERIMENTAL DESIGN

I. SAMPLING DESIGN

During the summer of 1965, field observations were made on 382 systematically located plots. For each plot, site quality, percent crown closure, stand density, percent Douglas-fir, and average percent of defoliation was estimated. The number of plots to be sampled was determined by three criteria:

1. A minimum of at least five plots for every combination of the classes of site (three classes), crown closure (four classes), and percent Douglas-fir (five classes).
2. The amount of variation estimated to occur between plots of similar composition, site, and stocking.
3. The amount of time available to collect data.

Initially, sample plots were located along north-south oriented lines in each section of land within the study area. Lines were spaced fifteen chains apart, with the first line in each section being placed ten chains from the most accessible section corner or quarter corner. The first plot on each line was located one chain from the base section line, and each plot thereafter, three chains from the previous plot. With this spacing on a line one mile long, twenty-seven sample points could be located.

After sampling the whole study area with this spacing of plots, there remained a need for more data from land classed as having a site index of sixty. To fill this need, additional plots were located on lines that were located between the first set of lines sampled. This additional sampling resulted in extra plot data being collected on site 40 and site 50 areas. All of the plot centers were marked with plastic flagging; none were permanently marked.

II. MEASUREMENT OF THE VARIABLES

Independent variables.

Site. Site quality was expressed as an index based on the average height of the dominant or codominant second-growth Douglas-fir at an age of fifty years. Tree age was determined by extracting a core of wood with an increment borer at breast height on one or more trees located near the plot center, and counting the number of annual rings on the core. Ten years were added to the ring count for the average number of years required for a Douglas-fir on Lubrecht Forest to grow to breast height.

The height and age of each bored tree was applied to site index curves prepared by the U.S. Forest Service for second growth Douglas-fir in Region One. If the index of a tree was between two site classes, additional trees were measured until the site index of the plot was definitely established.

Because plots were only three chains apart, it was not necessary to measure the site index of every plot. In this area, the site was fairly homogeneous, with most of the creek bottom-land being classified as site 60 and the remainder of the area as site 40 or 50. One-hundred and three trees were measured for site index determination on 90 plots; site index was estimated on the other plots.

Stand stocking. Stand stocking was determined at each sample point by (1) measuring basal area per acre, and (2) counting the number of stems on a twenty-foot fixed radius plot.

Basal area per acre was readily determined at each plot center by using a Spiegel-Relaskop. The number of "in" trees counted, multiplied by basal area factor (BAF) used equals basal area per acre. A 20 or 40 BAF was used in heavily stock stands, and in open stands, a 5 or 10 BAF was used. By selecting the appropriate BAF at each plot center, an average of six to eight trees were counted per plot. Basal area per acre was recorded separately for each species.

To determine the number of stems, a count was made by species of all trees over six feet tall and not more than twenty feet from the center of each plot. The size of the stems was not recorded.

Crown closure. Crown closure refers to "the proportion of the ground area covered by the vertical projection of the canopy" (Society of American Foresters, 1958). Several tools have been devised to measure crown closure. The one used in this study was a pocket-sized spherical densiometer developed by P. E. Lemmon (1957). Crown closure readings from the reflecting mirror of the densiometer are readily expressed as percent of total crown closure. At each plot center, four readings were made, one while facing in each cardinal direction. This took no more than four minutes to do. Readings were recorded to the nearest four percent and then averaged to get a single value for each plot.

Percent Douglas-fir. Percent Douglas-fir was determined by two methods. The first method expressed as a percent of the total, the number of

Douglas-fir trees counted on the twenty-foot radius plot.

In a similar fashion, the second method expressed the percent of the basal area of the stand that was Douglas-fir. As with the first method mentioned, no additional data had to be collected for this determination. The percent Douglas-fir by basal area per acre was easily calculated by expressing as a percent of the total, the number of Douglas-fir stems counted as "in" with the Relaskop.

Tree height and crown length. Total tree height and crown length were measured for each tree counted as "in" with the Relaskop. Using the Relaskop at one chain distance from the tree, height was measured to the nearest ten feet and crown length to the nearest five feet.

Dependent variable (percent defoliation).

Although defoliation is not perfectly correlated with spruce budworm populations and is not a complete expression of the total damage done to the forest, it is a valuable index of the general impact of a budworm outbreak.

Accurate measurement of defoliation is very slow and difficult. Fortunately, the tedium of measuring needle loss directly can be avoided by using the curvilinear regression shown in Figure 4. The curve was prepared by the U.S. Forest Service and published in Research Note 86 (Terrell, 1961). With this curve, it is necessary to only determine the percent of shoots that show no loss of current needle growth; a great savings of time in the field was thus achieved.

The percent of shoots showing no current defoliation was carefully estimated for each Douglas-fir sampled with the Relaskop. A seven-power binocular was used to examine the crown of trees over fifteen feet tall; trees shorter than this were examined without aid of a binocular. Shoots were selected for examination from the middle one-third of the crown on all sides of the tree. The initial practice of averaging the percent of undamaged shoots of each third of the crown was abandoned upon observing that this average was not significantly different from the value obtained from the middle one-third only. This observation has been noted and statistically confirmed by Terrell (1961).

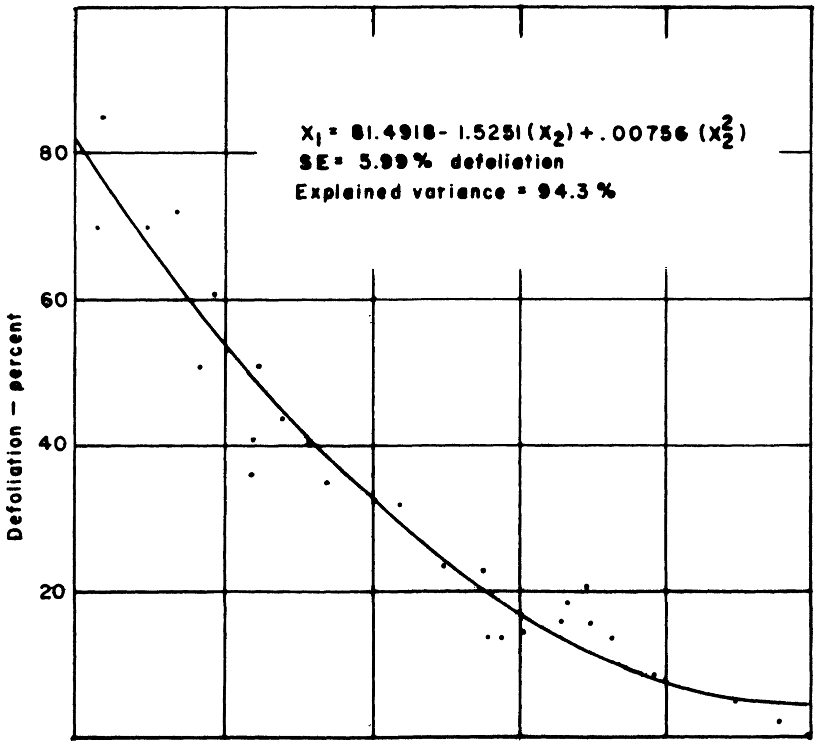


FIGURE 4

RELATION OF DEFOLIATION TO UNDAMAGED SHOOTS
(From Research Note 86, by Terrell
(1961))

In the understory, the six nearest trees, regardless of species, not over one chain from plot center, and not over two inches in diameter, were recorded by species and by height to the nearest foot. Of these six trees, any that were Douglas-fir were carefully examined to determine percent defoliation. In most cases, the crowns of these trees were short enough to allow examination of the whole crown, rather than just a portion.

Average overstory defoliation for each plot was obtained by averaging the defoliation of all of the Douglas-fir included in the variable plot sample. The average defoliation of the understory on each plot was similarly determined from Douglas-fir trees under two inches in diameter. Average understory defoliation was not computed for those plots that did not have Douglas-fir reproduction within one chain of plot center.

III. COMPUTER ANALYSIS

Most statistical computations were done by an electronic computer. Computations for using the Duncan Multiple Range test were done on a desk calculator.

FIGURE 5

A DOUGLAS-FIR SHOWING VERY HEAVY DAMAGE

CHAPTER V

RESULTS

I. RELATION OF STAND CONDITIONS TO OVERSTORY DEFOLIATION

For an analysis of variance of overstory defoliation, 300 plots were selected from the 382 plots that were measured. There were a maximum of only five plots for each combination of percent Douglas-fir class, crown closure class, and site class. Plots in excess of this number were randomly withdrawn from the sample so that the variance analysis could be conducted on an equal number of repetitions of each class. This procedure removed 82 plots from the total number of plots measured, leaving 300 for testing.

On these 300 plots, defoliation of the overstory averaged 44.1 percent. In Table II, average percent defoliation is given by site class, percent Douglas-fir class, and crown closure class, with 100, 60, and 75 plots used per class, respectively, in computing the averages.

TABLE II

AVERAGE OVERSTORY DEFOLIATION, LISTED BY SITE, CROWN CLOSURE, AND PERCENT DOUGLAS-FIR CLASSES

Site Index	Average Percent Defoliated	Percent Crown Closure	Average Percent Defoliated	Percent Douglas-fir*	Average Percent Defoliated
40	47.8	0-25	35.4	0-20	26.2
50	53.0	26-50	47.6	21-40	35.2
60	31.4	51-75	48.7	41-60	50.2
		76-100	44.7	61-80	54.7
				81-100	54.2

*Percent Douglas-fir was determined by computing basal area per acre.

