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Title: THE INFLUENCE OF SERAL COAST RANGE VEGETATION ON THE GROWTH HABIT OF JUVENILE DOUGLAS-FIR

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A detailed analysis was performed on the juvenile growth of six types of Douglas-fir stock under the influence of typical seral Coast Range vegetation. Objectives were to analyze competitive influences important to the growth of tree seedlings and evaluate differences between stock type characteristics and growth patterns in response to competition of several kinds. Results were also compared as far as possible with an earlier analysis of the same trees to investigate the changing competitive status of Douglas-fir of various sizes as their competitors grow.

Initial seedling height was consistently important in explaining variation in the seven-year growth of tree seedlings associated with a variety of vegetation groups, regardless of stock type. Correlations of growth with stock type and site location were also significant, although the importance of stock type decreased with the increasing age of the trees, while the importance of site increased. In addition, there was more unexplained growth variation at seven years

than at five years indicating that factors not included in regression models, such as microsite variation and/or increasing size of trees, are becoming increasingly more important in determining seedling growth.

At six and seven years, vegetation on cutover sites explained only a limited portion of the variation in current growth. Vegetation effects on tree seedlings appear to be cumulative however, with past competitive stress highly correlated with the present status of tree seedlings. In addition, after four or five field seasons, the competitive status of juvenile tree seedlings has already been determined and there is little tendency for change either to a more favorable or less favorable competitive environment without interference. Seral vegetation is more competitive and hence has a greater influence on tree seedlings if it overtops them, as with tall hardwoods and sprouts which reduce available light, than when it encroaches on them from the side or below as with low shrubs and herbs.

The advantages of using larger stock types in mesic to moist Coastal brushy areas are still obvious at seven years, even though seedling growth at this time is not significantly different between stock types, vegetation groups or sites. Larger seedlings maintain their initial height advantage, are able to become 'established' (reach 4-1/2 ft.) up to three years before smaller seedlings and have higher survival rates than smaller seedlings. In addition, larger stock types are less susceptible to adverse site influences and damage than smaller stock types, at seven years.

Intensive forest management is dependent upon reforestation success. Options which enhance the survival and growth of crop trees in the early years of a rotation allow for increased and more dependable yields in subsequent years. The use of larger stock types on brushy Coast Range sites is an effective alternative for meeting these reforestation goals.

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THE INFLUENCE OF SERAL COAST RANGE VEGETATION ON THE GROWTH HABIT OF JUVENILE DOUGLAS-FIR

I. INTRODUCTION

Several million acres of high-site land in the Coast Range of Oregon are occupied by stable brush communities. Successful reforestation of this land is dependent both on seedling survival and on subsequent growth of surviving seedlings. In order to more accurately predict the growth potential of a given tree on a particular site, it is important to determine what habitat factors impose limits on this growth, and what innate characteristics of the tree may enable it to survive and grow in spite of these limitations. An understanding of these factors and their interrelations is important for the formulation of successful reforestation strategies.

Recent work has shown that both survival and growth are related to initial seedling height; that larger trees, being less susceptible to adverse site conditions, are more likely to become established and dominate the site (Iverson 1976). The relationship between size and growth is postulated to be most important at a midpoint of the extremes of vegetative competition. Growth of all sizes of seedlings is unrestricted where there is no competition. No seedlings may emerge where brush occupies the site fully and puts total restraints upon growth. One can therefore visualize a continuum of increasing brush competition, where at the lower end all trees do well, and with increasing competition, the survival and growth of the seedlings becomes increasingly dependent upon their ability to either outgrow competitors or survive in the shade (Newton 1973). Under the most severe brush, no conifers may be able to establish themselves. This thesis is a detailed examination of this principle.

Observations of growth over a spectrum of competitive interactions are needed to determine at what stage and under what conditions a tree can dominate the site. This requires an understanding not only of the growth characteristics of the seedling, but also an understanding of how seedling growth and competitive relations are modified by the surrounding vegetation during the critical establishment period.

The purpose of this study is to contribute to the knowledge needed to determine the juvenile growth potential of seedlings under a variety of competitive stresses on a number of Coast Range sites. The detailed analysis of the growth of Douglas-fir stock types attempts to quantify those influences which are important to the growth of the seedling, and to explore differences among stock type characteristics and growth patterns over time.

The specific objectives are to:

1. Evaluate Iverson's growth models of 1976 to determine if patterns which explained five-year growth are still apparent at seven years.

2. Evaluate differences between stock types in terms of absolute and relative growth, growth rates, resistance to damage and performance under a variety of brush types.

3. Document changes in the competitive status of seral vegetation surrounding tree seedlings and evaluate what influences these have had on the outlook for growth.

4. Determine which factors are most important in explaining variation in absolute and relative growth through the

seventh-year for tree seedlings growing on cutover lands in the Coast Range.

5. To translate the biological findings of the first four objectives into practical recommendations for silvicultural practice.

II. LITERATURE REVIEW

Introduction

The literature review attempts to consolidate relevant information in areas related to the thesis topic. These include:

1. A review of factors which influence seedling growth in brushfields such as those encountered in the Oregon Coast Range.

2. A summary of pertinent information regarding the growth characteristics of brush species known to compete with Douglas-fir seedlings on seral sites.

3. A review of factors needing consideration by regeneration foresters in terms of stock type selection and silvicultural techniques to aid reforestation efforts.

4. A compilation of methods and evaluation techniques used by other researchers to investigate competition interactions in field situations.

A. Factors Influencing Seedling Growth in Natural Environments

The environment of a plant has been defined to be the sum of all external forces and substances affecting the growth, structure and survival of the plant (Billings 1952). The interrelations within this environment are not unilateral or simple, and in general the structure and function of any ecosystem is determined by dynamic interactions between a number of biotic and abiotic components.

Plant communities growing on different sites serve as indicators of the net effects of all the interacting complex of extrinsic and intrinsic factors we call environment (Bailey 1968). A coniferous tree seedling, as a component of a seral forest community, is subject to a number of external forces which influence its chance for survival and growth. Major obstacles to seedling survival and growth in the Oregon Coast Range often result from the combined influences of herbaceous and woody vegetation growing in proximity to the seedling and interacting with the physical environment. In brushfields, major stresses may include insufficient levels of light, browse injury by animals and mechanical damage from litterfall. Moisture stress may also be limiting on south-facing slopes and shallow soils, but may be difficult to evaluate as shading from live vegetation cover also helps to reduce radiation load. The casual agents of these stresses are interrelated, but can be looked at separately.

Solar radiation is the basic energy source of photosynthesis and subsequent seedling growth, and consequently is a common limiting factor for seedling establishment in brushy areas. Douglas-fir is generally classified as a relatively intolerant species, and its growth is retarded under limited light (Isaac 1943). Decreased levels of light can affect dry-matter production and distribution in at least two ways including:

1. It can decrease the rate of photosynthesis/unit leaf area; and
2. It increases the leaf area added/unit of dry matter produced (Brix 1967).

Conifer seedlings, for example, which are under partial or full overtop by shrubs may have an appearance of satisfactory height, but they will have a weak spindly appearance due to etiolation and uneven distribution of photosynthate (Allen 1969).

In general then, low levels of light can result in reduced growth rates, depletion of food reserves, and the ultimate decline of a plant (Newton 1964b). The exact amount of light required by conifer seedlings for satisfactory growth depends upon a number of environmental variables, and requirements will vary. To investigate this matter, an experiment by Isaac (1943) was designed to observe the growth of Douglas-fir seedlings under ventilated shade frames which admitted different levels of light. He concluded that Douglas-fir reproduction has little or no chance of successful establishment in anything less than 20% of full overhead light, even when there is no root competition. For reasonable seedling growth, he suggests that 50% of full light is probably necessary on level ground where radiation is direct. On north-facing slopes the need for light is probably higher, and on south-facing slopes somewhat less.

Another study by Strothmann (1972) investigated what levels of shade, if any, would promote the best survival and early growth of Douglas-fir on hot, dry southerly aspects. His results were less conclusive, but in general he found that both height and diameter growth were inversely proportional to the amount of shade received. Results from this experiment were confounded by removal of competing vegetation on the site, and he suggests that different results might be obtained under more typical field conditions.

In terms of moisture stress, it is known that in grassy areas, a primary stress factor to coniferous seedlings is limited moisture. Attempts to reforest old field plantations with coniferous stock have often resulted in failure. This failure is attributed in part to efficient moisture depletion by grass and associated herbs (Newton 1964a). In general, available soil moisture is critical to seedling survival particularly when it is reduced enough so as to induce lethal moisture stress within the plant. The amount of moisture available to a seedling can vary with season, elevation, slope, aspect and vegetation on the site. The extent to which surrounding seral vegetation depletes soil moisture varies with the species type and vegetation biomass.

Another factor limiting seedling establishment and growth in some areas may be animal activity and associated damage. The most serious offenders in the Oregon Coast Range are deer (Odocoileus spp.), elk (Cervus spp.) and various rodents (Dimock and Black 1969).

It is well known that heavy big-game use of young timber plants sometimes hinders the re-establishment of timber after logging or fire. Browsing and trampling by both deer and elk suppresses height growth of seedlings and may cause seedling death. Repeated browsing for several years can result in the suppression of growth as well as an extension of the harvest rotation schedule (Smith 1974). Moderate use by deer on the other hand, is thought to have little adverse affect on trees (Dimock 1970), and in fact may benefit the conifer seedlings by reducing competition from some plant species favored by deer such as bitter cherry (Prunus emarginata (Dougl.) Walp.) elderberry

(Sambucus racemosa L.) and vine maple (Acer circinatum Pursh) (Crouch 1974).

A number of different variables can influence the extent to which big-game will trample or browse on seedlings. These include the shrub plant community, elevation, deer density, severity of winter, season of the year or seedling height and vigor (Hines and Land 1974).

Work by Hooven (1977) has shown that mountain beaver (Aplodontia rufa Raf.) will feed on a variety of plant species depending on availability. They will feed on Douglas-fir seedlings, often clipping seedlings at the ground level. Damage decreases about five years after planting, but older trees may sustain damage to the lower trunk and roots.

Other potentially damaging rodents include the brush rabbit (Sylvilagus bachmani Wat.) and snowshoe hare (Lepus americanus Erxl.), both of which prefer the edge of brush and open areas (Hooven and Black 1976). Snowshoe hare is thought to be the principal source of clipping damage in seedling plantations, but brush rabbit damage may also be important to the Coast Range (Mitchell 1950).

Another possible stress on conifer seedlings in brushfields is accumulation of litter. The potential for litterfall damage to seedlings in brushy areas is a combined result of low light levels causing etiolated seedlings with reduced mechanical strength and an abundance of detritus from self-shading shrub parts. Once a seedling is suppressed to this point, its chances for survival and establishment are markedly reduced (Newton and Zavitkovski 1971).

Any one of the previously discussed potential stress agents can cause reduced conifer stocking in plantations on both grassy and brushy sites. Individual or combined stresses may result in regeneration failure. In addition, aspect, topography, slope, elevation, soils and climate can interact with any or all of the above influences, and it is the interrelatedness of these physical and biological factors which increase the complexity of their influences and render single-factor problem solutions of limited utility.

Pioneer seres, or early regeneration sites, are naturally unstable biological communities. After a disturbance, habitats change. The trajectory of vegetation development carries micro-habitats both into and out of favorable species habitat conditions for both plants and animals (Smith 1974). Examining the growth of conifer seedlings in such seral communities should provide insight into the range of tolerance of developing conifers to the biological and physical environment at each stage. It should also provide insight into the ability of the conifer population to develop beyond this stage.

Of particular interest is the stature of a tree seedling in relation to that of the surrounding vegetation. Clearly, the likelihood of a seedling's survival and growth in a seral community is dependent upon its development relative to that of competing species, both spatially and temporally. Observations of growth in a spectrum of competitive interactions are needed to determine at which stage and under what conditions a tree can be expected to dominate the site.

B. Growth Characteristics of Competing Brush Species

It has been estimated that hardwoods and fast-growing shrubs are dominant on more than 2.4 million acres of highly productive land in the Oregon-Washington Coast Range and in the foothills of the Cascade Range in Washington (Gratkowski, et al. 1973). The prevalence of these species on the best growing sites in the Douglas-fir region suggests that the relative competitive advantages of brush species may be enhanced by climates and soils innately most favorable for conifers. The components of competition on favorable sites, therefore, deserve detailed attention.

Competition is in part a function of the amount of spatial overlap between plants and it must be considered as a dynamic process inevitably leading to full utilization of one or more limiting site resources. The growth habits of the crop tree seedlings and the surrounding brush species are major components of competition. While it is often hard to isolate the competitive contribution of one brush species in a heterogeneous mixture, it is possible to classify brush species by their potential growth rates and the nature of their influence on tree seedlings. The allocation of available site resources, and hence the subsequent yields obtained on any given site, depend in part upon how the dominance potential of planted seedlings compares to that of the associated vegetation. In a juvenile seral community then, the growth habits of all species and their populations on a given site will determine the space occupied by each and eventually the species composition in a dominant community.

Brush species with high dominance potential include such fast growers as red alder (Alnus rubra Bong.), bigleaf maple (Acer macrophyllum Pursh), bitter cherry and willow (Salix spp.). These species naturally pioneer a site soon after a major disturbance and in doing so make it difficult to establish preferred conifer trees.

Red alder, for example, may have a juvenile growth rate exceeding that of Douglas-fir by a factor of ten in the first five years (Newton, et al. 1968). The height growth for alder is greatest from three to five years after establishment, after which there is a gradual decrease in annual increment until maximum height is reached (Newton, et al. 1968). Adequate conifer regeneration in potential alder areas then, is assured only if conifers are established prior to invasion of the site by alder. The term 'adjustment period,' as defined by the above authors, refers to the difference in time of establishment needed to insure continuous dominance of conifers. They determined that for alder, Douglas-fir needs an average head start of four to nine years depending on site conditions. Unless this advantage is given, the conifer will be relegated to an understory position and eventual mortality due to divergent juvenile growth rates. Because of the seral nature of alder, an adjustment in time is not usually possible.