To aid in stabilizing the variance that is usually associated with a wide range of percentages, a transformation of the percentages to angles by the formula

$$\text{Angle} = \text{Arcsin}\ \sqrt{\text{Percentage}}$$

is recommended (Steel and Torrie, 1960). Transformed values of percent defoliation were used in all analyses of variance. Figures 6, 7, 8, 10, and 11, therefore show transformed values of defoliation, rather than percent defoliation.

A Duncan multiple range test was made of the variation between treatment means. The difference required to show significance at a 99 percent level of confidence between a given number of means, is shown in the form of bars on each bar graph of group averages (Figures 6, 7, 8, 10, and 11).

Site quality.

The analysis of variance in Table III shows that a highly significant difference in defoliation exists between sites.

TABLE III

ANALYSIS OF VARIANCE OF OVERSTORY DEFOLIATION, FOR THREE LEVELS OF SITE QUALITY

Source	Sum of Squares	D.F.	Mean Squares	F. Ratio	Signif.
Total	104,286.68	299			
Treatment	11,246.02	2	5,623.01	17.95	**
Residual	93,040.66	297	313.27		

**Highly significant difference (.99 probability)

Figure 6 on page 29, shows that the difference between site 40 and site 50 is not significant at the 99 percent confidence level, but that there is a highly significant difference between sites 40 and 60, and between sites 50 and 60.

Percent Douglas-fir.

The analysis of variance in Table IV shows that a highly significant difference in defoliation exists between classes of percent Douglas-fir. Figure 7 on page 30, indicates that there is no significant difference between the percent Douglas-fir classes 41-60, 61-80, and 81-100. This suggests that stands containing over forty percent Douglas-fir suffer about the same degree of defoliation by the spruce budworm. Below forty percent, defoliation decreases at approximately the same rate as percent Douglas-fir decreases.

TABLE IV

ANALYSIS OF VARIANCE OF OVERSTORY DEFOLIATION, FOR FIVE CLASSES OF PERCENT DOUGLAS-FIR

Source	Sum of Squares	D.F.	Mean Squares	F Ratio	Signif.
Total	104,286.68	299			
Treatment	18,616.67	4	4,654.17	16.03	**
Residual	85,670.01	295	290.41		

** Highly significant difference (.99 probability)

Figure 7 also indicates that similar results can be obtained using either basal area or number of stems to determine percent Douglas-fir. Coefficients of correlation for these two methods (Table V, page 32) suggest that slightly better correlation of defoliation to percent Douglas-fir might be obtained by using basal area. However, computed

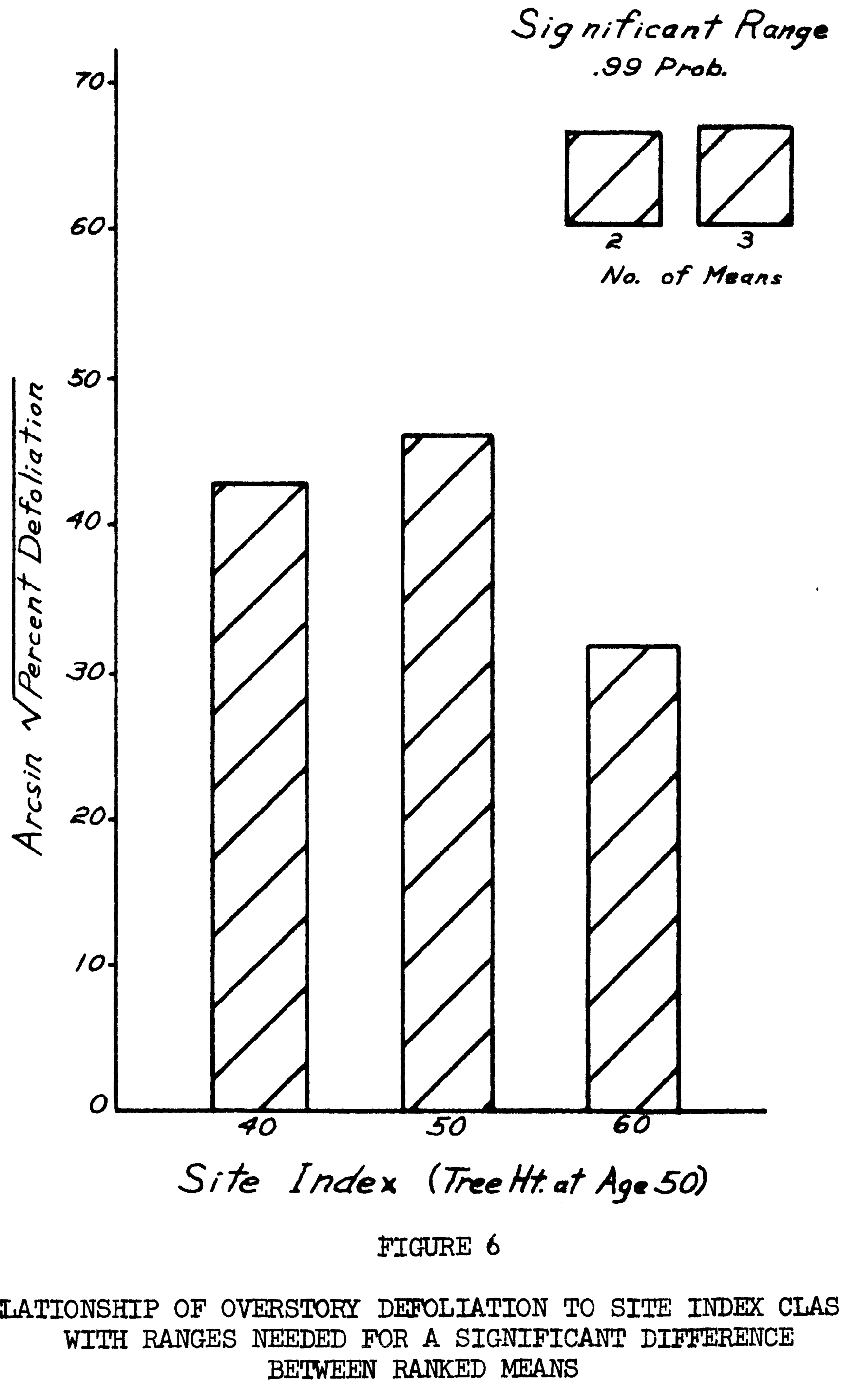


FIGURE 6

RELATIONSHIP OF OVERSTORY DEFOLIATION TO SITE INDEX CLASS, WITH RANGES NEEDED FOR A SIGNIFICANT DIFFERENCE BETWEEN RANKED MEANS

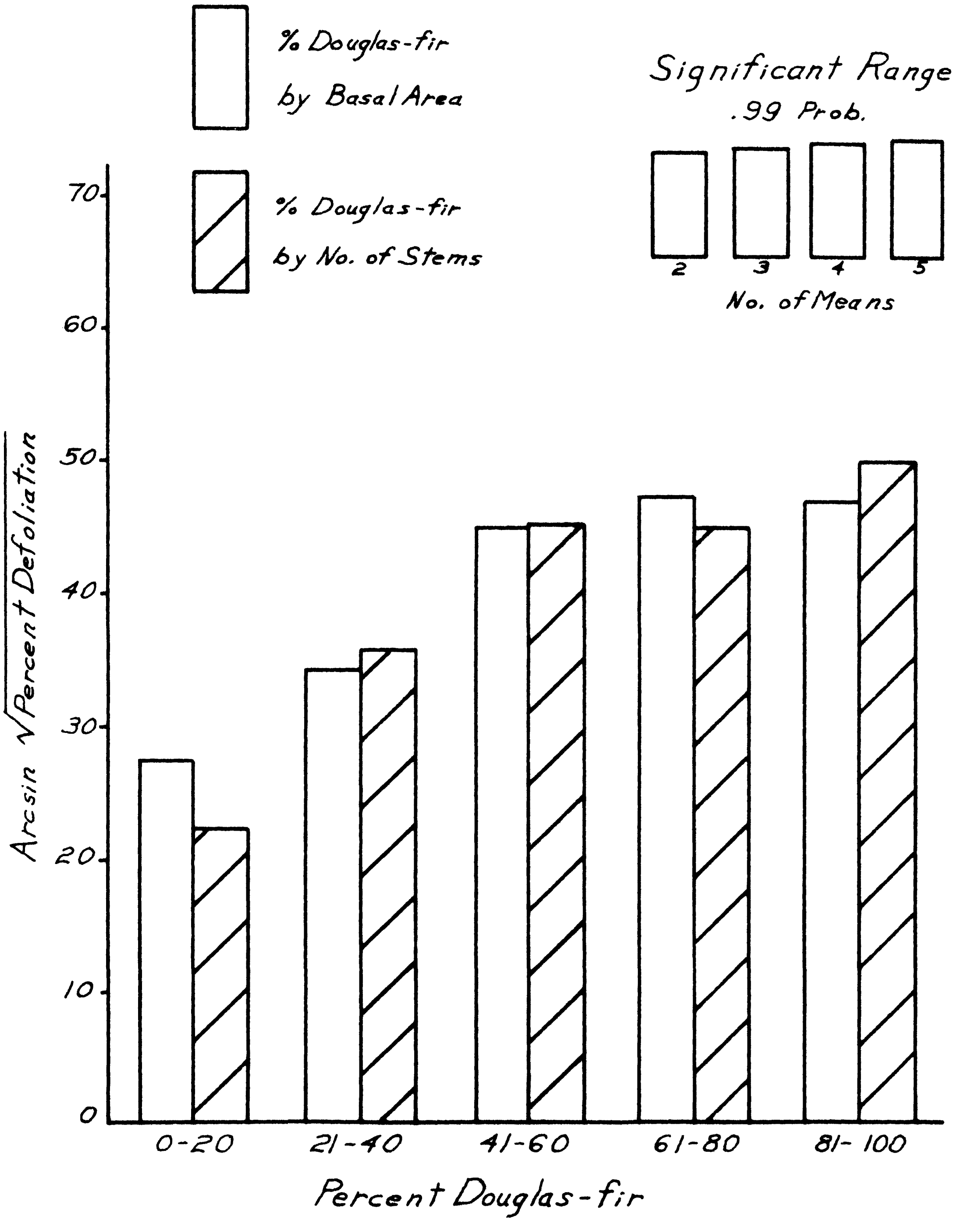


FIGURE 7

RELATIONSHIP OF OVERSTORY DEFOLIATION TO PERCENT DOUGLAS-FIR CLASSES, USING TWO METHODS TO DETERMINE PERCENT DOUGLAS-FIR "t" values show the slight difference in coefficients to be not statistically significant.

TABLE V

COEFFICIENTS OF CORRELATION* OF PERCENT DOUGLAS-FIR TO BUDWORM DEFOLIATION

Method of Determining Percent Douglas-fir	Site 40 & 50	Site 60
Basal Area	.406812	.602324
Number of Stems	.358171	.497316
Student's t	.70 (n.s.)	.82 (n.s.)

*These coefficients are based on the regression, $Y=aX^b$; other lines of regression tested yielded less significant correlation coefficients.

Crown closure.

The analysis of variance in Table VI shows that there is a very significant difference in defoliation between classes of crown closure.

TABLE VI

ANALYSIS OF VARIANCE OF OVERSTORY DEFOLIATION, FOR FOUR CLASSES OF CROWN CLOSURE

Source	Sum of Squares	D.F.	Mean Squares	F Ratio	Signif.
Total	104,286.68	299			
Treatment	3,595.76	3	1,198.59	3.52	**
Residual	100,690.92	296	340.17		

**Very significant difference (.98 probability)

Results shown in Figure 8 on page 34, and in Figure 9 on page 35, indicate that there is no significant difference in defoliation between crown closure classes, 26-50, 51-75, and 76-100 percent, but that defoliation of Douglas-fir in stands having 0-25 percent crown closure is significantly less than of the other classes.

Although the correlation coefficients of the curves shown in Figure 9 are quite low, they are the highest that could be obtained, using three methods of estimating stand stocking (number of stems, basal area, and crown closure), and three different equations ($Y=a+bX$, $Y=a+bX+cX^2$, and $Y=aX^b$).

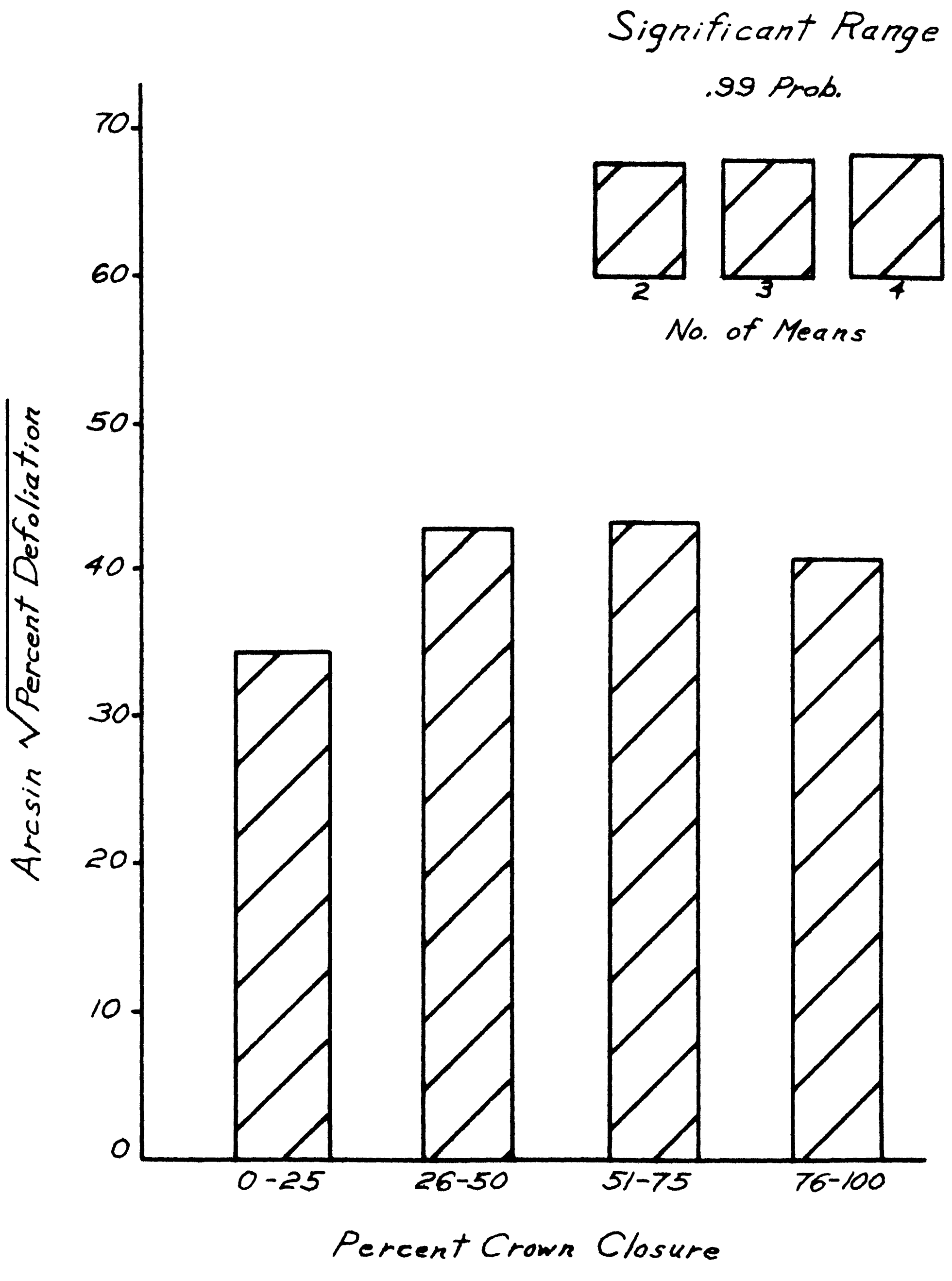


FIGURE 8

RELATIONSHIP OF OVERSTORY DEFOLIATION TO CROWN CLOSURE CLASS, WITH RANGES NEEDED FOR A SIGNIFICANT DIFFERENCE BETWEEN RANKED MEANS

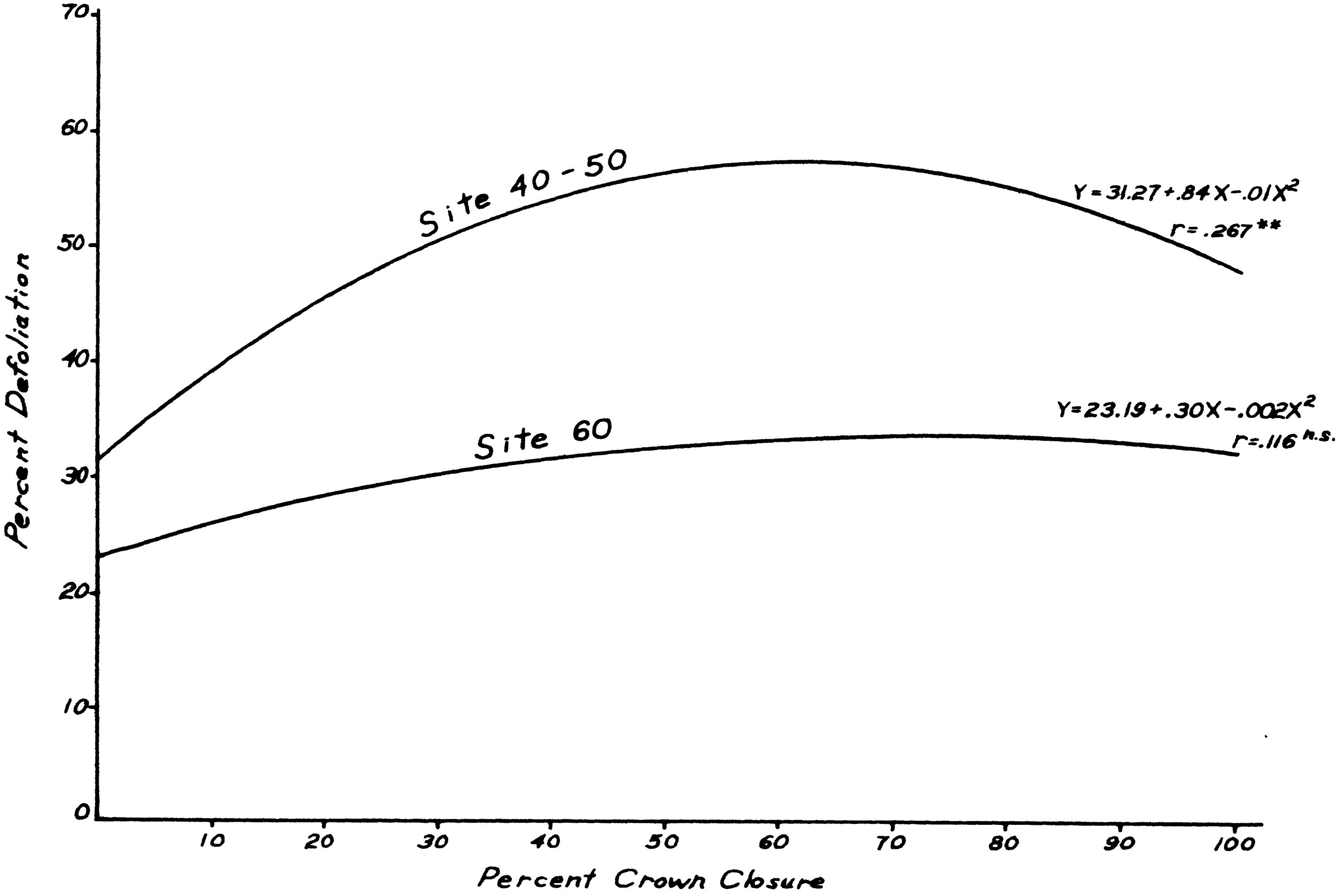


FIGURE 9

REGRESSION OF DEFOLIATION ON CROWN CLOSURE

Stand density.