Bigleaf maple is another species with high dominance potential. Although it does not grow in thick stands as does alder, it is still notorious for its large radial and height growth potential. Often conifers close to a bigleaf maple stump may be in the open in the first year or so after planting, but will be completely overtopped as the maple grows. In contrast to alder, which originates primarily from seed after disturbance, maple is a vigorous sprouter, and sprouting stumps after logging form numerous maple-dominated gaps in plantations.

In general then, under canopy conditions such as those created by these fast growers, even the largest and fastest growing conifers may not be able to maintain a position in the canopy and hence are relegated to suppressed status and low survival.

Brush species with an intermediate dominance potential include species such as salmonberry (*Rubus spectabilis* Pursh), vine maple and elderberry. These species develop from sprouts or seed following logging or other disturbance, and can cause seedling mortality and growth losses if they invade the area at the time of or prior to planting of coniferous seedlings.

Work by Allen (1969) has shown that after clearcutting, salmonberry has the potential for rapid height and lateral growth. He concludes that the growth in height of the salmonberry shrubs and the initial size of opening in which conifers are planted are especially important variables in determining encroachment on seedlings. Preliminary work from other field studies have also shown that the prospects of establishing coniferous trees decreases with the number of years subsequent to salmonberry invasion (Newton 1977). After four years, chances for conifer establishment are virtually nil. According to Allen (1969) both rapid growth of shrubs and simultaneous increase of rodent populations contribute to decreased planting success with increasing age of salmonberry.

Vine maple and elderberry are also vigorous sprouters, and are noted for their rapid early growth (Ruth 1956). Under suitable conditions, these species can increase rapidly in biomass and percentage crown cover (USDA 1937). As with salmonberry then, the prospects of establishing Douglas-fir may be decreased if establishment is not prompt.

Slower growing species such as ceanothus (Ceanothus velutinus Dougl.), manzanita (Arctostaphylos columbiana Piper) and other evergreen shrubs often form thick stands from persistent seeds following burning. Snowbrush can attain maturity in ten years or less, and can cause mortality, suppression and growth retardation of Douglas-fir during the first decade of development (El Hassan 1967).

The growth of snowbrush is represented by the typical sigmoid curve. Studies on snowbrush in the Cascades revealed that after a slow start it shows a steep increase between the ages of three and ten years and reaches a maximum of 2.7 meters in 13 to 15 years (Zavitkovski and Newton 1968).

In general then, ceanothus may be an obstacle to establishment of coniferous species if the conifers are not established concurrently. Delays in planting of seedlings can result in a longer dominance period for the ceanothus (Zavitkovski, et al. 1969).

Snowbrush also seems to be a prolific producer of litter compared with other plant communities (Bray and Gorham 1964). Suppressed conifers in snowbrush stands may be subject to further stress from mechanical injury especially under the influence of a heavy snow pack

(Zavitkovski and Newton 1968).

Other brushy competitors include the bracken (*Pteridium aquilinum* (L.) Kuhn.) and sword ferns (*Polystichum munitum* (Kaulf.) Presl.), thimbleberry (*Rubus parviflorus* Nutt.), and salal (*Gaultheria shallon* Pursh). These species also grow quickly and may overtop young conifers (Iverson 1976).

Herbaceous species, especially grasses, are also efficient moisture depleters. Young Douglas-fir seedlings subjected to depletion of soil moisture in the upper layers of the soil profile may either die in the first season or survive several years of poor growth (Newton 1967, Preest 1975).

In summary, the resources available for the welfare of a young tree in a particular ecosystem may be expressed very substantially in terms of the vegetation surrounding it. Among these, the dominant cover presumably exerts the most influence and warrants the most critical attention.

C. Reforestation Considerations: Silvicultural Techniques and Stock-type Selection

Requirements for successful reforestation include the selection of well-adapted seed and species and the proper outplanting of physiologically healthy seedlings (Tinus 1974). These considerations alone will not insure reforestation success, as the seedlings will be influenced after planting to a large extent by prevailing microsite factors. Young seedlings are particularly vulnerable to these site factors; one adverse factor may be enough to decrease growth and survival, but the interacting of several may complicate the prescription for amelioration (Chen 1974). It seems logical, therefore, to first examine the planting sites for features that may interact to cause losses, then to combine habitat management techniques with a choice of seedlings whose features render them less vulnerable to the adverse influences remaining after treatment.

Site factors can be modified to some extent by a variety of management practices, and the effects can be widespread or localized depending on the technique used. Management practices have been developed to alleviate problems associated with animals, vegetation and extreme physical site factors.

Techniques used to reduce various types of animal damage include: constructing fences, use of Vexar® tubes, protective paper ('budcaps'), or applications of chemical deterrents such as TMTD (tetramethylthiuram disulfide) for rabbits (Sylvilagus spp.) or BGR (big-game repellent) for big-game problems. Poisons and traps have been used for other rodents such as mountain beaver.

Vegetation can be changed or in some cases virtually eliminated with a variety of site preparation techniques such as prescribed burning, mechanical clearing, use of selective herbicides, or some combination of these methods. These techniques will not only reduce vegetative competition, but may also reduce slash and debris, reduce animal habitat, and expose mineral soil for a seedbed.

Various techniques designed to reduce problems with harsh site factors include the use of various mulches to reduce problems associated with moisture stress; increasing the depth of planting to reduce problems with frost heaving; and reducing heat stress by creating shade with either artificial barriers or with debris and slash found on the site (Greaves 1978).

In general, there is a wide spectrum of silvicultural techniques that may be used subsequent or prior to planting which will improve a seedling's chance of survival. Any of these practices, however, may add to the landowners gross costs. For this reason, the use of seedlings whose inherent abilities enable them to overcome adverse site factors, with a minimum of maintenance, may be desirable.

A significant amount of research has been done on the influence of site factors on the growth potential of tree seedlings and on the effects of seedling characteristics on growth in well-prepared sites. Less research has been done, however, on the characteristics of the seedlings that influence their adaptability in different environments.

In terms of seedling characteristics, it is known that high grades of stock survive better than poor grades (Pomeroy et al. 1949), and that transplants are generally superior to seedlings in a number of environments (Mullin and Howard 1973). Also, for any given nursery regime, there is some evidence that large seedlings perform better in the field than small ones from the same lot (Smith 1975, Newton 1973). A standard of minimum acceptable size will vary between seedling populations, but 2-0 Douglas-fir seedlings weighing less than four grams (fresh weight) should be discarded (Lavender and Zaerr 1976). In addition, shoot-root ratios can improve survival, and hardiness in a seedling is desirable for tolerance to freezing, drought and storage (Borkenhagen and Iyer 1976).

Of particular interest to regeneration foresters, however, are characteristics of tree seedlings which enable them to overcome various adverse site factors including limited light and water resources, animal damage and litterfall.

In a review of recent literature on this subject, Chetock (1976) found the following generalities to be true:

1. Large seedlings should be utilized in areas characterized by strong plant competition and animal damage, particularly where soil moisture is not limiting.

2. Seedlings with well developed root systems have a higher survival potential on droughty sites; and

3. Morphological traits are not consistently reliable indicators of seedling quality.

The general success of large planting stock in brushy areas is exemplified in work done by Iverson (1976). His observations on the performance of a variety of stock types on brushy areas led to the conclusion that there is a strong correlation between seedling height and survival which may in part be due to their faster growth rate, and lower susceptibility to shading and litterfall damage. In addition, Iverson found that the growth potential of seedlings may be predicted by a relationship involving initial seedling size and some quantitative index of competition. His data show strong correlations between seedling height and survival in the presence of dominant vegetation, shrubby 'overtoppers' in particular.

The long term growth advantage of using larger stock in brushy areas is also illustrated by Smith, et al. (1968), who found that the effects of various factors on seedling size at the time of planting have persisted for nearly two decades. In field work examining the performance of various stock types, Smith (1975) also found large Douglas-fir to be biologically superior to smaller stock in terms of potential for growth, provided that it is of physiologically high quality. The physiological condition of a seedling or transplant is another important variable which can influence performance in the field. In general, this condition is largely determined by the environment in which the plant is grown and to which it is exposed after lifting, both before and during the planting operation (Chetock 1976). When the physiological condition of large and small stock is equally good, the potential for development in brushy areas should be much greater for the large stock.

To further illustrate the advantages of large stock, recent work by Chetock (1976) has shown that in general, large seedlings demonstrated superior survival potential on adverse sites characterized by strong plant competition, rocky and stony ground, or exposed southern slopes. He also states that mechanical rigidity in withstanding the pressures of falling detritus and surface soil movement also favors seedlings of larger stem diameter.

To relate the choice of stock type to potential for animal damage, work has shown that planting large Douglas-fir stock may help to evade damage by animals (Newton and Black 1965), and that deer browsing may be reduced after Douglas-fir reaches 60 cm. in height (Hines and Land 1974). Data from Hartwell (1973) also suggest that damage from wildlife feeding injuries on Douglas-fir plantations can be substantially reduced in some situations by planting transplant stock three to four feet in mean height. In field studies, Hartwell found that the greatest benefit from using large stock was obtained in the densest type of ground cover.

By general hypothesis, large stock is expected to be more resistant to wildlife damage primarily because of its greater height and stem diameter (Hartwell 1973). In addition, large Douglas-fir seedlings having greater residual size may have a larger capacity to grow after being browsed (Iverson 1976). It remains to be determined, however, if growth lost by browsing on large seedlings is less than that in smaller seedlings. If so, the use of large seedlings on sites with heavy animal activity may be desirable based on this growth advantage alone.

Another important consideration when evaluating stock type selection, is the time for seedlings to become established and the length of the juvenile growth period. Data from Iverson (1976) suggest that up to four or more years competitive advantage can be gained by selection of extremely large planting stock. This competitive advantage when combined with the higher chances of survival could presumably lead to shorter rotations of more fully stocked stands. If this relationship were consistent, the incentives for using large stock are strong. Smith (1975) concluded that increased survival and growth associated with the use of tall stock are sufficiently promising that any short-term savings resulting from use of small trees should be reviewed critically by land owners and managers.

D. Evaluating Competition: Factors to Consider

Competition in a plant community usually begins when the immediate supply of a necessary factor falls below the combined needs of the associated vegetation. Vegetative competition is very difficult to measure, and the cause-effect relationships between growth and survival are often obscure (Bella 1971). Competition, which in part is a function of the amount of spatial overlap between plants, must be considered as a dynamic process. In perennial brushfields, the growth habits of all dominant vegetation on a site must be evaluated through the period of establishment for brush and conifer for accurate interpretation of plant interactions. A study of competition cannot be conducted independent of succession, for the ability to predict what type of vegetation will colonize a clearcut under given conditions affects the future management situation, hence the selection of species, size of planting stock, and the probability of success (Overton 1972).

Individual plants and species have long been recognized by their growth responses as phytometers of their environments. The occurrence and relative dominance of a species on a site is largely a result of the margin between the sum of adverse effects of all the interacting environmental factors and the tolerance of the available species (Bailey and Poulton).

In general, measures of competition provide the link between the tree seedling and the vegetation surrounding it. Quantitative estimates can serve as a basis for projecting rates of growth and prospects of mortality.

In evaluating competition stresses of tree seedlings, it is desirable to have some method that expresses the position of a tree relative to an integrative index of the influences of its neighbors in three dimensions. In a study of competitive growth relations, a main problem is in separating the competition effects from the influences of other factors such as history of the tree and genetic characteristics, as well as microsite and climatic variation.

A number of competitive evaluation techniques and indices have been developed for trees of various sizes (Bella 1971, Arney 1972, Moore et al. 1973, Hatch et al. 1975, Keister and Tidwell 1975). There is much variation in exact procedures used, but many rely on measures of crown surface area, volume classes, basal areas and diameter growth. Often mathematical models are developed which describe growth relations between plants.

Many of these formats are applicable to conifers in stands greater than 15 years old, where the main competitive effects are from other crop trees rather than seral brushy vegetation. There is a need, therefore, for reliable methods with which to evaluate competition between younger conifer trees and other plant species.

Techniques that have been used for small trees include measurements of the rate of weed invasion, the number of weeds or shrubs in a given area, and/or the heights, diameters and growth characteristics of competing species (Allen 1969). One approach used by Opie (1968) evaluates competition within a tree's influence zone, which he defines as the area over which a tree competes for site factors. The working hypothesis behind this method is that the total competitive effect in each tree is a function of the relative influence zone overlap between a seedling and its competitors, thus the effect of individual competitors depends on their size relative to that of the subject trees.

A similar approach used by Iverson (1976) evaluates competition from three levels of influence. Vegetation surrounding a seedling is separated into overtopping, encroaching and ground cover influences, and estimates of the amount of competition at each level are obtained to evaluate overall competitive relations.

Still another approach is to evaluate distances between competing vegetation and subject trees. While not directly related to evaluating competition, work by Reukema (1959) and by Smith (1958) on the influence of spacing of trees at time of planting, has shown that Douglas-fir seedlings grow larger when given the space to grow. Additional work by Isaac (1937) has also shown that after ten years of age, trees grown at a wider spacing showed greater height growth. Therefore, while these ideas refer to the spacing of crop trees, presumably the spacing of conifers in relation to brush species may show a parallel relationship. Only open grown trees growing on favorable sites may have the ability to utilize site resources without interference by competitive influences.

In general, quantifying competition should add to an understanding of the composition, productivity and long-term success of conifers in a brushfield. By evaluating tree growth under a variety of different types of competitive interactions, one should be able to predict the potential of tree seedlings of given characteristics, and how this potential is modified by interactions in brushfields. This thesis examines some specific relations between Douglas-fir seedlings and associated species in an attempt to describe competition in terms of characteristics of both conifer and competitor and their relation to each other.

III. METHODS AND PROCEDURES

A. Research Approach

The International Paper stock type study was initiated in 1970 to investigate the juvenile growth of various Douglas-fir planting stock. At that time there were indications that container grown stock could be planted at a faster rate and with greater efficiency than 2-0 bare-root stock. As a result of this it was speculated that seedling survival and growth could be increased. The field study was designed in conjunction with International Paper's regular planting program, and records of survival and injury to individual seedlings were recorded by International Paper Company personnel until 1974.

Initial evaluations of this data indicated that transplant and bare-root stock, rather than containerized stock, performed better in the field. Not only was survival greater, but growth appeared to be better on brushy sites.

A subsequent investigation of these seedlings by Iverson (1976) evaluated survival and growth data in terms of stock type characteristics and one year of competition estimates. Results from this study indicated that both survival and growth are related to the initial height of seedlings, with larger stock types performing better on a wide variety of brushy sites.

At this point, it was of interest to determine how juvenile tree growth is influenced as the seral vegetation on a site changes. To this end, the vegetation surrounding individual trees was re-evaluated so a competition trajectory could be established. A goal of the present analyses was to synthesize previously recorded data with a second year of competition estimates, and to re-evaluate the growth of various stock types relative to the development of the vegetation surrounding these tree seedlings.

B. Description of Study Sites

1. Location of Sites and Experimental Design

The experimental study sites are established at various locations throughout the Hinman Tree farm, owned by the International Paper Company, and situated in the Coast Range between Gardiner and Lorane, Oregon (Figure 1). A total of seventeen study sites were established by International Paper Company personnel during the five planting seasons between 1970 and 1974. To obtain a wide spectrum of information, the sites were located on different aspects and slopes in a randomized block arrangement. Each study site (block) was further divided into six plots. Each plot contained between three and six Douglas-fir stock types (experimental units), including container-grown, seedlings and transplants; 25 trees of each type were planted on the plots in rows with an approximate 6 x 6 foot spacing. Table 1 shows the numbers of each stock type planted during each of the respective planting seasons. Figure 2 illustrates a typical plot layout.

2. Geology and Soils

Based on the natural vegetation classification system developed by Franklin and Dyrness (1973), the study sites are all located in

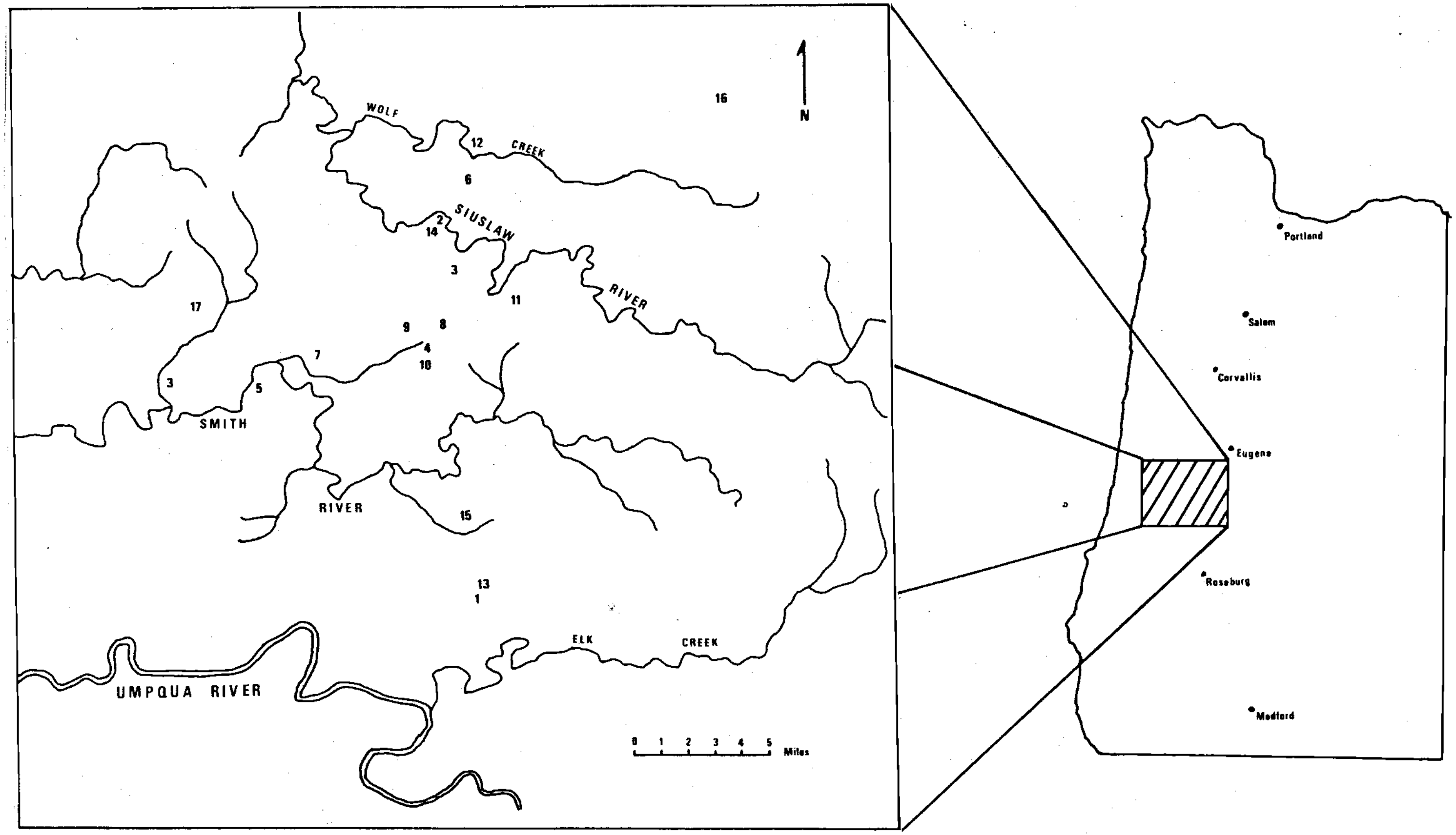

Figure 1. Map illustrating location of study sites.

TABLE 1. Numbers and types of seedlings established by year.

	1970	1971	1972	1973	1974
1-0 plugs	700	575	600	150	300
1-0 bullets	700	575	600	150	
2-0 seedlings	700	575	600	300	300
1-1 transplants		150	600	150	
1-2 transplants	700		300		
2-1 transplants		150	300	150	300
US plugs					300
TOTALS	2800	2025	3000	900	1200

Grand Total: 9,925

Figure 2. Twin sisters location (site #5) illustrating typical plot layout. Photograph taken in 1975.

the 'Coast Range Province.' The area is underlain by the Flournoy and Tyee formations (Baldwin 1976). The Flournoy formation is rhythmically bedded sandstone with thin siltstone layers. The Tyee formation is rhythmically bedded with micaceous sandstone grading upward into siltstone (Baldwin 1976). Soils which have developed from this sandstone have a wide range of characteristics. Two typical groups are the Haplumbrepts (Western Brown Forest soils), and the Haplohumults (Reddish Brown Lateritic soils) which are described in greater detail in Franklin and Dyrness (1973).

3. Climate

Climatically, the Western Coast Range is characterized by warm, relatively dry summers and wet mild winters. Annual average precipitation is between 160 and 180 cm., with approximately 90% of the total precipitation falling during the winter months (Franklin and Dryness 1973). A high percentage of the precipitation is related to the movement of cyclonic storms from the Pacific Ocean to the west. Storm frequency is low during the summer season.

In terms of temperature extremes, January mean minimum temperatures vary between 0.0 and 2.5^{O}C, while July mean maximum temperatures vary between 20.0 and 27.0^{O}C (Franklin and Dyrness 1973). The area is typically overcast in winter, with frequent fogs during the summer.

4. Vegetation

The generalized vegetation map of Franklin and Dyrness (1973, pg. 45) places the study sites within the Picea sitchensis and Tsuga heterophylla zones. Typical tree species in these areas include

Picea sitchensis, Tsuga heterophylla, Tsuga plicata and Pseudotsuga menziesii. Successional species on recently disturbed sites in these areas may include Alnus rubra, Acer macrophyllum and Castanopsis chrysophylla. Early successional trends also favor development of dense shrub communities dominated by Rubus spectabilis, Sambucus racemosa var. arborescens, as well as Acer circinatum, Gaultheria shallon, and Ceanothus velutinus (Franklin and Dryness 1973). A complete list of all vegetation recorded on the sites can be found in Appendix A.

5. Additional Information

The topography of the area is described as mature, with steep mountain slopes and ridges that are often extremely sharp (Franklin and Dyrness 1973). Figure 3 illustrates the general terrain of the study area.

Portions of the Hinman Tree farm are located within boundaries of the Oxbow burn, which started in 1966, and ultimately burned more than 40,000 acres of forested land. Six of the plots established in 1970 and all 24 established in 1971 are located in the burn. The plots reflect establishment conditions four and five years after the fire, respectively (Iverson 1976).

C. Field Procedures: Background Information and Data Collection

Background information for this thesis includes a previous thesis completed on the same study sites by Mr. Richard D. Iverson, and an additional four years of data collected by various International Paper

Figure 3. Typical terrain of the study area. Facing east from Oxbow Summit.

Company personnel, and corrected by Iverson.

Data obtained by the International Paper personnel include measurements of tree height and observations of animal damage for every surviving tree from year of establishment through 1974. Tree height and animal damage were recorded by Iverson in 1975 in addition to the following parameters:

1. estimates of vegetative competition;
2. the presence of soil ravelling around the tree;
3. the presence of debris on the tree;
4. the occurrence of top die-back;
5. the presence of chemical damage; and
6. aspect and slope measurements on each site.

Of particular interest are the procedures developed by Iverson to construct quantitative estimates of competition. Recognizing that seral vegetation may influence tree seedlings differentially from several strata, the quantification of competition for his study was divided into estimates of overtopping, encroaching and ground cover influences. Iverson describes the field procedures for estimating these influences as follows:

> "The overtopping influence was estimated by visualizing the percent occupancy of vegetation in an imaginary cone projected at 60^{o} around its axis above each seedling, with the apex of the cone at the bottom of the 1975 internode.
>
> An estimate of the amount of encroachment was derived by determining what proportion of the area surrounding the seedling was occupied by non-overtopping woody vegetation. Only the vegetation near the drip-line of the seedling was counted when determining the 'percent encroachment.'
>
> The amount of ground cover around each tree was classi-

fied into four categories with a heavy amount of ground cover being classified into category four and a light amount into category one. However, for purposes of the statistical analyses, the ground cover estimates were analyzed on a percent basis (i.e., a class of four was the same as 100%, three was 75%, two was 50%, and one was 25%).

A record of the species of competing woody vegetation was also kept to facilitate the evaluation of differences in survival and growth which may be attributable to the association of the seedlings with certain species groups."

Figure 4 illustrates the use of the 'imaginary cone' and 'drip-line' techniques to estimate competition.

All trees on the plots were remeasured for the parameters listed above excluding aspect and slope, during the summer of 1977. The second year of competition data will provide time-sequential information necessary to establish a competitive influence trajectory, and a useful method for evaluating the performance of the coniferous trees under changing competitive stress.

In addition to the previous measurements, supplementary data was taken to help quantify competitive influences including:

1. Average herbaceous ground cover depth (rounded to the nearest one-half foot) within a 5' radius of each tree;

2. Height and radial growth of competing overtopping species, estimated for a two-year time period;

3. Distance between stems of the tree seedlings and stems of any overtopping competitors;

4. Estimated height of competing overtoppers above the tree seedlings;

5. Estimates of which vegetation will dominate the site ten years in the future.

Data collected on trees established in 1972, 1973 and 1974 will

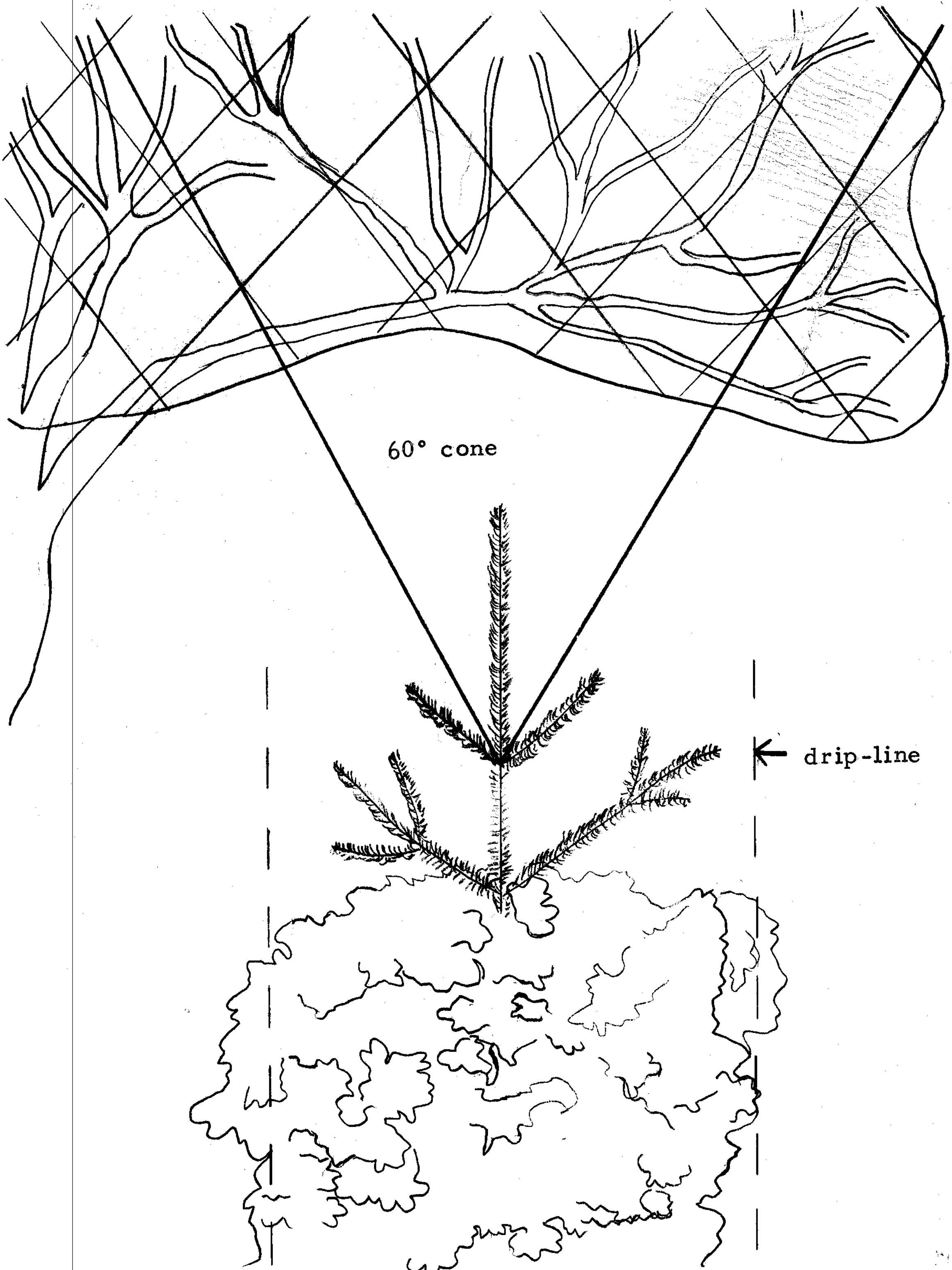

Figure 4. Use of 'imaginary cone' and 'drip-line' techniques to estimate competition.

not be included in this analysis, as the early data records for these trees were not in finalized form for computer evaluation. Information analyzed, then, included only data from trees established in 1970 and 1971, and involved a data base of over 4,000 trees.