Stand density was expressed in terms of basal area and number of stems. In Table VII are listed the coefficients of correlation by site class and form of regression tested.

TABLE VII

COEFFICIENTS OF CORRELATION OF STAND DENSITY TO DEFOLIATION

Method of Determining Stand Density	Site Class	Form of Regression		
		$Y=a+bX+cX^2$	$Y=a+bX$	$Y=aX^b$
Number of Stems	40-50	.0969	.0554	.0069
	60	.0728	.0139	.0430
Basal Area	40-50	.0869	.0078	.0362
	60	.0655	.0008	.0679

None of the coefficients in Table VII are statistically significant. However, by using only data from plots on sites 40 and 50, and plots that had over ten stems counted, coefficients were raised from .0969, .0554, and .0069, to .1917, .1841, and .2133 respectively; the last three are significant at the .95 level of conficence. This change in values suggests that the low coefficients were partly the result of sample plots being too small.

II. RELATION OF STAND CONDITIONS TO UNDERSTORY DEFOLIATION

Damage to the understory was analyzed by the same method as for the overstory except that data from only 180 plots were used. Extra replications were randomly eliminated from the analysis.

Average defoliation on these plots was 51.4 percent. In Table VIII, average defoliation is given by site class, crown closure class, and percent Douglas-fir class, with 60, 45, and 34 plots used per class, respectively, in computing the averages.

TABLE VIII

AVERAGE UNDERSTORY DEFOLIATION, LISTED BY SITE, CROWN CLOSURE, AND PERCENT DOUGLAS-FIR CLASSES

Site Index	Average Percent Defoliated	Percent Crown Closure	Average Percent Defoliated	Percent Douglas-fir*	Average Percent Defoliated
40	53.2	0-25	29.7	0-20	33.9
50	53.4	26-50	57.2	21-40	43.5
60	47.6	51-75	60.0	41-60	53.9
		76-100	58.8	61-80	66.2
				81-100	59.6

*Percent Douglas-fir was determined by computing basal area per acre.

Site.

The analysis of variance in Table IX shows that no significant difference in defoliation exists between sites.

TABLE IX

ANALYSIS OF VARIANCE OF UNDERSTORY DEFOLIATION, FOR THREE LEVELS OF SITE QUALITY

Source	Sum of Squares	D.F.	Mean Squares	F Ratio	Signif.
Total	67,616.56	179			
Treatment	580.03	2	290.01	.77	no
Residual	67,036.53	177	378.73		

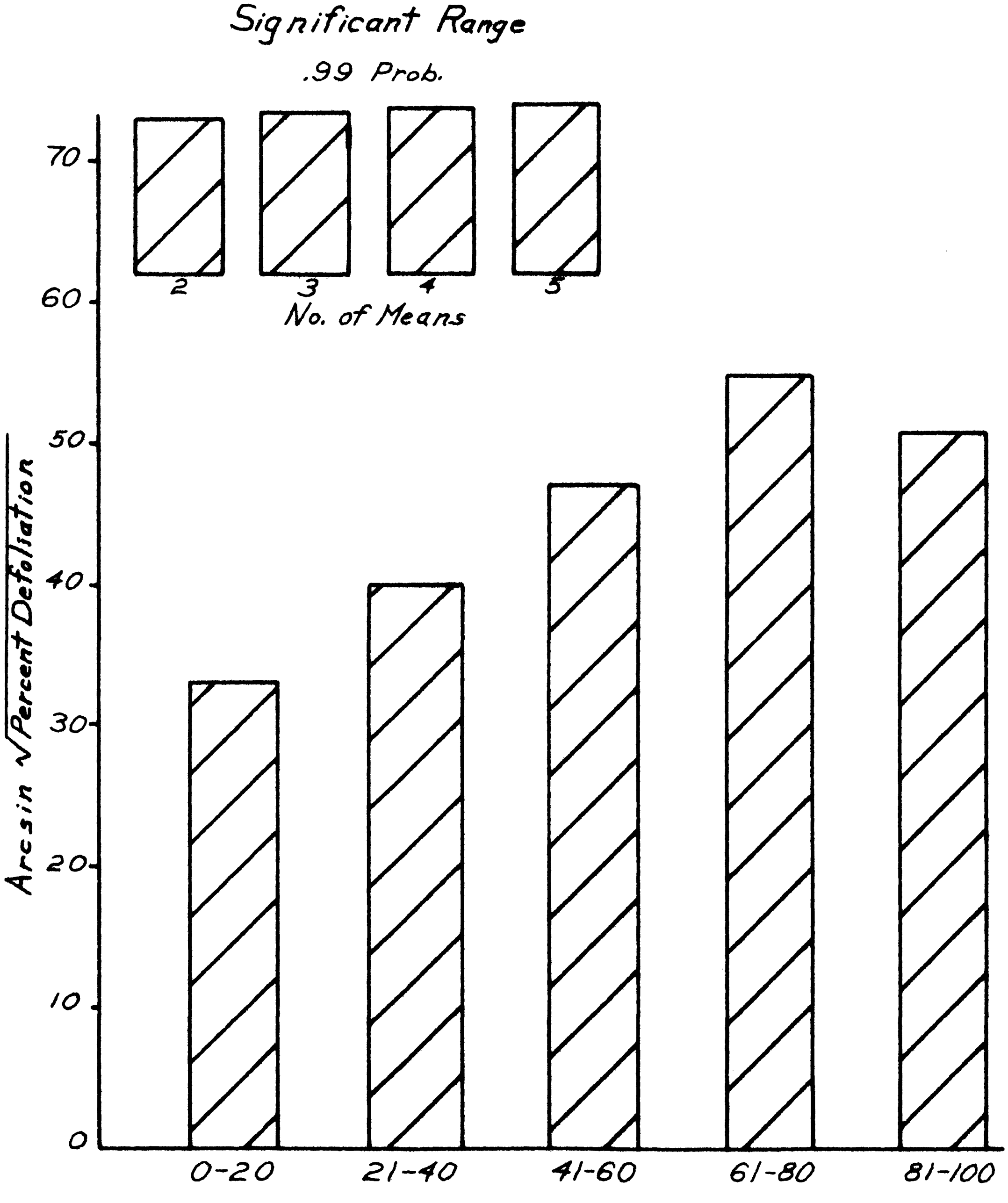


FIGURE 10

RELATIONSHIP OF UNDERSTORY DEFOLIATION TO PERCENT DOUGLAS-FIR WITH RANGES REQUIRED FOR A SIGNIFICANT DIFFERENCE BETWEEN RANKED MEANS

Percent Douglas-fir.

The analysis of variance in Table X shows that there is a highly significant difference between classes of percent Douglas-fir.

TABLE X

ANALYSIS OF VARIANCE OF UNDERSTORY DEFOLIATION, FOR FIVE CLASSES OF PERCENT DOUGLAS-FIR

Source	Sum of Squares	D.F.	Mean Squares	F Ratio	Signif.
Total	67,616.56	179			
Treatment	10,971.80	4	2,742.95	8.47	**
Residual	56,644.76	175	323.68		

**Highly significant difference (.99 probability)

Crown closure.

The analysis of variance in Table XI shows a highly significant difference in defoliation to exist between classes of crown closure.

TABLE XI

ANALYSIS OF VARIANCE OF UNDERSTORY DEFOLIATION, FOR FOUR CLASSES OF CROWN CLOSURE

Source	Sum of Squares	D.F.	Mean Squares	F Ratio	Signif.
Total	67,616.56	179			
Treatment	12,053.83	3	4,017.94	12.73	**
Residual	55,562.73	176	315.70		

**Highly significant difference (.99 probability)

Figure 11 shows that defoliation of the understory responds

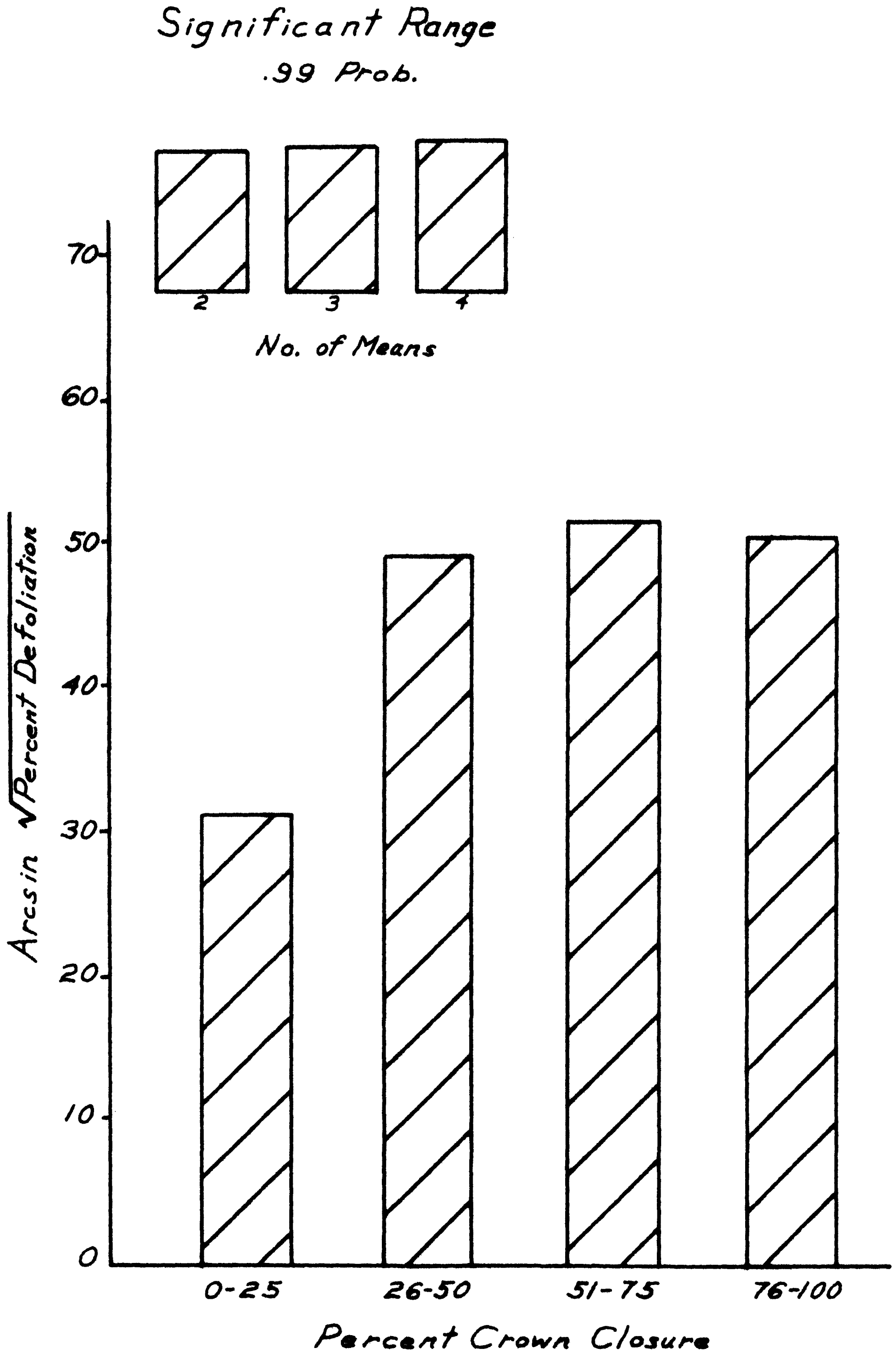


FIGURE 11

RELATIONSHIP OF UNDERSTORY DEFOLIATION TO CROWN CLOSURE, WITH RANGES REQUIRED FOR A SIGNIFICANT DIFFERENCE BETWEEN RANKED MEANS to change in crown closure in nearly the same pattern as does overstory defoliation. The only important difference noted is that defoliation is about ten percent higher on the understory between 25 and 100 percent crown closure.

III. RELATION OF TREE HEIGHT AND CROWN LENGTH TO DEFOLIATION

As tree height increases, defoliation decreases. This relationship is illustrated in Figure 12 on page 42, with lines of regression shown by site class, and also for all sites combined. The skewed angle of the regression for site 40 is probably the result of the low correlation on that site of tree height to defoliation.

Although the correlation coefficients of the other regressions in Figure 12 are statistically significant, they are quite low. The low values can likely be attributed to the tremendous variation in defoliation for a given tree height, caused by such stand conditions as crown closure, site quality, and stand composition.

Two tests were made to determine if crown length might have some relationship to defoliation. In the first test, an analysis of variance was made for 10, 20, and 30 foot crown length classes on trees thirty to forty feet tall, on poor sites. The computed F ratio, shown in Table XII, was not significant. Average defoliation of the three classes was 58.3, 65.9, and 63.4 percent, respectively.

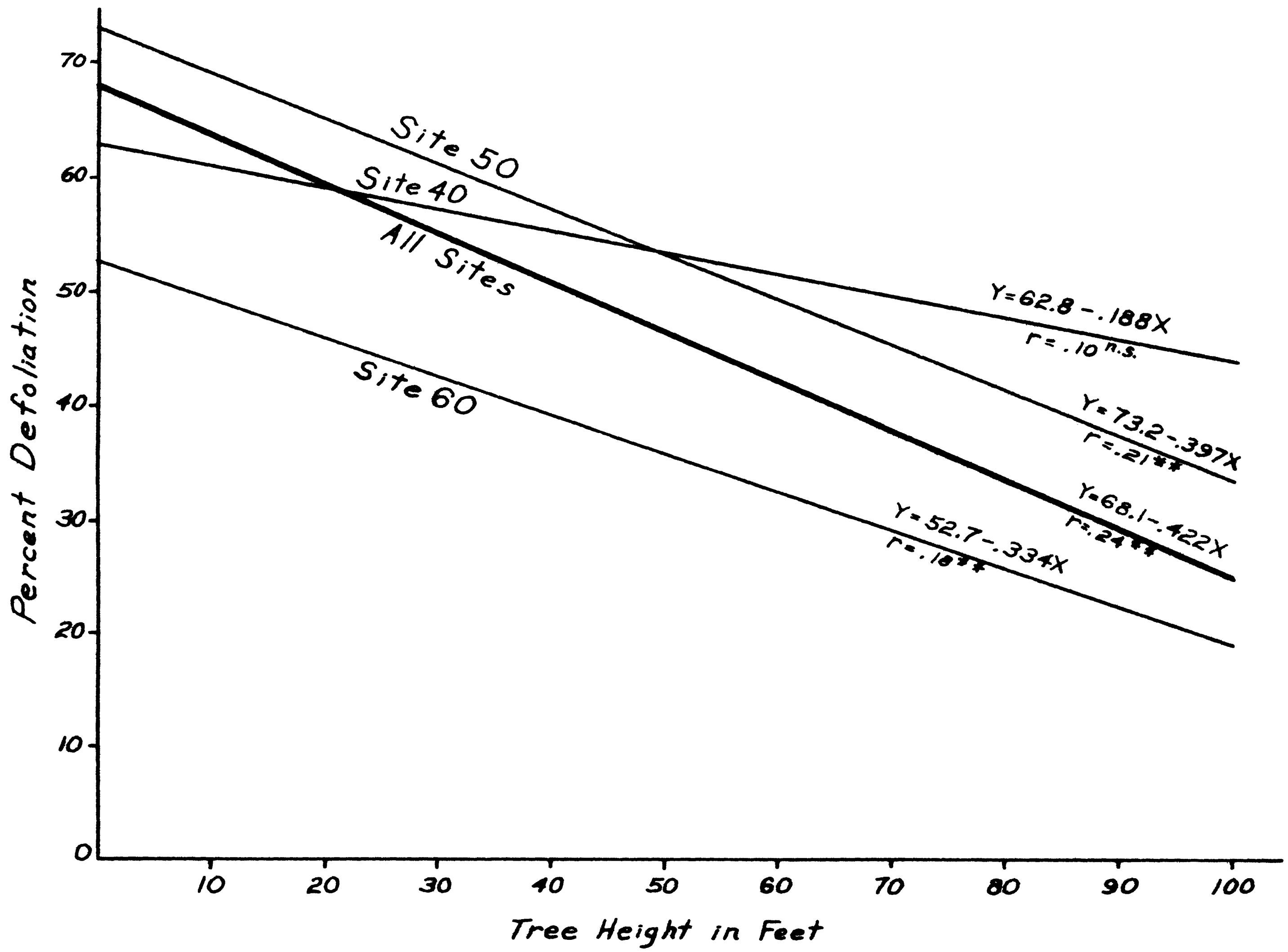


FIGURE 12

REGRESSION OF DEFOLIATION ON TREE HEIGHT

TABLE XII

ANALYSIS OF VARIANCE OF OVERSTORY DEFOLIATION, FOR THREE CLASSES OF CROWN LENGTH ON TREES 30 FEET TALL

Source	Sum of Squares	D.F.	Mean Squares	F Ratio	Signif.
Total	18,945.74	89			
Treatment	429.16	2	214.58	1.01	no
Residual	18,516.58	87	212.83		

The second test was made on trees 40 to 50 feet tall for crown lengths of 20, 30, and 40 feet. As in the first test (Table XII), Table XIII shows these results also to have no significance. Average defoliation of the three classes was 57.4, 66.0, and 56.4 percent, respectively.