IV. STATISTICAL ANALYSES AND RESULTS

The Oregon State University-International Paper cooperative stock-type study is a time-sequential research project which requires that continuity be maintained in the research and development of the data. The statistical analyses for this thesis were designed to facilitate direct comparisons with observations made in 1975, and to build from previously observed patterns and relationships. This investigation is primarily concerned with how growth of Douglas-fir during the first seven years is influenced by surrounding seral vegetation and seedling morphological characteristics.

The statistical analyses can be divided into several sections, each of which examines data from a different perspective. Section A evaluates data gathered in 1977 with techniques developed by Iverson in 1975. Analyses in section B explore relationships between initial seedling height and tree growth response. Section C synthesizes information gathered in 1975 and 1977 to evaluate tree growth response and changes in competitive status over time. Finally, section D examines differences between types of damage sustained by different stock types during the 1977 field season.

Due to intrinsic differences in the data sets for trees established in 1970 and 1971, analyses for the 1971 trees were modified in most instances to account for an unbalanced number of surviving trees by stock type and inadequate sample sizes in certain vegetation groups.

Section A. Covariance Analysis: Investigating the importance of stock type and initial size in determining seedling growth

The first analyses utilized the covariance technique employed by Iverson (1976) to investigate the effects of several variables on the height growth of seedlings. Figure 5 illustrates the relationship of the present covariance analyses to those performed previously. Iverson examined 1975 height growth in relation to seral vegetation present in 1975. Similarly, this analysis examined 1977 height growth in terms of vegetation present in 1977 (identified hereafter as "77"). In addition, to allow time for competitive influences to be expressed, 1977 height growth was also examined by vegetation present in 1975 (identified hereafter as "75-77").

Prior to these analyses, trees that had sustained damage detrimental to their growth were deleted. Undamaged seedlings were then partitioned into six groups based on the type of vegetation surrounding the tree. These vegetation groups are summarized in Table 2 and by Iverson (1976) as follows:

> "Trees in group one were associated with vegetation that had a high dominance potential (ability to dominate the site at some time in the future) and exerted an overtopping influence. The associated vegetation in this group included *Acer macrophyllum*, *Cornus nuttalli*, *Cornus occidentalis* and *Alnus rubra*. Trees in group two were associated with vegetation that had an important overtopping effect on the tree but whose dominance potential is limited by maximum potential height. *Rubus parviflorous* and *Pteridium aquilinum* were included in this group. Trees in group three were associated with woody vegetation that had a limited overtopping influence and a low dominance potential. Many of the woody shrubs encountered on the plots were included in this group and the specific species are detailed in Appendix A, where all vegetation encountered in the study is delineated by classes. Trees in group four were assoc-

1970 Trees

1976

1975 height growth correlated with 1975 vegetation groups.

1978

Analysis I. Covariance Analyses

1977 height growth correlated with 1977 vegetation groups.

1977 height growth correlated with 1975 vegetation groups.

1971 Trees

1975 height growth correlated with stock type and site location.

Analysis II. 1971 Covariance

1977 height growth correlated with stock type and site location.

Figure 5. Relationship of the present analyses of covariance (Section A) to those performed by Iverson in 1976.

TABLE 2. Vegetation Group Criteria

Group	Characteristics
One	Vegetation surrounding tree has high dominance potential; seedling is overtopped.
Two	Dominance potential of vegetation surrounding the tree is high, but is limited by maximum potential height; seedling is overtopped.
Three	Vegetation surrounding tree has low dominance potential; seedling is overtopped.
Four	Vegetation surrounding tree has low dominance potential; seedling is encroached.
Five	Vegetation surrounding tree has a low dominance potential; seedling is associated with only low-lying herbaceous species.
Six	No significant vegetation surrounding tree.

> iated with the same types of species as in group three but the vegetation exerted an encroaching rather than an overtopping influence. Trees in group five were associated with just the ground cover species. Pteridium aquilinum was included in this class if it did not exert an overtopping influence. Therefore, the trees in this group experienced competition only from low-lying herbaceous vegetation. Finally trees in group six did not have competitive vegetation associated with them. In this group, the area surrounding the tree was essentially bare."

Analysis I - 1970 Covariance Test: effect of stock type on growth

In the model for 1970 trees seven-year height growth was the dependent variable with stock type independent of height as the factor being tested. Both initial height of the seedling at time of planting and competitor density estimates were used as covariables. Density in this analysis, refers to the numerical measure of competitive influence as described in the field procedures. For overtopped trees (vegetation groups 1, 2 and 3) density was the percentage cone occlusion. For trees with encroaching vegetation (group 4), density was the percentage encroachment. Density for trees associated with ground vegetation (group 5), was the percentage ground cover. Zero values were recorded for density in vegetation group 6. A separate analysis was conducted for each vegetation group. The rationale for this approach is that it offers an independent test of stock types, regardless of their initial size and status with respect to vegetation groups.

Results of the analyses of covariance testing the effect of stock type on growth (77) are discussed by vegetation group. Table 3 summarizes the adjusted mean growth and deviation from the overall vegetation group means for all stock types.

For trees associated with overtopping vegetation in group one, the covariate initial seedling height was important in explaining variation in seven-year growth, but density of competitors was not significant. Results also show a significant difference in the adjusted seven-year growth between stock types, with 2-0 seedlings having the largest growth followed by 1-2 transplants, 1-0 plugs and 1-0 bullets. This indicates that 2-0 seedlings grew rapidly for a given size, but the larger seedlings displayed greater growth on an absolute scale (Table 1, Appendix B).

Density was important in explaining variation in seven-year growth of overtopped trees in group two, but initial seedling height was not significant here. There were no significant differences in adjusted (for the covariates) seven-year growth between stock types, although 1-0 plugs and 1-0 bullets grew more than either 2-0 seedlings or 1-2 transplants. The number of observations for the 2-0 seedlings and 1-2 transplants in this group were quite low, which suggests that most of the bare-rooted seedlings were able to outgrow their overtopping competitors in earlier years. The low number of seedlings still remaining in this group may be those whose initial physiological condition was poor, hence they were not able to outgrow competitors and their present growth rates remain low. Also of interest, is that of all vegetation groups examined, growth was always lowest in group two where vegetative competition came solely from bracken or thimble-

TABLE 3. Adjusted mean growth and deviation from the overall 1977 vegetation group means for all stock types.

Stock Type	Adjusted Mean Growth (cm)	Deviation (cm)	No. of Observations
Vegetation Group One			
P	137.31	-35.96	9
B	110.72	-62.55	4
2-0	247.90	74.63	13
1-2	197.14	23.87	24
Vegetation Group Two			
P	87.66	27.28	33
B	84.08	23.70	24
2-0	43.04	-17.34	9
1-2	26.73	-33.65	2
Vegetation Group Three			
P	160.92	-8.22	44
B	151.67	-17.47	28
2-0	174.40	5.26	30
1-2	189.56	20.42	35
Vegetation Group Four			
P	264.91	-18.00	83
B	238.48	-44.43	79
2-0	315.04	32.13	157
1-2	313.21	30.30	249
Vegetation Group Five			
P	178.05	-8.54	75
B	165.64	-14.65	62
2-0	201.24	14.65	118
1-2	201.44	14.85	128
Vegetation Group Six			
There were no observations of trees without competing vegetation in 1977.			

berry (Table 2, Appendix B). Figure 6 illustrates a tree seedling overtopped by bracken.

Differences in the seven-year growth for overtopped trees in group three are explained by both density and initial seedling height, although density explained more variation. There were no significant differences in adjusted seven-year growth between stock types other than those attributable to initial height (Table 3, Appendix B).

The adjusted growth of trees associated with encroaching vegetation in group four was significantly different between stock types, with 1-2 transplant and 2-0 seedling stock having the greatest growth, followed by the 1-0 plugs and bullets. Both initial height and density were important in explaining differences in growth, with initial height explaining more of this variati n. In addition, the highest growth values observed came from trees associated with encroaching vegetation in this group (Table 4, Appendix B).

Variations in growth for trees associated with low-lying herbaceous vegetation, group five, were explained by initial height and density, with initial height explaining more variation. Again there was a significant difference in the adjusted growth between stock types, with growth for 1-2 transplants and 2-0 seedlings almost equal and greater than the growth for 1-0 plugs and 1-0 bullets (Table 5, Appendix B).

Although there were no observations of trees without competing vegetation present (group six), vegetation groups five and six are similar in that both represent substantially disturbed sites. A

Figure 6. Tree seedling overtopped by bracken.

lack of significant vegetation in these groups, particularly when other environmental conditions such as light and moisture are apparently favorable, suggests that logging activities have adversely affected the sites through soil compaction, loss of A_1 horizon and/or incorporation of bark into the soil. The mean growth of trees in these vegetation groups is also less than that with encroaching vegetation in group four. These observations suggest that factors other than competing vegetation are also influencing the growth of these trees.

Figures 7 and 8 illustrate the mean growth for all stock types, adjusted and unadjusted for initial height and density, under the different vegetation groups, respectively. Results with and without covariance are quite similar, although unadjusted growth shows a somewhat greater spread among stock types, reflecting their differences in initial heights.

In general, coefficients of multiple determination (r^2) for all the previous analyses were low. This indicates that the ability of the independent variables to explain variation in seven-year growth within vegetation groups is limited.

Results from the second analysis of covariance, testing the effect of stock type on growth (75-77), are presented by vegetation group. Table 4 summarizes the adjusted mean growth and deviation from the overall vegetation group means for all stock types.

Unlike the results from the previous regression analysis, variation in the seven-year growth of overtopped trees in group one was

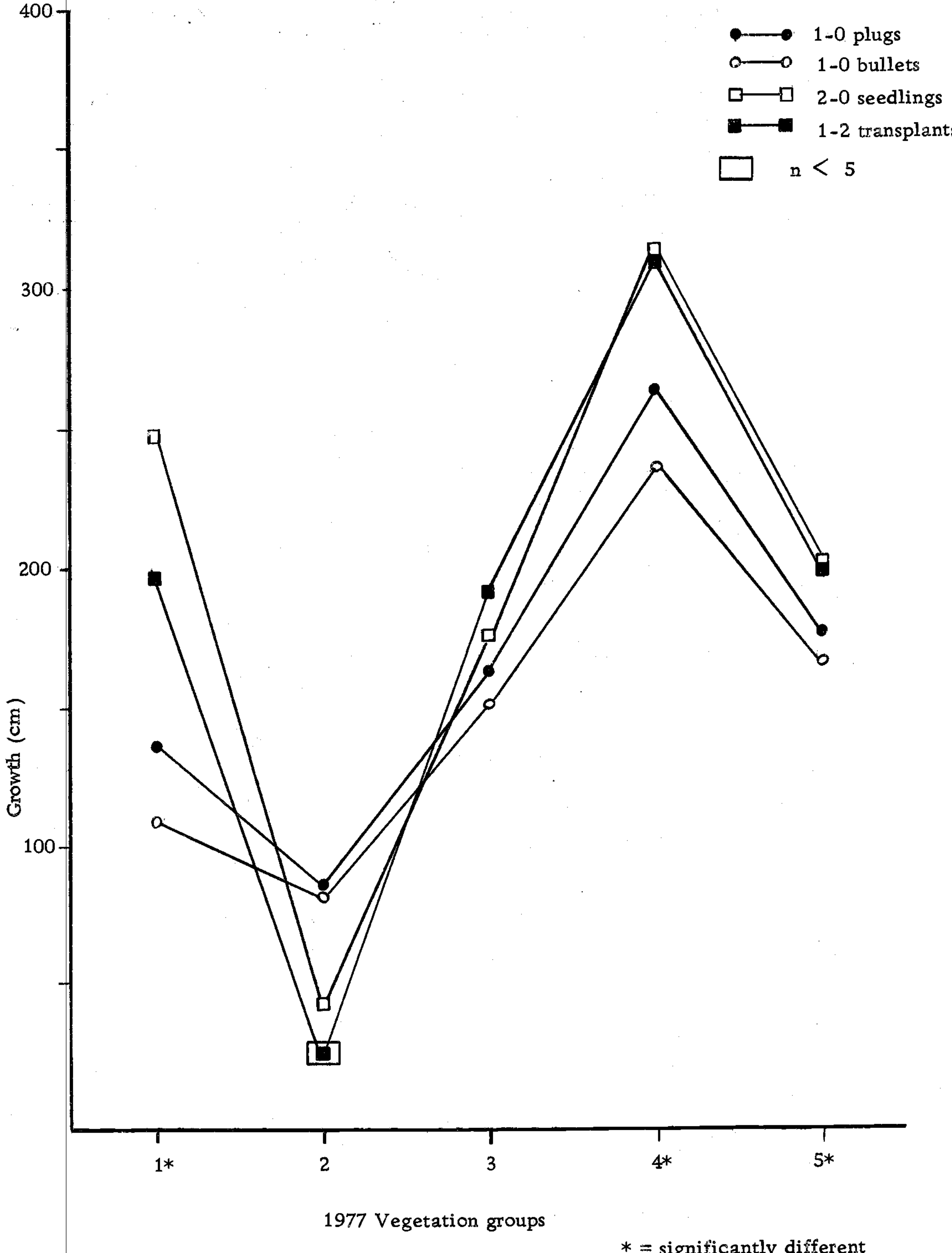

Figure 7. Average seven-year growth, adjusted for initial height and density, against 1977 vegetation groups. 1970 trees.