TABLE XIII

ANALYSIS OF VARIANCE OF OVERSTORY DEFOLIATION, FOR THREE CLASSES OF CROWN LENGTH ON TREES 40 FEET TALL

Source	Sum of Squares	D.F.	Mean Squares	F Ratio	Signif.
Total	27,291.86	101			
Treatment	106.14	2	53.07	.19	no
Residual	27,185.72	99	274.60		

CHAPTER VI

DISCUSSION

I. FIELD TECHNIQUES

Use of the spherical densiometer.

Some of the field work might have provided less variable data had certain modifications been made in techniques. The use of the spherical densiometer to determine crown closure is a good example.

As explained previously, a crown closure reading was made with a spherical densiometer in each cardinal direction from the plot center, and these averaged to arrive at a mean crown closure value for the plot. When the center happened to be in the middle of a small open area that was entirely encompassed by dense Douglas-fir stands, or when the plot center was directly under a tree that stood solitarily in a meadow, very misleading crown closure readings were obtained. The variation caused by this error in sampling should have been remedied by taking the four readings at least twenty feet from the plot center in their respective cardinal directions.

Another problem encountered in using the spherical densiometer is that crown closure readings vary with change in tree height. Considerable sampling error can result from this cause in stands which lack uniform height. The problem might be avoided by determining crown closure from aerial photographs. However, due to the uniformity of the stand heights within the study area, and to the difficulty in accurately locating plot center on photographs, the use of aerial photographs does not seem to have been warranted for this study.

Variable plot sampling.

Use of the Relaskop greatly accelerated field sampling, especially in determining basal area and in selecting trees to be measured for defoliation. In open stands, however, optical limits of the Relaskop often permitted only one or two trees to be sampled. The resulting small size of the sample consequently increased the sample error of the computed percent Douglas-fir,and the error of the average plot defoliation percentage. For example, in an open stand that was actually composed of twenty-five percent Douglas-fir and had an average defoliation of forty percent, the Relaskop sampled two trees, of which one was a Douglas-fir that was twenty percent defoliated, and the other a pine. The two-tree sample indicates that fifty percent of the basal area of the stand is composed of Douglas-fir and that average defoliation is twenty percent. This is an error of twenty-five percent and twenty percent, respectively, from the real values.

To assure a more accurate determination of percent Douglas-fir based on basal area and to allow for variation in defoliation, at least six trees should have been included in the sample. Either a special two-factor or three-factor prism could have been used to obtain the required sample, or the "in" or "out" status of additional trees could have been easily calculated on a slide rule.

Fixed radius plot.

As pointed out on page 36, the radius of twenty feet was too small for the fixed-size plot to give consistant data on the number of stems per acre. Consequently, low stem counts in open stands resulted in quite variable stand density and percent Douglas-fir values when based on number of stems.

In the most open stands, use of a one-fifth or one-fourth acre plot would have resulted in more consistant data on stem counts. In dense stands, though, a fifth-acre plot would have included 500 to 1000 stems. This problem could have been resolved by using a large plot in open stands and a small plot in normally or heavily stocked stands.

The fixed size plot might also be a suitable alternative to using the Relaskop for determining the basal area for each species. For example, in open stands, a one-fourth acre plot could be used, and in dense stands, a tenth-acre plot might suffice, to measure basal area. Defoliation damage could then be determined on the five Douglas-fir nearest to plot center.

II. EFFECT OF STAND CONDITIONS ON BUDWORM DEFOLIATION

Effect of site quality on defoliation of the overstory.

Defoliation of the trees in the overstory was considerably less on good sites (site 60) than on poorer sites (sites 40 and 50). The reason for this is not definitely known. Possibly, better soil conditions and moisture availability on good sites effects a physiological change in the foliage of Douglas-fir, making it less palatable than needles of trees on poor sites. Research is presently lacking on this subject, but is needed to better understand the feeding preferences of the budworm.

Another possible explanation is that trees are generally more shaded and a cooler climate prevails where there are good sites. Such areas are not as favorable as warm and sunny sites for budworm egg-laying activities and survival.

The difference in defoliation between the good sites and poor sites was revealed surprisingly well, considering that almost all of the site 60 land was located in narrow strips along streams, and was surrounded by rather dense timber that was standing on much poorer quality land. The difference in defoliation between the good and poor sites would probably have been even greater had the area of good site quality been larger; only eleven percent of the study area was site 60 land.

The lack of a significant difference between site classes 40 and 50 indicates that the budworm is not sensitive to such a slight difference in sites. It is worth noting, however, that the difference between these sites is only slightly less than significant at the ninety-five percent level of confidence. The five percent by which average defoliation on site 50 exceeds that on site 40 might be a reflection of the higher percent crown closure on site 50; average crown closure was 53.5 percent on site 50, but only 35.9 percent on site 40.

Effect of site quality on defoliation of the understory.

Statistically, defoliation of understory Douglas-fir was not significantly different on site 60 from that on site 40 and 50. The difference in overstory defoliation between sites was not evident in the understory. The ease with which a very small number of budworm can defoliate such small-crowned fir may account for defoliation being so nearly the same on all sites. Generally, a difference in defoliation begins to show between good and poor sites as trees increase from twenty to thirty feet in height. This trend is shown in Figure 13.

Effect of tree height on budworm defoliation.

The data clearly show defoliation to decrease with an increase in tree height. A reason for this pattern can only be presumed. A plausible explanation might be that smaller trees with smaller crowns require less feeding upon by the budworm to be defoliated. If this is the real reason, then it seems even more strange that the overstory suffers much greater damage than the understory in balsam fir stands in the Eastern states (Mott, 1963). This difference in feeding habits by budworm on Douglas-fir and balsam fir must be due either to physiological differences of the two tree species, or to a peculiar variation in feeding habits of the eastern and western forms of spruce budworm.

Effect of percent Douglas-fir and crown closure on budworm defoliation.

The increase in defoliation is quite pronounced as crown closure increases from five to forty percent. Defoliation also shows a similar increase as the percent Douglas-fir in the stand increases to about forty percent. Above forty percent Douglas-fir and forty percent crown closure, an increase in these variables is accompanied by only a gradual increase in defoliation. At about eighty percent crown closure and eighty percent Douglas-fir, maximum defoliation is attained.

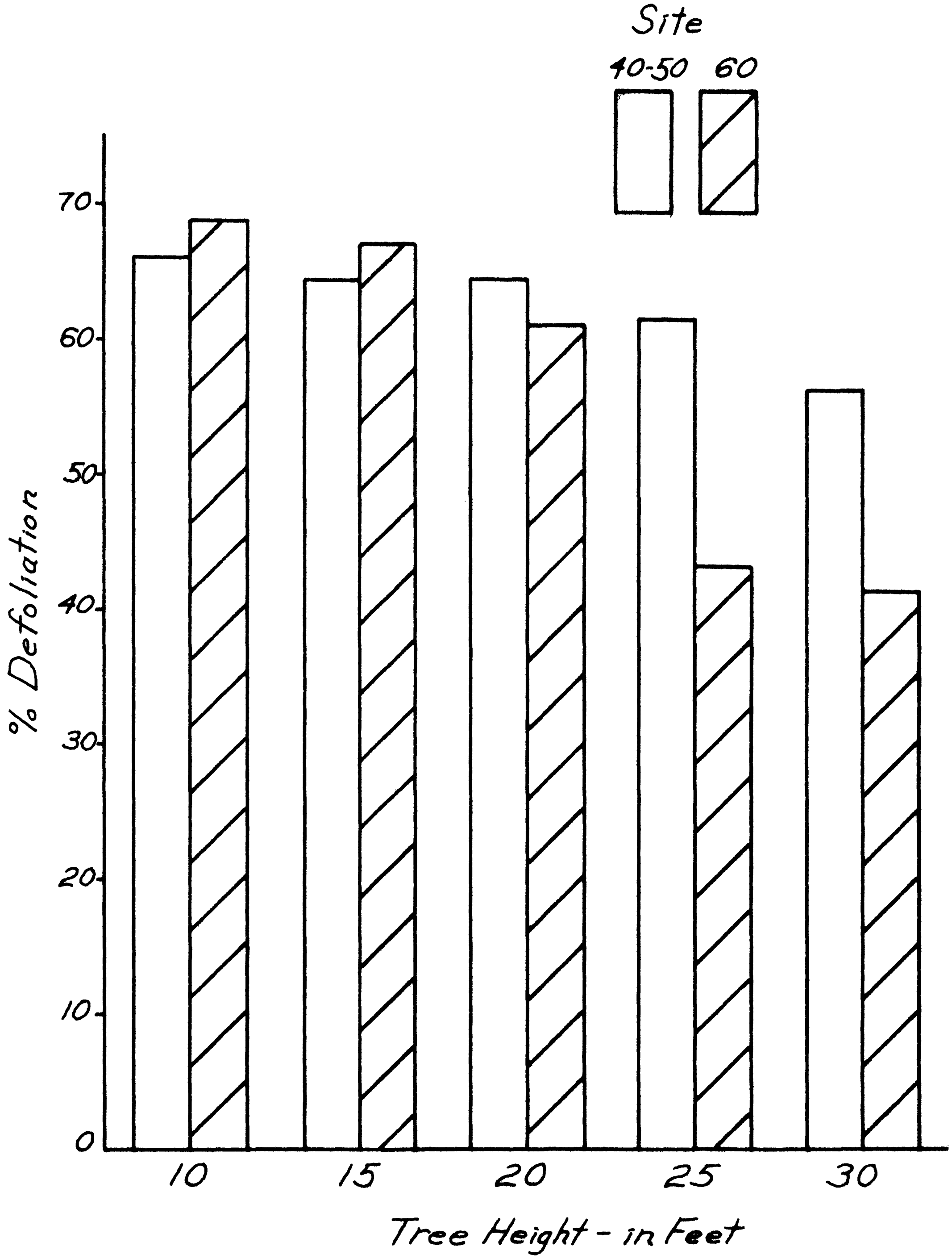


FIGURE 13

RELATIONSHIP OF SAPLING HEIGHT TO AVERAGE PERCENT DEFOLIATION

Above eighty percent crown closure, a rather peculiar decrease is noted in defoliation. This decrease may either be real, or due to error in sampling and analysis. Possibly, very dense stands of fir are so shaded and cool, that budworm dispersal is probably greater in more open stands than in dense ones, due to more air movement between trees.

Another cause of the decrease in defoliation values may be the eighty-one percent limit of maximum defoliation imposed by using the regression curve shown in Figure 4 on page 24. A regression curve might easily show this decrease if, on plots with 80 to 100 percent crown closure, defoliation values are more scattered about the mean.

A small percent of pine in the stand will not have much effect on defoliation caused by the budworm. However, in stands composed of over sixty percent pine, and also in areas where pure pine stands mix with pine-fir stands, the pines act as a buffer in preventing a concentrated increase in a large population of budworm.

III. FOUNDATION FOR A RISK RATING SYSTEM

Combining crown closure and percent Douglas-fir classes.

By combining crown closure and percent Douglas-fir classes as done in Table 10 on page 52, and shown in Figure 16a on page 56, information was obtained that might be used in predicting stand risk of defoliation for given stand conditions. Defoliation for each of the eight classes was derived by averaging the percent crown closure and percent Douglas-fir specified in the second and third columns of the table. Figures 14 and 15 illustrate the effect on defoliation of combining crown closure and percent Douglas-fir classes, as well as showing the difference in defoliation between good and poor sites, and between the overstory and understory.

TABLE XIV

PERCENT DEFOLIATION, BY CLASSES COMPOSED OF INCREASING PERCENTS OF CROWN CLOSURE AND DOUGLAS-FIR

Class	(1) Crown Closure Percent		(2) Percent Douglas-fir	Average Percent Defoliation (3)*			
				Overstory		Understory	
				Site 40-50	Site 60	Site 40-50	Site 60
1	0-25	--	0-20	31.4	8.7	31.8	9.0
2	0-25 26-50	-- --	21-40 0-20	33.8	10.1	34.8	19.6
3	0-25 26-50 51-75	-- -- --	41-60 21-40 0-20	47.4	30.9	46.7	38.7
4	0-25 26-50 51-75 76-100	-- -- -- --	61-80 41-60 21-40 0-20	43.1	24.4	53.7	39.9
5	0-25 26-50 51-75 76-100	-- -- -- --	81-100 61-80 41-60 21-40	51.5	36.4	60.0	58.9
6	26-50 51-75 76-100	-- -- --	81-100 61-80 41-60	62.1	37.7	72.1	64.1
7	51-75 76-100	-- --	81-100 61-80	69.5	41.2	70.2	69.4
8	76-100	--	81-100	60.3	59.4	73.8	71.8

*Averages in column are for all plots that were classed within the limits shown in columns (1) and (2). Classes are numbered to correspond with increasing percents of crown closure and Douglas-fir. For further explanation, see Figure 16a on page 56.