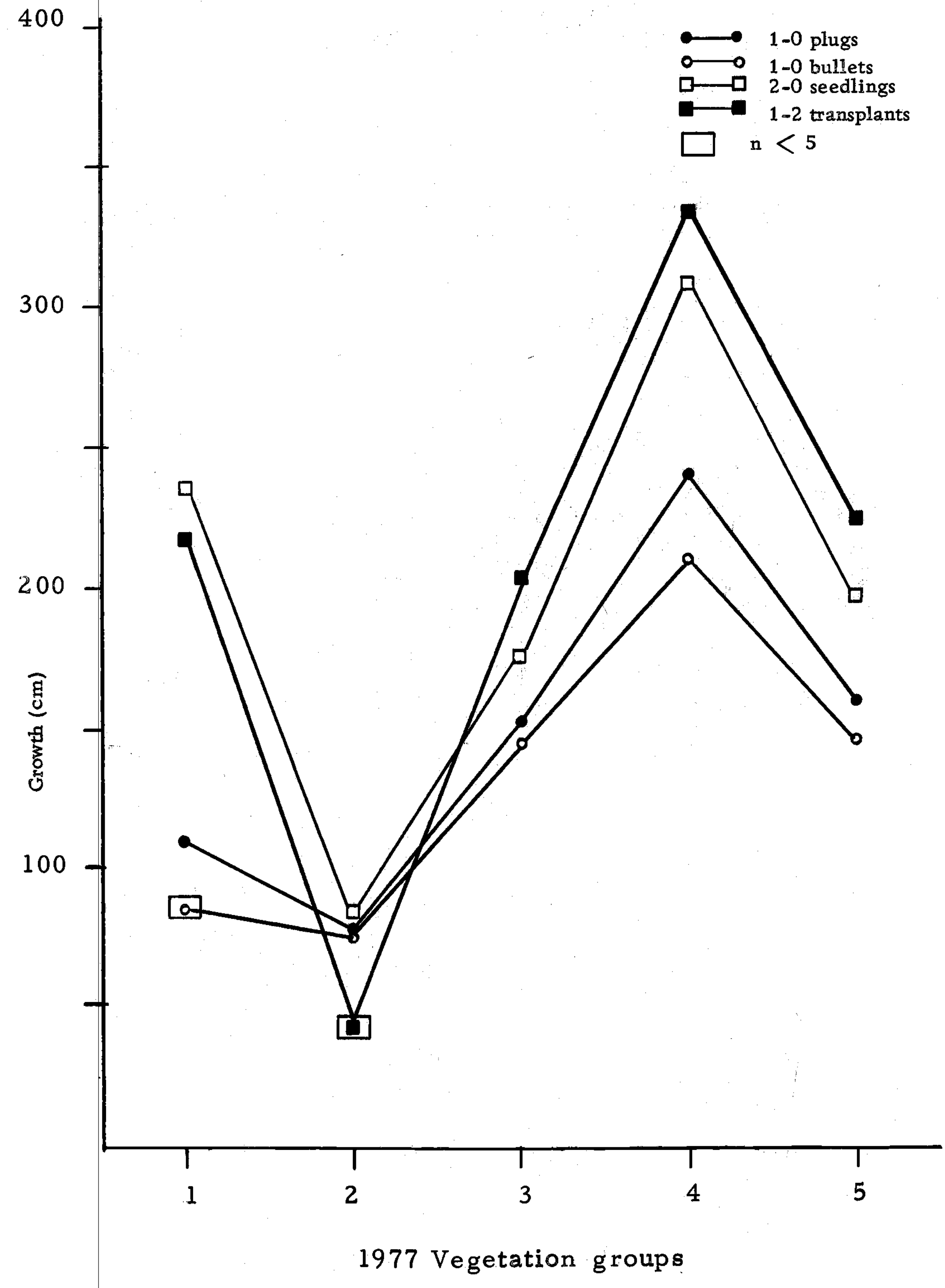

Figure 8. Average seven-year growth against 1977 vegetation groups. 1970 trees; unadjusted for covariables.

TABLE 4. Adjusted mean growth and deviation from the overall 1975 vegetation group means for all stock types.

Stock Types	Adjusted Mean Growth (cm)	Deviation (cm)	No. of Observations
Vegetation Group One			
P	171.49	-8.02	13
B	116.82	-62.69	2
2-0	244.97	65.46	7
1-2	184.75	5.24	20
Vegetation Group Two			
P	114.36	-14.95	45
B	117.29	-12.02	36
2-0	147.06	17.75	29
1-2	138.51	9.20	22
Vegetation Group Three			
P	148.74	-30.96	41
B	146.11	-33.59	28
2-0	207.99	28.29	33
1-2	215.96	36.26	51
Vegetation Group Four			
P	221.41	-54.19	7
B	259.16	-16.44	15
2-0	341.93	66.33	39
1-2	279.91	4.31	34
Vegetation Group Five			
P	248.54	-0.51	129
B	216.21	-32.84	111
2-0	263.78	14.73	203
1-2	267.68	18.63	300
Vegetation Group Six			
P	182.24	-18.11	10
B	189.08	-11.27	5
2-0	223.78	23.43	16
1-2	206.31	5.96	11

explained by both initial seedling height and density, with initial height explaining more variation. There were no significant differences in the seven-year growth when adjusted for the covariables, between stock types (Table 6, Appendix B).

Similar results were obtained for overtopped trees in group two initial seedling height and density explained variation in the dependent variable and there were no significant differences in the adjusted seven-year growth between stock types. Again out of all vegetation types, growth was least for seedlings associated with bracken and thimbleberry (Table 7, Appendix B).

The variation in seven-year growth for overtopped trees in group three was explained by both initial height and density. In addition, the differences in mean seven-year growth between the stock types were significant, with 1-2 transplants having the greater growth followed by 2-0 seedlings, 1-0 plugs and bullets (Table 8, Appendix B).

There were significant differences between seven-year stock type growth for trees associated with encroaching vegetation in group four. The greatest growth per unit of seedling size was attained by 2-0 seedlings. Initial seedling height was important in explaining variation, while density was insignificant (Table 9, Appendix B).

Differences in growth between stock types were significant for trees associated with low-lying herbaceous vegetation in group five. Both initial seedling height and density were important in explaining this variation, although initial height explained more of the variation (Table 10, Appendix B).

For trees with no competing vegetation recorded, there was not a significant difference in the adjusted growth between stock types. Also, initial seedling height was not important in explaining variation in seven-year growth (Table 11, Appendix B). Figures 9 and 10 illustrate the mean growth for all stock types, adjusted and unadjusted for initial height and density, as they are associated with the different vegetation groups.

As in the first covariance analyses (77), multiple correlation coefficients for these analyses were also low but highly significant Again this indicates the limited ability of the independent variables to explain variation in seven-year growth within any given class of competitor.

Figure 11 illustrates the percentage of trees, by stock type, associated with each vegetation group in 1975 and 1977. Most obvious is a migration of trees from group five in 1975 to group four in 1977. This suggests that the vegetation on the site has increased in stature and the species have changed from herbaceous to woody. The percentages of trees associated with vegetation in groups two and three have also decreased to some extent, this indicating that a small percentage of overtopped trees in 1975 were able to outgrow their overtopping influence during the two-year period between 1975 and 1977.

In both covariance analyses (77 and 75-77), a pooling of observations in all vegetation groups would have increased the total variance greatly. All of the increase would have been attributable to the vegetation type effect, and would have shown vegetation to have an

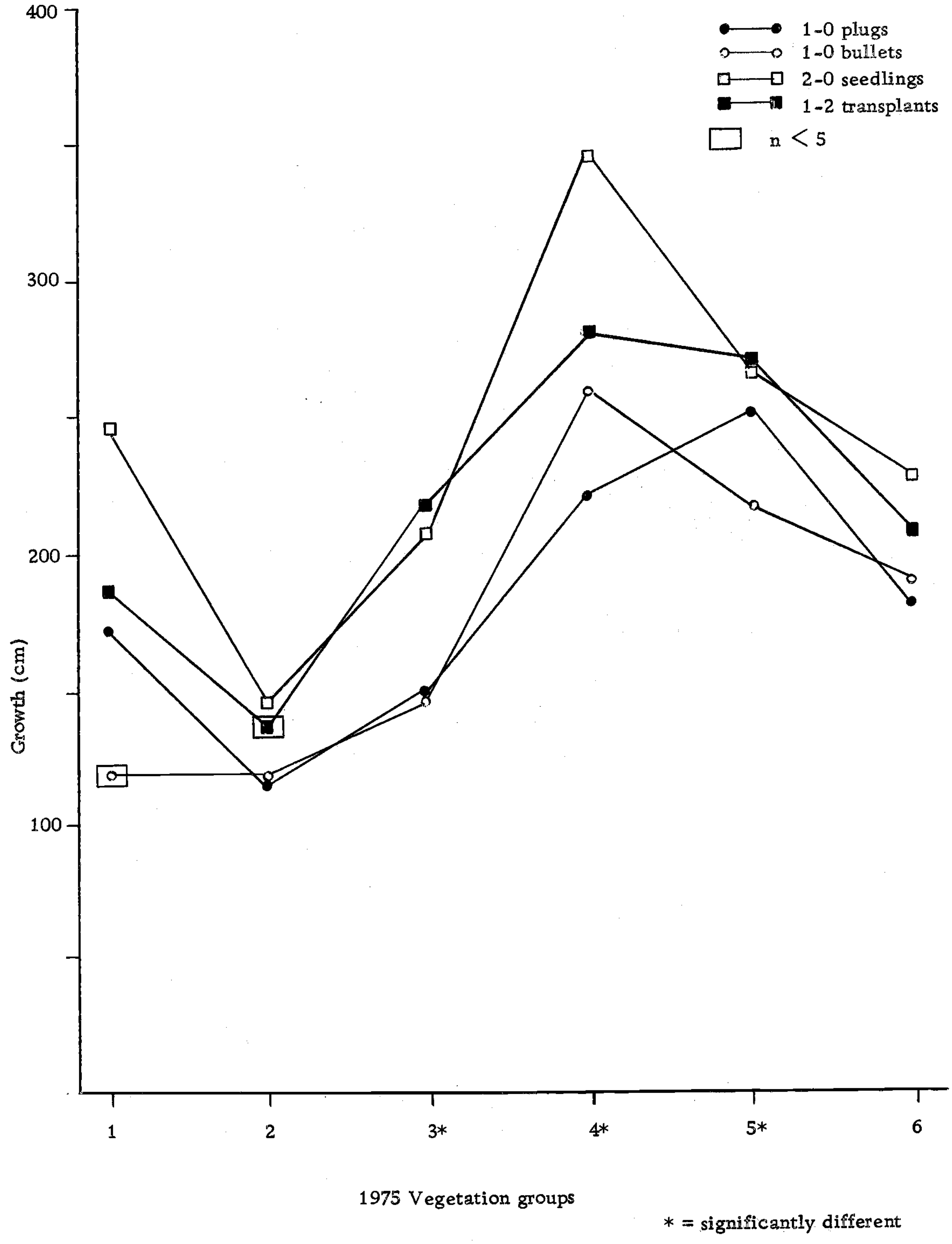

Figure 9. Average seven-year growth, adjusted for initial height and density, against 1975 vegetation groups. 1970 trees.

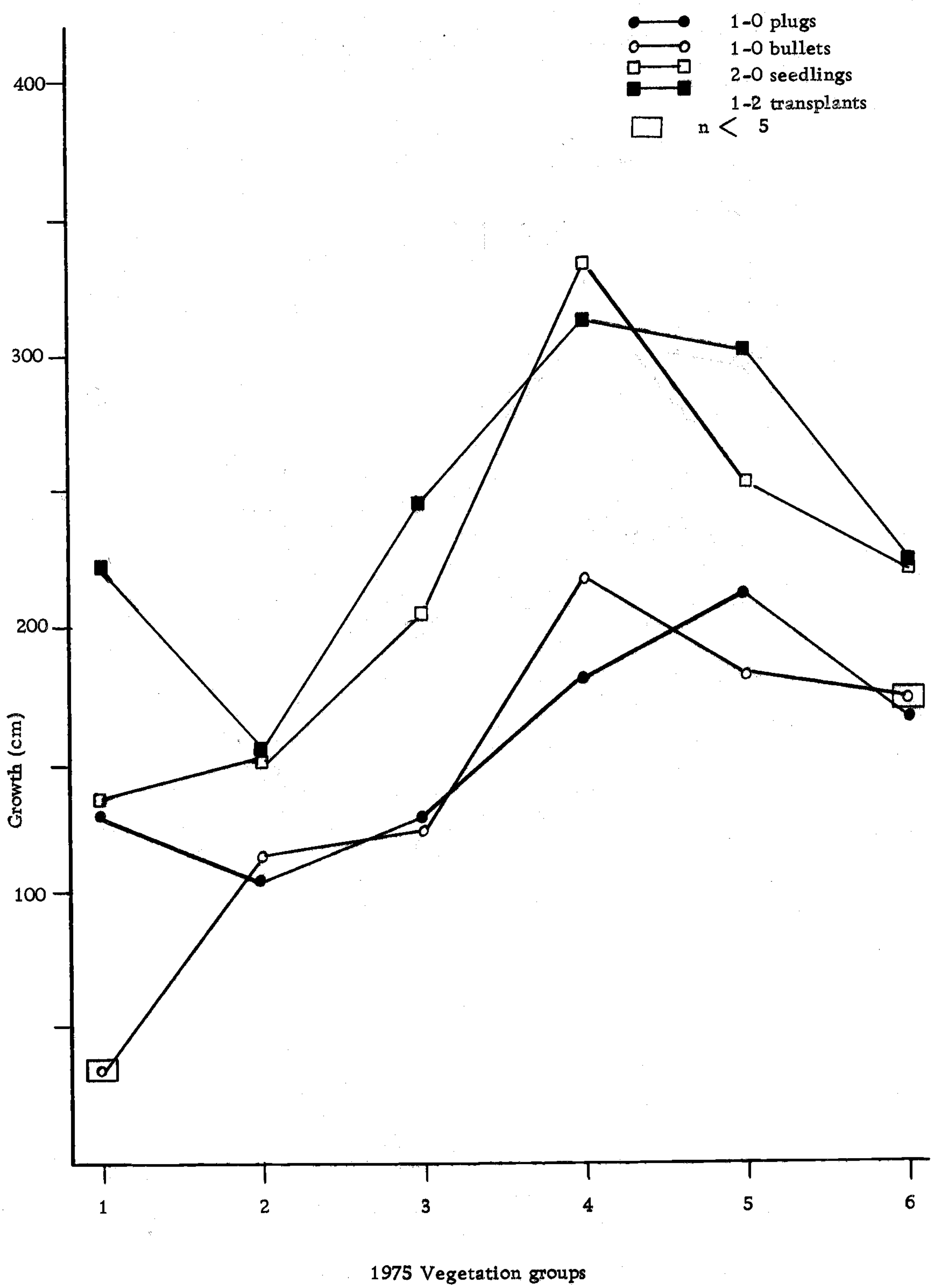

Figure 10. Average seven-year growth against 1975 vegetation groups. 1970 trees; unadjusted for covariables.