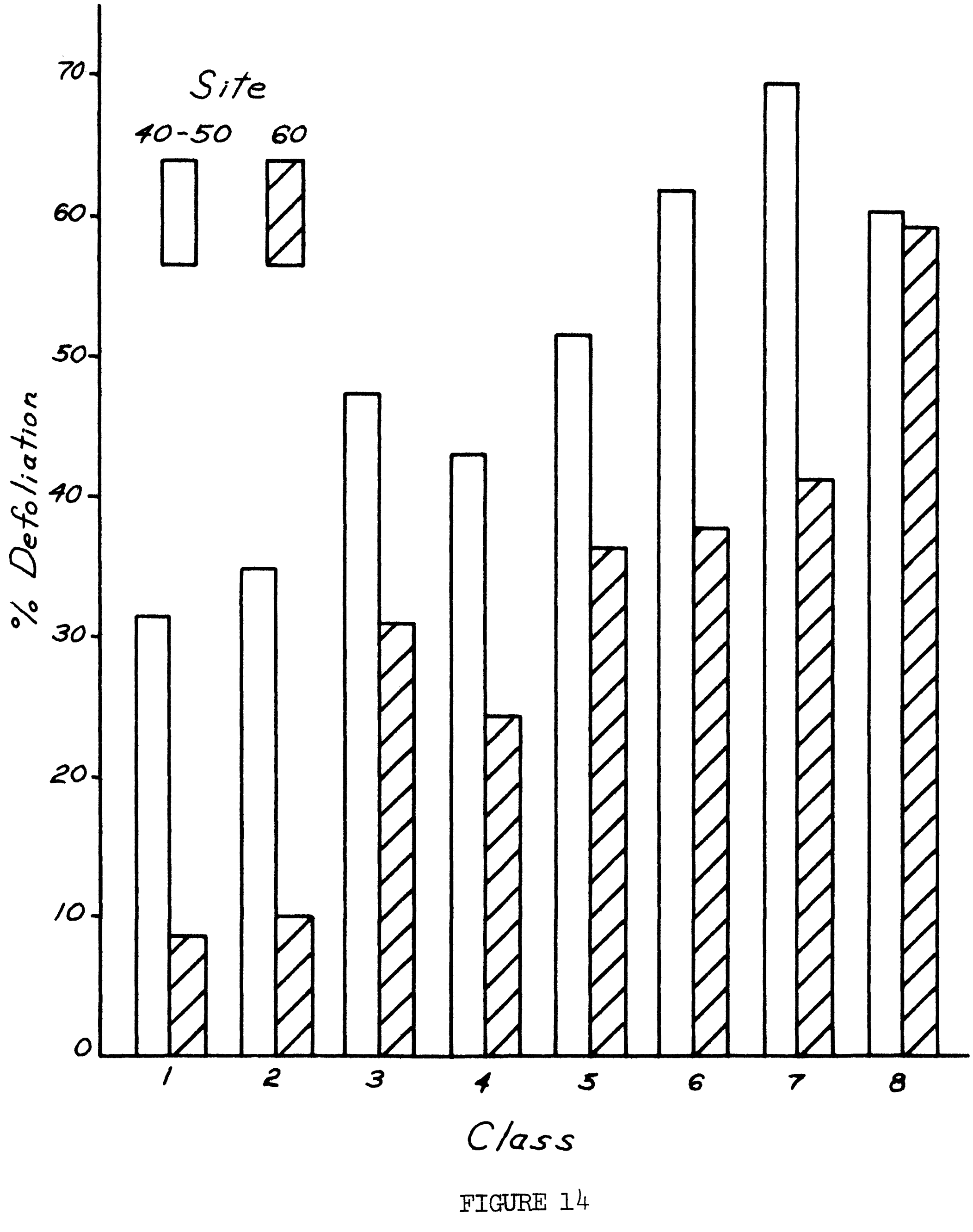


FIGURE 14

RELATIONSHIP OF OVERSTORY DEFOLIATION TO COMBINED CROWN CLOSURE AND PERCENT DOUGLAS-FIR CLASSES

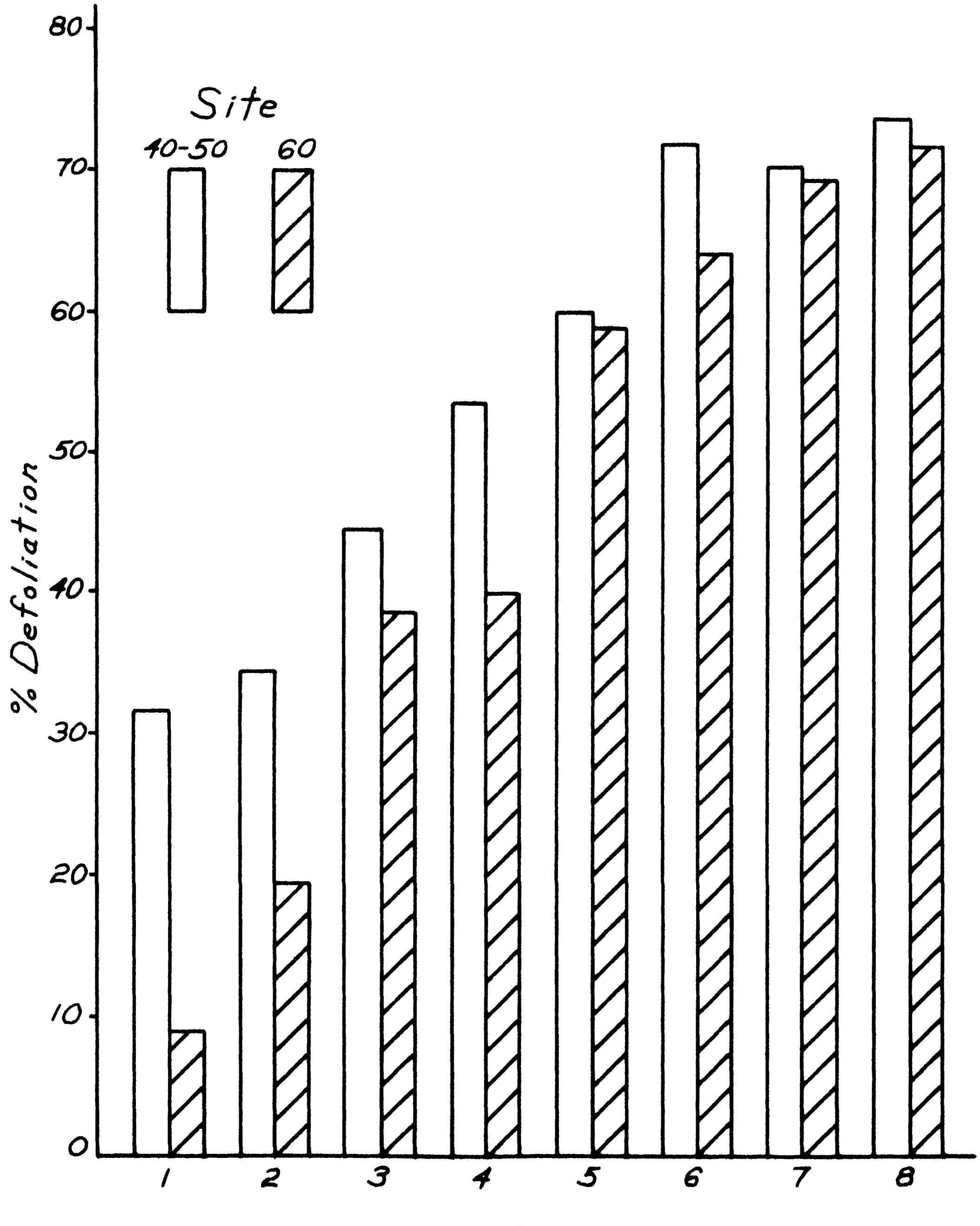


FIGURE 15

RELATIONSHIP OF UNDERSTORY DEFOLIATION TO COMBINED CROWN CLOSURE AND PERCENT DOUGLAS-FIR CLASSES

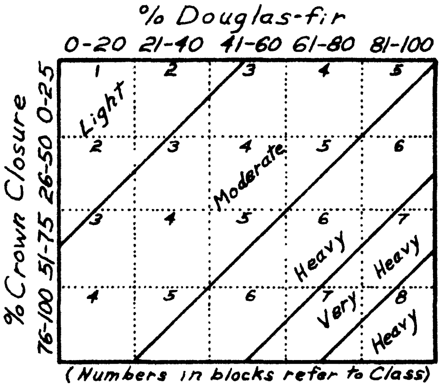
Risk-prediction diagrams for second-growth Douglas-fir stands.

The four diagrams in Figure 16 on page 56, provide an easy method for estimating the risk of the second-growth Douglas-fir stands on Lubrecht Forest being defoliated by spruce budworm. Two of these diagrams are prepared for stands averaging more than thirty feet in height, with one chart each for good sites and poor sites. The two additional diagrams are for young stands whose average tree height is less than thirty feet.

Most of the data needed for applying these diagrams to an area can be derived from aerial photographs. Good estimates of crown closure, average stand height, and percent Douglas-fir can be made for large areas more rapidly from photographs than from ground surveys. Site quality information can either be estimated by photo-interpretation, or be determined from ground reconnaissance.

Like any other method of predicting insect damage, these diagrams are not infallible. It is important to remember that these charts are derived from ponderosa pine and Douglas-fir stands on Lubrecht Forest, and so may give misleading results if applied to other timber types or in other localities. Also, other populations of spruce budworm under different environmental conditions might produce different results, even though stand conditions were similar. Further tests should be made to determine the applicability of the charts. Such tests could be made on infested second-growth Douglas-fir stands of the Rocky Mountain Region, with stand conditions estimated from aerial photographs that were taken prior to the infestation.

% Defoliation		Damage
0-20	---	Very Light
21-35	---	Light
36-50	---	Moderate
51-65	---	Heavy
Over 65	---	Very Heavy



(Numbers in blocks refer to Class)

Figure 16a
Site 40-50, Stand Over 30 Feet Tall

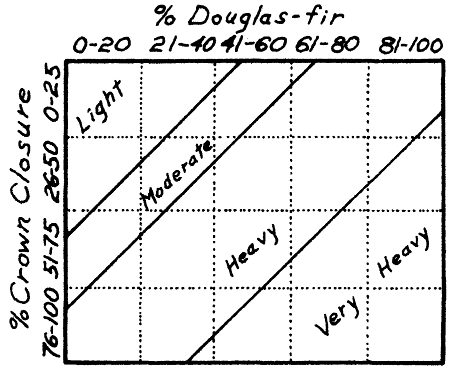


Figure 16b
Site 40-50, Stand Under 30 Feet Tall

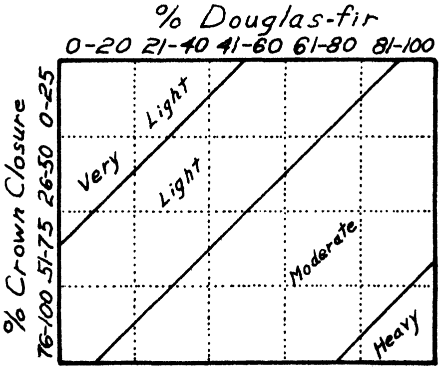


Figure 16c
Site 60, Stand Over 30 Feet Tall

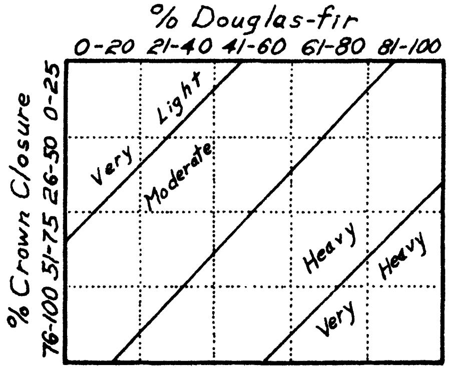


Figure 16d
Site 60, Stand Under 30 Feet Tall

FIGURE 16

SPRUCE BUDWORM DEFOLIATION TRENDS FOR COMBINED CROWN CLOSURE AND PERCENT DOUGLAS FIR CLASSES

IV. THE FEASIBILITY OF USING SILVICULTURE TO REDUCE STAND RISK

Before prescribing a silvicultural treatment to reduce risk, several factors must be considered. These include: (1) height of the stands; (2) size of the proposed treatment area; (3) stand composition and uniformity of timber type; (4) quality of the sites; and (5) quality and type of timber contiguous to the proposed treatment unit.

Silvicultural treatment to reduce the risk of defoliation of the Douglas-fir should probably not be attempted on poor sites when the percentage of Douglas-fir in the stand is over forty percent. Part "a" and "b" of Figure 16, indicates that above forty percent Douglas-fir, defoliation can be held to a moderate level only by creating a crown closure of less than fifty percent. Rather than reduce stand stocking to such a low level, other means of budworm control should be used, or the fir should be removed, favoring the ponderosa pine. Removal of the fir in stands composed of over forty percent fir would likely result in an inadequately stocked stand.

Figure 16d suggests that in very young stands on good sites, the budworm will not be affected by silvicultural treatment any more than on poor sites.

The only stands in which risk reduction might be effective are those stands whose average height is over thirty feet and that are on good site quality land. Figure 16c shows that the only high risk stands on good sites should theoretically be ones composed of more than eighty percent fir and whose crown closure exceeds seventy-five percent. In these stands, selective thinning could be used to remove low vigor trees and to open the canopy to perhaps fifty percent crown closure. Stands containing a mixture of pine and fir would require less thinning than stands of pure Douglas-fir; Figure 16c serves as a guide as to approximately how much less.

CHAPTER VII

CONCLUSIONS

In the Rocky Mountain Region, land management generally is not conducted intensely enough to justify thinning or modifying stand composition solely for the purpose of reducing the risk of a stand being defoliated by the budworm. Because the spruce budworm is so widespread and is such a threat to the Douglas-fir market in this Region, however, consideration of the risk of infestation should be integrated into the planning of all proposed stand improvement and timber sale programs in Douglas-fir timber types.

If it is desired to attempt to reduce the risk of budworm damage by silvicultural treatment, consideration should first be given to the size of the timber, the type and extent of the timber needing treatment, the site quality, and the crown closure of the stand. No one set of rules would apply to all stands where risk reduction might be performed. The diagrams shown on page 56, for various stand conditions might be useful in predicting the vulnerability of Douglas-fir stands to budworm damage on Lubrecht Forest and adjacent forests.

If possible, aerial photographs should be used to classify risk of stands to budworm damage. Ground surveys require much time to conduct, and give more accuracy than is necessary to make a risk classification.

This study has shown the relationship of site quality, percent Douglas-fir tree height, and crown closure to budworm defoliation. Also revealed was the need for investigation to study the relationship of tree physiology to feeding preferences of the budworm. Understanding the cause of the not infrequent incidence of damaged and undamaged Douglas-fir standing together (Figure 17), or the reason for certain Douglas-fir to remain undamaged in the midst of a heavily defoliated stand, (Figure 18), may lead to a more satisfactory method of reducing stand risk than by using silviculture.

FIGURE 17

EXAMPLE OF AN UNDAMAGED DOUGLAS-FIR STANDING NEXT TO ONE WITH HEAVY TOP DAMAGE

FIGURE 18

EXAMPLE OF DOUGLAS-FIR REPRODUCTION REMAINING UNDAMAGED IN THE MIDST OF A HEAVILY DEFOLIATED OVERSTORY

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