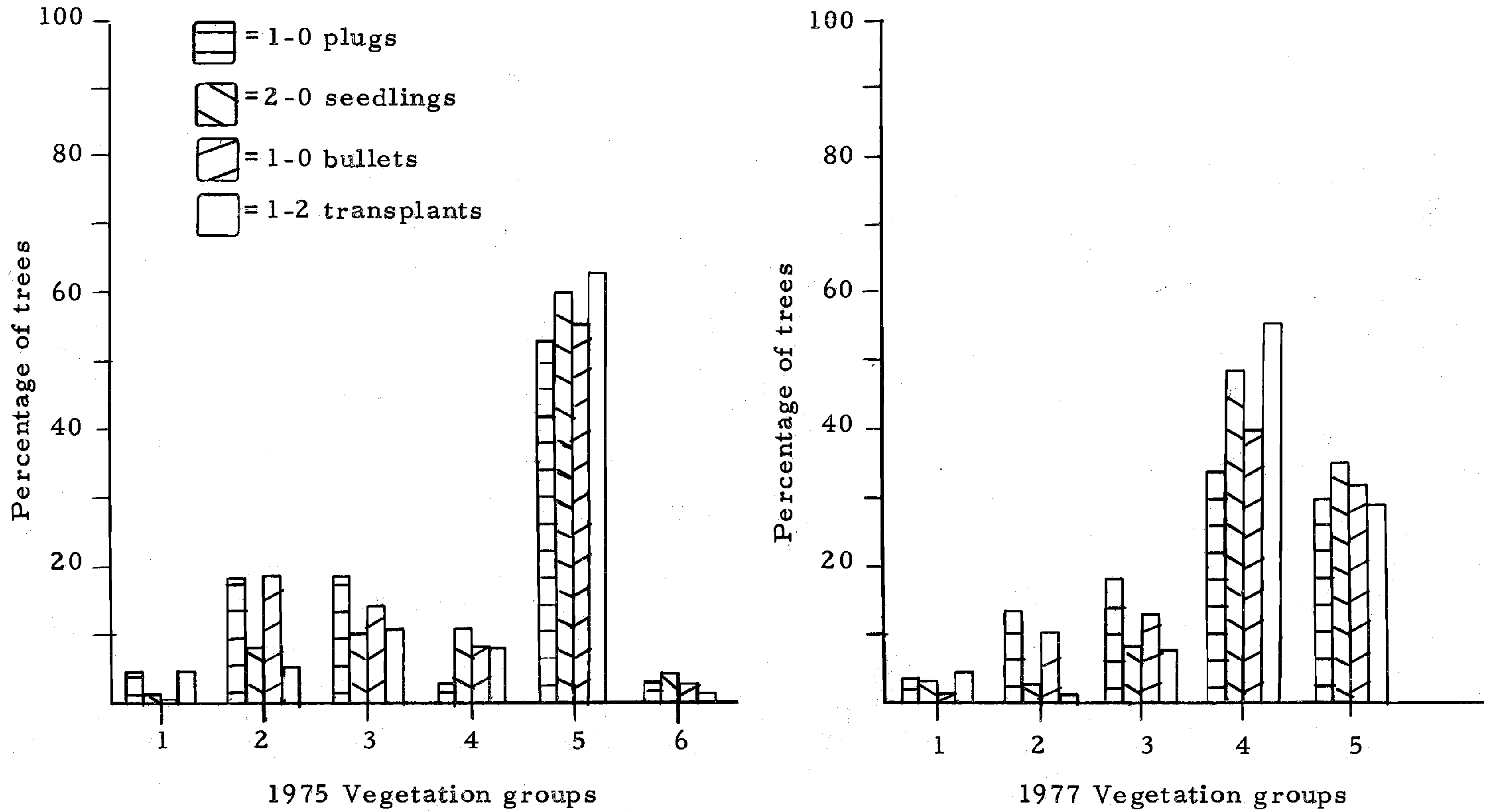

Figure 11. Percentage of trees in each vegetation group, by stock type. 1975 and 1977 vegetation groups; 1970 trees.

important influence on growth. It also would have greatly increased the percentage of variation explained and improved the predictive value of the analyses.

Analysis II - 1971 Covariance: effect of stock type and site on growth

Only one analysis of covariance was performed in the model for 1971 trees due to uneven data distribution. Damaged seedlings were eliminated from the data set to reduce confounding, but trees were not partitioned into vegetation groups. For this analysis, six-year height was investigated as a function of stock type and planting site. Initial seedling height was the covariable.

Results of this analysis of covariance indicated significant differences in the adjusted six-year tree growth both between stock types and between sites, with 2-1 transplants having the greatest growth, followed by 2-0 seedlings, 1-1 transplants, and 1-0 plugs and bullets. In addition, initial height was important in explaining this variation in growth (Table 12, Appendix B).

Figure 12 illustrates mean six-year growth for all stock types adjusted and unadjusted for initial height. As in the 1970 data, the adjustment for seedling height tends to decrease the differences attributable to stock type.

Comparisons of results from all the previous regressions with results obtained in 1976 show some interesting trends. The significance of all variables in each analysis of covariance performed are summarized in Table 5.

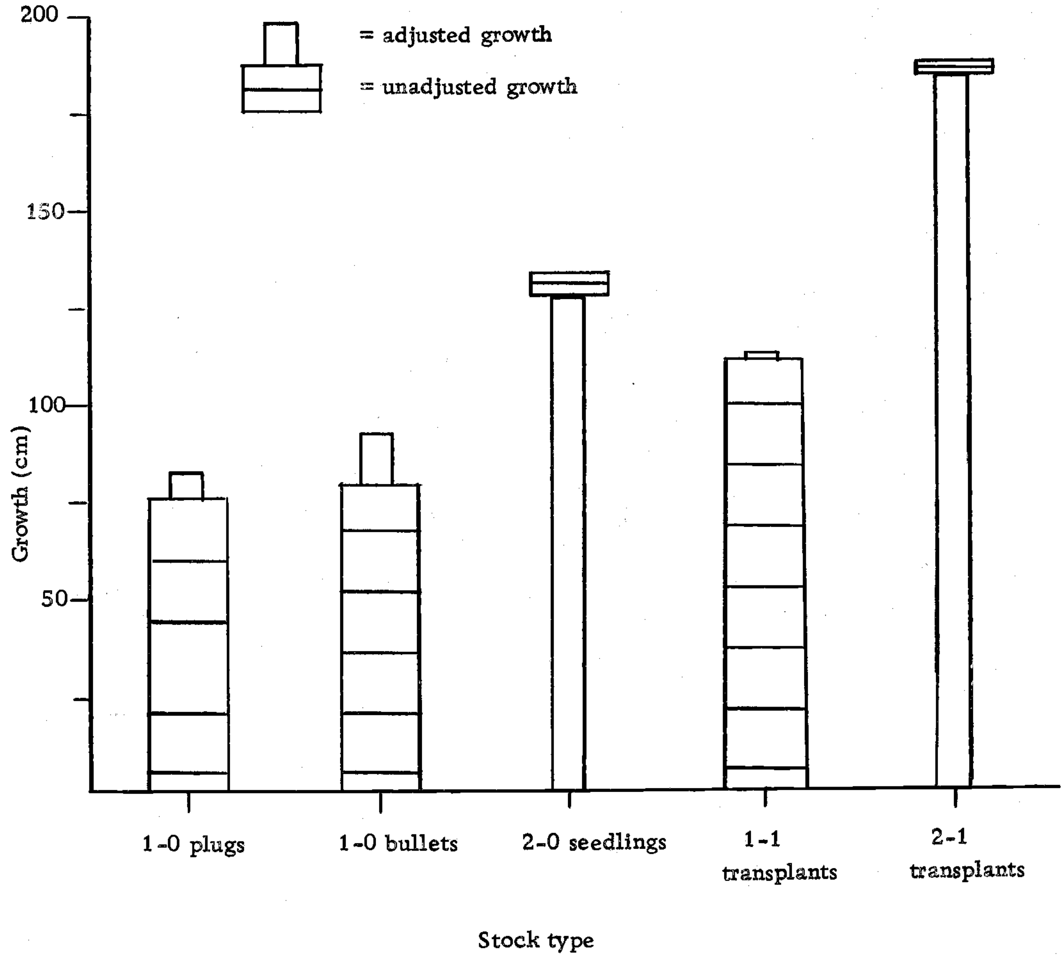

Figure 12. Average six-year growth, adjusted and unadjusted for initial height, by stock type. 1971 trees.

TABLE 5. Summary of analysis of covariance results for all model factors 1975 and 1977.

Factors / Analysis	Stock Type 75[1]	Stock Type 77	Stock Type 75-77	Initial Height 75	Initial Height 77	Initial Height 75-77	Density 75	Density 77	Density 75-77
1970 Trees									
Vegetation Group One	NS	S	NS	S	S	S	S	NS	S
Group Two	NS	NS	NS	S	NS	S	S	S	S
Group Three	S	NS	S	S	S	S	NS	S	S
Group Four	S	S	S	S	S	S	NS	S	NS
Group Five	S	S	S	S	S	S	NS	S	S
Group Six	NS	-	NS	S	-	NS	-	-	-

1971 Trees

Factors	Stock Type 75	Stock Type 77	Site 75	Site 77	Initial Height 75	Initial Height 77
	S	S	S	S	S	S

[1] 75 = growth to 1975 correlated with vegetation present in 1975.
77 = growth to 1977 correlated with vegetation present in 1977.
75-77 = growth to 1977 correlated with vegetation present in 1975.

S = Significant at 0.05 level or above.
NS = Not Significant at 0.05 level.

For 1970 trees, similar patterns emerge as expected, in the data sets which examine five-year growth by 1975 vegetation groups (75), and seven-year growth by 1975 vegetation groups (75-77). Identical results were obtained in terms of significant differences in adjusted mean growth between stock types under different vegetation groups. The importance of initial height in explaining variations was also similar, and only in group six (no competition recorded) were different results obtained; 75-77 data show that initial height is no longer important in explaining growth variations six years after planting where all trees are clearly dominant. The only other discrepancy between these data sets shows density significant in explaining growth variation at seven years but not at five years for overtopped trees in group three and five.

Results from analyses examining seven-year growth by 1977 vegetation groups (77) were similar in most respects to the previous data sets but different patterns also emerge. This in part may be due to change in the competitive status of vegetation surrounding the tree between 1975 to 1977. In addition, although identical field procedures were used to estimate seedling competition, this information was recorded by different persons in 1975 and 1977. This may have influenced results to a minor extent. Discrepencies between this set and the previous data sets are discussed below.

Unlike the previous data sets, significant differences were found in the seven-year growth between stock types for overtopped trees in vegetation group one. Also, no significant differences were found between stock types associated with overtopping vegetation in group three and there were no records of trees associated with no vegetation. Initial height was not important in explaining variation in growth for trees in group two. Also, density was not significant in explaining variation for overtopped trees in group one, but was significant for overtopped trees in group three.

In summary, there is general agreement in results from all data sets for 1970 trees (75, 77 and 75-77). Points of discrepancy occur as to the significance of certain dependent variables in different vegetation groups. Where differences occur, they are between analyses in which small proportions of total variance are explained by main effects.

For 1971 data, there was complete agreement in results obtained in 1975 and 1977. All variables included in the model were significant for both years' data in explaining variations in six-year growth.

Section B. Estimation of the Effects of Initial Height on Tree Growth

Important conclusions of Iverson's work were that both survival and growth of coniferous trees are positively related to initial seedling height, and that seedling growth is a function of initial size almost independent of stock type.

Stock type designation is determined by how trees are treated in the nursery in terms of number of years of seed-bed growth and number of years of transplanted growth. The growth of trees within a stock type presumably should be similar, while the growth of trees between stock types might logically be somewhat divergent.

Results of Iverson's analysis of covariance indicated that seedling size explained more of the variation in growth than did stock type for several vegetation groups. This suggests that stock type designation may not be consistently indicative of morphological characteristics, or that a characteristic such as height may be a better indicator of growth potential than the stock type designation.

The series of analyses in this section were designed to explore relationships between initial seedling size, stock types, vegetation groups and tree growth response. To this end, the analyses overlap with one another to some extent. Figure 13 summarizes the purposes and results of each analysis, and diagrams their relation to one another in terms of information flow.

Analysis III - Mean Initial Heights

To examine the amount of variation in initial heights both within and between stock types, the mean and range of initial height for all stock types were calculated.

Results from this analysis indicated a wide range of initial heights within stock types, and an overlap in initial heights between stock types. For 1970 trees, 1-2 transplants were larger than 2-0 seedlings which in turn were larger than 1-0 bullets and 1-0 plugs. For 1971 trees, 2-0 seedlings were larger than either 2-1 or 1-1 transplants. 1-0 bullets and 1-0 plugs had the lowest initial heights. There was also some variation between the mean and range of initial heights in the same stock types between 1970 and 1971. This is most

Analysis III. Mean Initial Heights

Purpose: Calculation of the mean and range of initial heights for all stock types.

Result: There is an overlap in the ranges of initial heights between stock types.

Analysis IV. Initial Height Variation

Purpose: To test if initial height is confounded by site and/or plot.

Result: Initial height is confounded by site and plot.

Analysis V. Calculation of Regression Coefficients of Growth on Initial Height

Purpose: To calculate the initial height regression coefficients. Included in the regression model is the independent variable plot, to reduce confounding. Also separate analyses are conducted for all stock types.

Result: Initial height regression coefficients calculated.

Analysis VI. Regressions with Initial Height Regression Coefficients

Purpose: To test for differences in the effects of initial height on final height and 1975-1977 height increment between sites, stock types and vegetation groups (models One and Two).

Results: There are significant differences in the effects of initial height on final height and height increment between vegetation groups. Coefficients for vegetation groups 3, 4 and 5 are positive while the coefficient for group 2 is negative.

Analysis VII. Regressions with Deletions

Purpose: To test for significant differences in the effects of initial height on final height and 1975-1977 height increment between vegetation groups, after deleting group 2.

Result: There are no longer significant differences in the effects of initial height on final height or height increment between vegetation groups. They are all the same and positive.

Figure 13. Diagram of the relationships between the analyses in Section B in terms of information flow.

noticeable for the 2-0 seedlings which had mean initial heights of 20.13 and 28.24 centimeters in 1970 and 1971, respectively (Figure 14).

Analysis IV - Initial Height Variation

To determine if initial height variation within stock types was randomly distributed over all study sites and plots, or if there was confounding between initial heights and site or plots, separate analyses of variance were conducted for all stock types, with initial height on site and plot adjusted for site.

Significant differences appeared between the initial heights of trees by stock types from plot to plot, and in all instances but two there were significant differences from site to site as well (Tables 13-21, Appendix B). This indicates that initial heights were confounded with plots and hence in the subsequent analysis, plot location was included as an independent variable in the model to reduce the effect of confounding.

Analysis V - Calculation of Regression Coefficients of Growth on Initial Height

The purpose of this analysis of variance was to obtain initial height regression coefficients (slopes) with dependent variables mean height in 1977 and 1975-1977 height increment (hereafter identified as "HT77" and "HTINC", respectively), and independent variables initial height and plot location. Differences in these initial height coefficients between sites, stock types and 1975 vegetation groups were

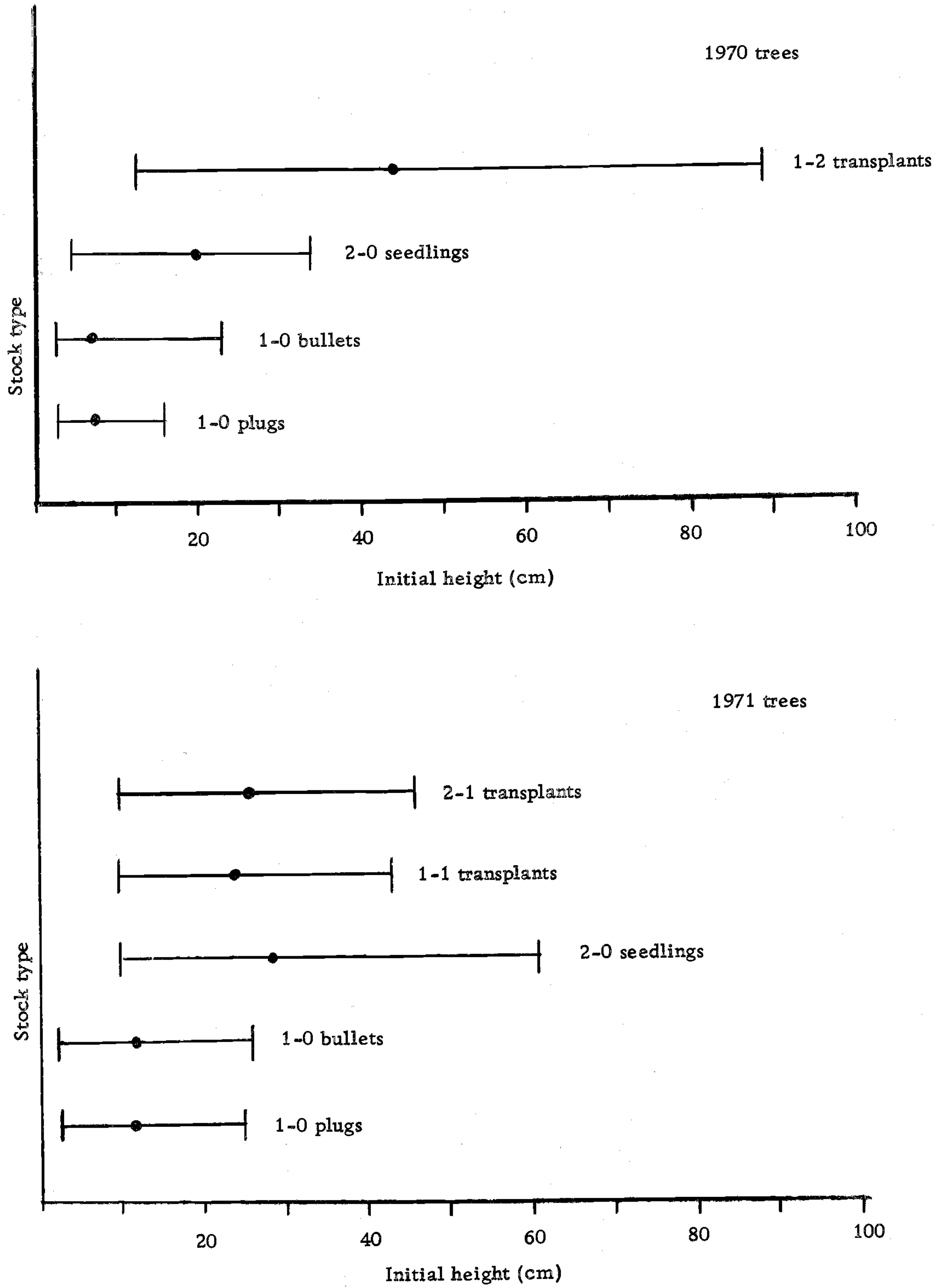

Figure 14. Mean and range of initial heights by stock type. 1970 and 1971 trees.

tested in separate analyses for all combinations of these variables.

The coefficients for initial height on growth of 1970 trees are summarized in Tables 22-29, Appendix B. Due to limited observations for several stock types, data from 1971 trees were not analyzed further.

Analysis VI - Regressions with Initial Height Regression Coefficients

This series of regression analyses was designed to test for differences in the effects of initial height on HT77 and HTINC between sites, stock types and 1975 vegetation groups. In all regressions, initial height regression coefficients calculated in Analysis V served as dependent variables. Independent variables included site, stock, vegetation group present in 1975 and a vegetation group by stock type interaction term. Vegetation groups one and six and site six were deleted due to limited numbers of observations.[1]

Variation due to stock type and vegetation group was subdivided in the above regressions. Two subdivision models (One and Two) were created, each of which divided sums of squares in a different manner to test different contrasts.

Model One subdivided stock sums of squares into linear and quadratic terms. These terms were then used to test for a possible

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[1]The multiple regression procedure utilized in this and subsequent analyses, estimates treatment (and other) effects by use of least squares procedures and indicator (non-quantitative) variables. The sums of squares for the analyses of variance presented in Appendix B are also calculated in this manner. The Statistical Analysis System (SAS) was the software used for this and all other analyses.

functional relationship between initial height and HT77 or HTINC. A significant linear term in this instance, would indicate a linear relationship between growth and initial height, while a significant quadratic term would indicate a lack of fit from a linear relationship. The linear term for the model was defined as:

-12.33 if stock = 1-0 plugs
-12.27 if stock = 1-0 bullets
0.0147 if stock - 2-0 seedlings
24.24 if stock = 1-2 transplants[1]

The stock term values are the deviations obtained by subtracting the mean initial height for each stock type from the mean initial height for all stock types. The quadratic terms were the linear terms squared.

Model One also tested contrasts between various vegetation groups including:

vegetation group 2 vs. group 3
the average of groups 2 and 3 vs. group 4
the average of 1-0 plugs and 1-0 bullets vs. the average of 2-0 seedlings and 1-2 transplants

Model Two tested differences between stock types including the following contrasts:

1-0 plugs vs. 1-0 bullets
2-0 seedlings vs. 1-2 transplants
the average of 1-0 plugs and 1-0 bullets vs. the average of 2-0 seedlings and 1-2 transplants

---

[1]Although 1971 trees were not analyzed further in this analysis, the linear term for 1971 trees in later analyses was defined as:

-5.68 if stock = 1-0 plugs
-5.48 if stock = 1-0 bullets
11.17 if stock = 2-0 seedlings

Vegetation groups sums of squares for model Two were subdivided into contrasts as follows:

group 4 vs. group 5
the average of groups 2 and 3 vs. groups 4 and 5

Results from regressions of initial height coefficients on site, stock type, vegetation group in 1975 and interaction term are summarized by dependent variable.

Vegetation groups were important in explaining variation among initial height effects on HT77. Initial height effects were consistent among stock types and between sites. In addition, the interaction term between stock type and vegetation group was non-significant (Table 30, Appendix B).

Models One and Two illustrated significant differences between the initial height coefficients in vegetation groups two and three only, where overtop was by bracken and/or thimbleberry, or other low-growing species. Model Two showed significant differences in initial height effects between the average of vegetation groups two and three (overtopping influence) and the average of groups four and five (encroaching vegetation or ground-cover)(Tables 31 and 32, Appendix B).

Variations in initial height coefficients from regressions with HTINC were explained in part by vegetation group. As with HT77, neither stock site nor interaction term were important in explaining variation in initial height effects on HTINC (TAble 33, Appendix B).

Significant differences appeared in initial height coefficients between vegetation groups two and three in both models One and Two. No other contrast terms in either model were significant (Tables 34 and 35, Appendix B).

Figure 15 illustrates the interactions between initial height and vegetation groups in determining final height and 1975-1977 height increment. Coefficients for vegetation groups three, four and five were positive while the coefficient for group two was negative. Due to the limited number of observations for group two, the predicted heights for trees in this group are less certain than the predicted heights for the other groups. This is indicated by a broken line.

Table 6 summarizes the results from the previous regressions for both dependent variables, 1977 height (HT77) and 1975-1977 height increment (HTINC).

Analysis VII - Regressions with Deletions

Results from the previous regressions showed positive effects of initial height on HT77 and HTINC, for all vegetation groups except group two, which had a negative coefficient. The number and size range of trees associated with group two vegetation were limited in a way that could have influenced results (Figure 11).

To re-test for significant differences in initial height coefficients between vegetation groups without this confounding, vegetation group two was deleted and regressions in Analysis VI were repeated.

After vegetation group two was eliminated, there were no longer significant differences in initial height coefficients between

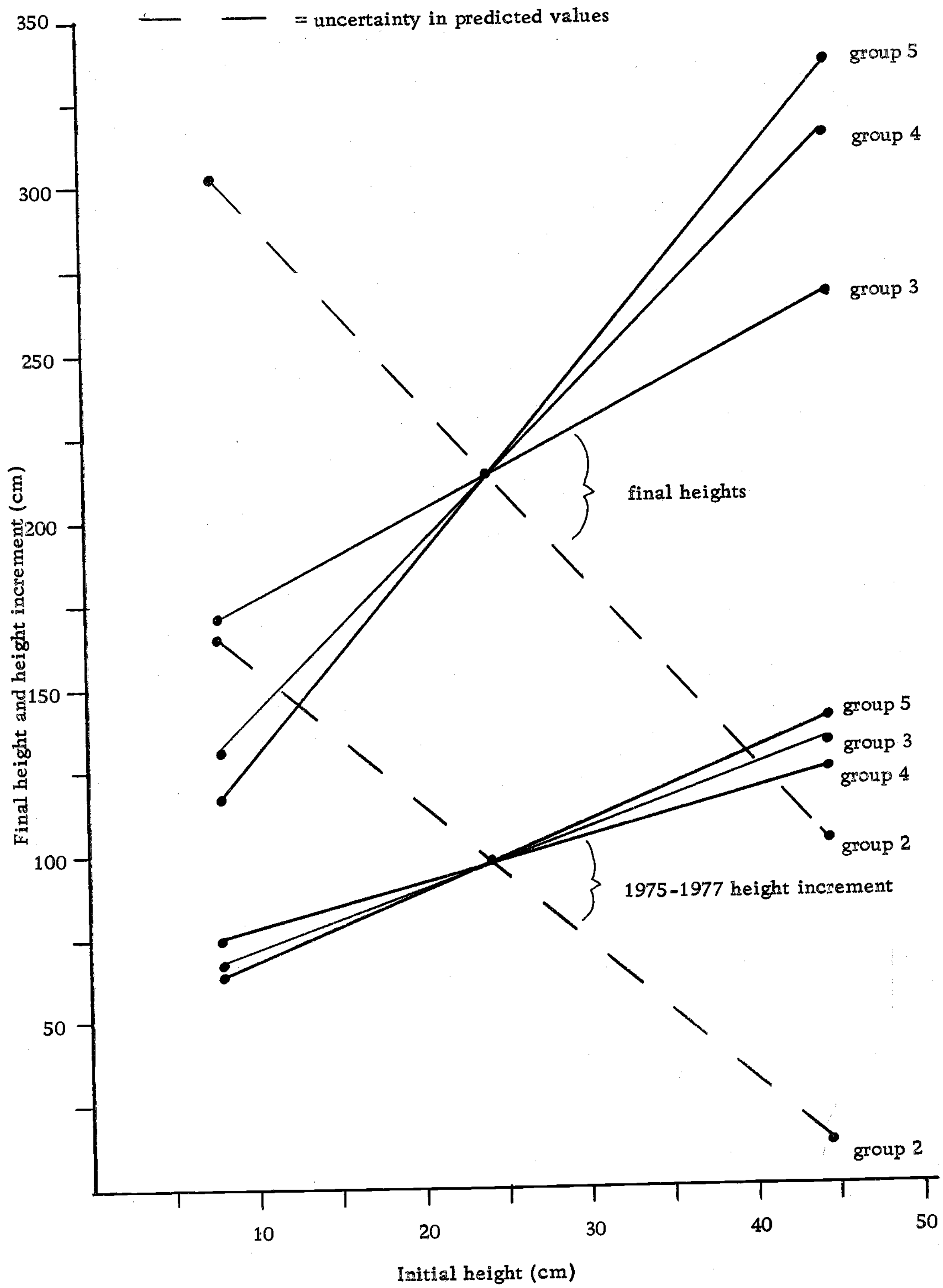

Figure 15. Predicted final heights and 1975-1977 height increments for seedlings associated with different vegetation groups. 1970 tree data averaged over all stock types.

TABLE 6. Summary of regression results from models exploring differences in initial height coefficients (slopes).

Factors (Models One + Two)	Dependent Variables: Slopes from regressions with height in 1977	Dependent Variables: Slopes from regressions with 1975-77 ht. increment
Site	NS	NS
Stock	NS	NS
linear	NS	NS
quadratic	NS	NS
lack of fit	NS	NS
1-0 plugs vs. 1-0 bullets	NS	NS
2-0 seedlings vs. 1-2 transplants	NS	NS
plugs + bullets vs. 2-0 seedlings + 1-2 transplants	NS	NS
Vegetation	S	S
Group 2 vs. 3	S	S
4 vs. 5	NS	NS
2 + 3 vs. 4	S*	NS
2 + 3 + 4 vs. 5	S*	NS
2 + 3 vs. 4 + 5	S	NS
Vegetation * stock	NS	NS

S = Significant at 0.05 level or above.
NS = Not Significant at 0.05 level.
* = Not interpretable.

vegetation groups (Tables 36 and 37, Appendix B). This suggests that the vegetation influence from overtopping bracken and thimbleberry is significantly different from all other vegetation groups tested which included overtop by other shrubby species, encroaching and ground-cover influences. It was not determined whether the negative coefficient in group two was influenced by a limited number of closely bunched observations, or if HT77 was actually less than initial height and HTINC, suggesting considerable top-dieback.

Section C. Analysis of Tree Growth in Terms of Site, Stock Type and Competition Estimates

The purpose of this section was to determine which variables were strongly correlated with absolute and relative growth of tree seedlings, and to determine if the competitive status of vegetation surrounding individual trees had changed from 1975 to 1977. Figure 16 summarizes the analyses in this section and their relation to one another.

In most instances, several of the independent variables in the regression models were identical for each analysis and similar results were obtained in regard to their significance, as expected. To avoid repetition in results, Analysis VIII will report results similar to all analyses with regard to the common variables, site and stock type. Other results from this analysis will concern the significance of different vegetation groups in determining seedling growth. Results from Analysis IX will illustrate the importance of density classes to seedling growth, and finally Analysis X will discuss correlations

Analysis VIII. Regressions Exploring Tree Growth

Purpose: To examine correlations between tree growth (absolute and relative) and site, stock type and 1975 vegetation groups. Sums of squares due to stock type and vegetation group are subdivided by two procedures (models One and Two). Separate analyses were conducted for: 1970 and 1971 trees, dependent variables (Mean Height 1975, Mean Height 1977, Mean 1975-1977 Height Increment), and models One and Two (12 Total).

↓

** Results from these analyses indicated there were not consistent significant differences in the effects of vegetation groups 1, 2 and 3 or groups 4, 5 and 6 on the dependent variables. There were, however, significant differences between the average of vegetation groups 1, 2 and 3 and the average of groups 4, 5 and 6.

↙ ↘

Based on this result, a density class criteria was developed to replace vegetation groups. The above regressions were then repeated in Analysis IX.

↓

Analysis XI. Regression Models with Density Classes

Purpose: To examine correlations between tree growth (absolute and relative) and site, stock type and density classes. Regressions in Analysis VIII repeated with density classes (12 Total).

Based on this result, a brush group classification was developed to investigate changes in competitive status of the brush. Vegetation groups 1, 2 and 3 were combined into brush group 1 (high competitive influence); groups 4, 5 and 6 were combined into brush group 2 (low competitive influence). Brush groups were used in Analysis X.

↓

Analysis X. Investigating Changing Competitive Status

Purpose: To determine how the competitive status of vegetation surrounding tree seedlings had changed from 1975 to 1977.

Actual and expected frequencies of trees in each brush groups were calculated. Six regressions were performed with dependent variables on site, stock type, 1975 brush group, 1977 brush group and interaction terms. Dependent variables included: 1977 height, 1977 diameter, 1977 volume, 1975-1977 height increment, 1975-1977 diameter increment, and 1975-1977 volume increment.

Figure 16. Summary of Section C analyses and their relation to one another.

between tree growth and brush groups present in 1975 and 1977.

Analysis VIII - Regressions Exploring Tree Growth

Regression analyses were performed to evaluate correlations between tree growth and various independent factors.

For trees established in 1970, dependent variables included: mean height at five years, mean height at seven years and 1975-1977 height increment (hereafter referred to as "M5", "M7" and "70INC", respectively). Dependent variables for 1971 trees included: mean height at four years, mean height at six years and 1975-1977 height increment (hereafter referred to as "M4", "M6" and "71INC", respectively). Independent variables for both years included site, stock type, vegetation group in 1975 and a stock type by vegetation group interaction term. Single degree of freedom tests for stock type and vegetation groups were also performed, where subdivisions were similar to those in Analysis VI (Models One and Two). For 1970 trees, vegetation groups one and six were deleted in this subsequent analysis due to limited observations.

Results from these analyses are discussed by establishment year.

Differences in M5 and M7 were partially explained by site, stock type and vegetation group, with stock type explaining more variation than site, and site more variation than vegetation group. This is a common pattern in many of the analyses in this section. In addition, the vegetation group by stock type interaction term was non-significant in both instances, as it was in all other regressions performed

(Tables 38 and 39, Appendix B).

After deletion of vegetation groups one and six, the regressions also showed the following differences for contrast terms.

Stock subdivisions for M5 and M7 show that differences between stock type growth were primarily linear. Both quadratic and lack of fit terms were non-significant for M5, although the quadratic term was significant for M7. This is the only instance where the quadratic term was important in explaining variation in growth for trees established in 1970 in Analysis VIII (Tables 40 and 41, Appendix B).

Other stock comparisons showed significant differences in the absolute heights of 2-0 seedlings and 1-2 transplants, and non-significant differences in the average heights of containerized seedlings (1-0 plugs and 1-0 bullets). In addition, a comparison of the average height of containerized seedlings with the average height of 2-0 seedlings and 1-2 transplants indicated they were significantly different after seven-years. These patterns were consistent in all analyses performed (Tables 42 and 43, Appendix B).

Vegetation contrasts for M5 and M7 indicated significant differences between the average heights of tree seedlings associated with vegetation groups 2 and 3 (overtopping categories) and the average height of seedlings associated with groups 4 and 5 (encroaching and ground cover categories). Other contrast terms were not significant or difficult to interpret as each subsequent comparison first averaged the significant differences between the overtopping groups (2 and 3) and the encroaching group (4) (Tables 40, 41, 42 and 43, Appendix B).

In general, the ability of the independent variables to explain differences in absolute heights (as above) was often greater than their ability to explain differences in relative heights (height increments). Therefore, results from regressions with 70INC are discussed separately.

Site, stock type and vegetation group were important in explaining differences in 70INC, with site explaining more variation than stock type (Table 44, 45 and 46, Appendix B).

Stock subdivisions again indicated primarily a linear trend between stock type growth, and also indicated that differences in the recent height increments of 2-0 seedlings and 1-2 transplants were not significant (Tables 45 and 46, Appendix B).

Vegetation contrasts were similar to those for M5 and M7, with major differences occurring between overtopping and non-overtopping groups (Tables 45 and 46, Appendix B).

Table 7 summarizes the significance of independent variables and contrasts in regressions with 1970 trees, all dependent variables.

Figure 17 illustrates the adjusted (for missing data) mean 1975 height, adjusted mean 1977 height and adjusted mean 1975-1977 height increment for each vegetation group, averaged over all stock types and sites. Figure 18 partitions the mean height in 1977 for each stock type into the percentage that can be attributed to the 1975-1977 height increment.

Stock type was more significant in explaining variation in M4, M6 and 71INC than any other variable, although vegetation group was

TABLE 7. Summary of the significance of independent variables and contrasts in regressions with 1970 trees, all dependent variables.

Independent Variables and Contrasts (Models One and Two)	Dependent Variables: Mean Height 1975 (five-year height)	Mean Height 1977 (seven-year height)	Mean 1975-1977 Height Increment
Site	S	S	S
Stock	S	S	S
linear	S	S	S
quadratic	NS	S	NS
lack of fit	NS	NS	NS
1-0 plugs vs. 1-0 bullets	NS	NS	NS
2-0 seedlings vs. 1-2 transplants	S	S	NS
1-0 plugs + bullets vs. 2-0 seedlings + 1-2 transplants	S	S	S
Vegetation	S	S	S
Group 2 vs. 3	NS	S	NS
4 vs. 5	NS	NS	NS
2 + 3 vs. 4	S	S*	S
2 + 3 + 4 vs. 5	S*	S*	S*
2 + 3 vs. 4 + 5	S	S	S
Vegetation * stock	NS	NS	NS

S = Significant at 0.05 level or above.
NS = Not Significant at 0.05 level.
* = Not interpretable.

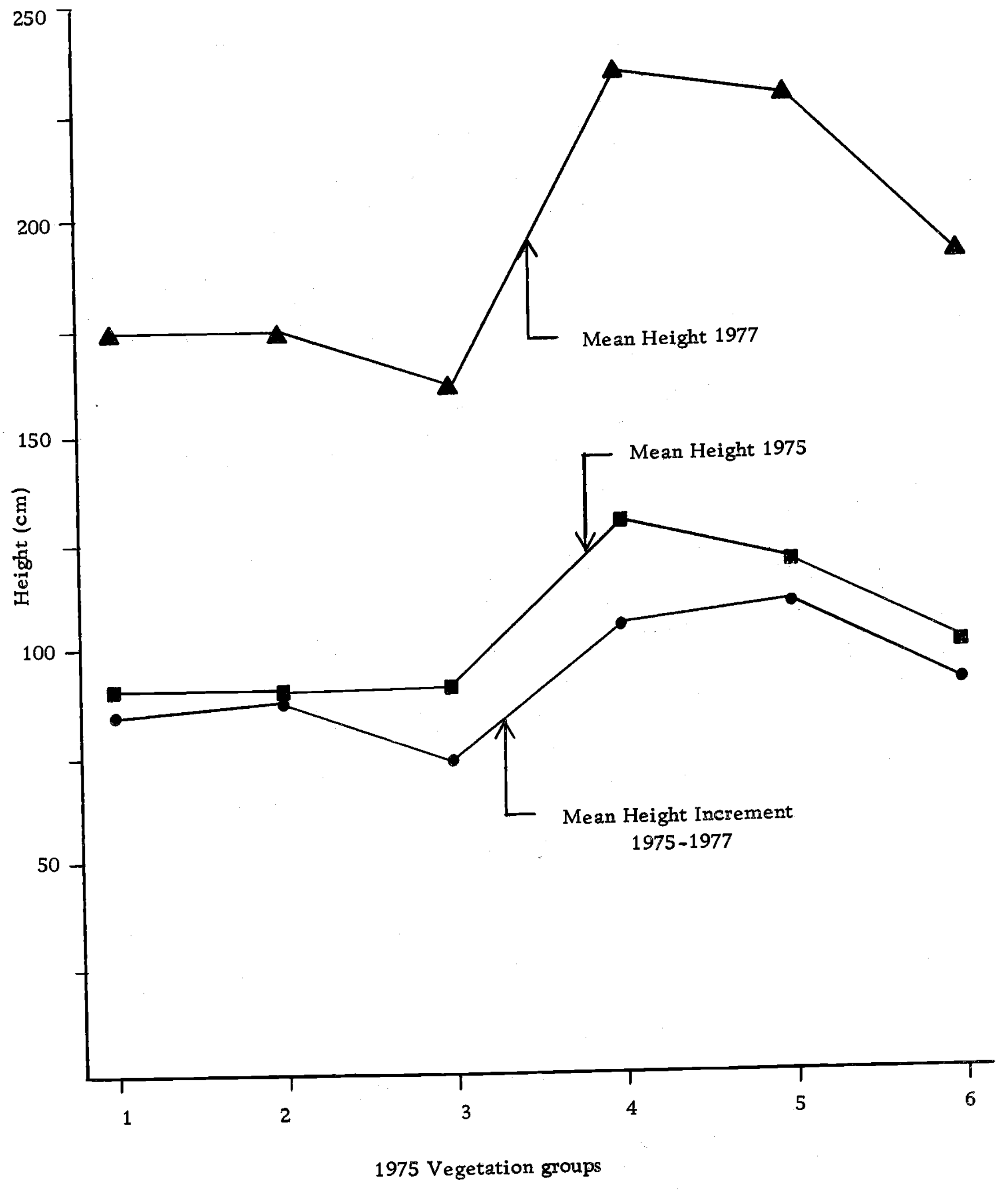

Figure 17. Mean height 1975, mean height 1977 and mean height increment 1975-1977 (adjusted for missing data) against 1975 vegetation groups. 1970 tree data averaged over all stock types and sites.

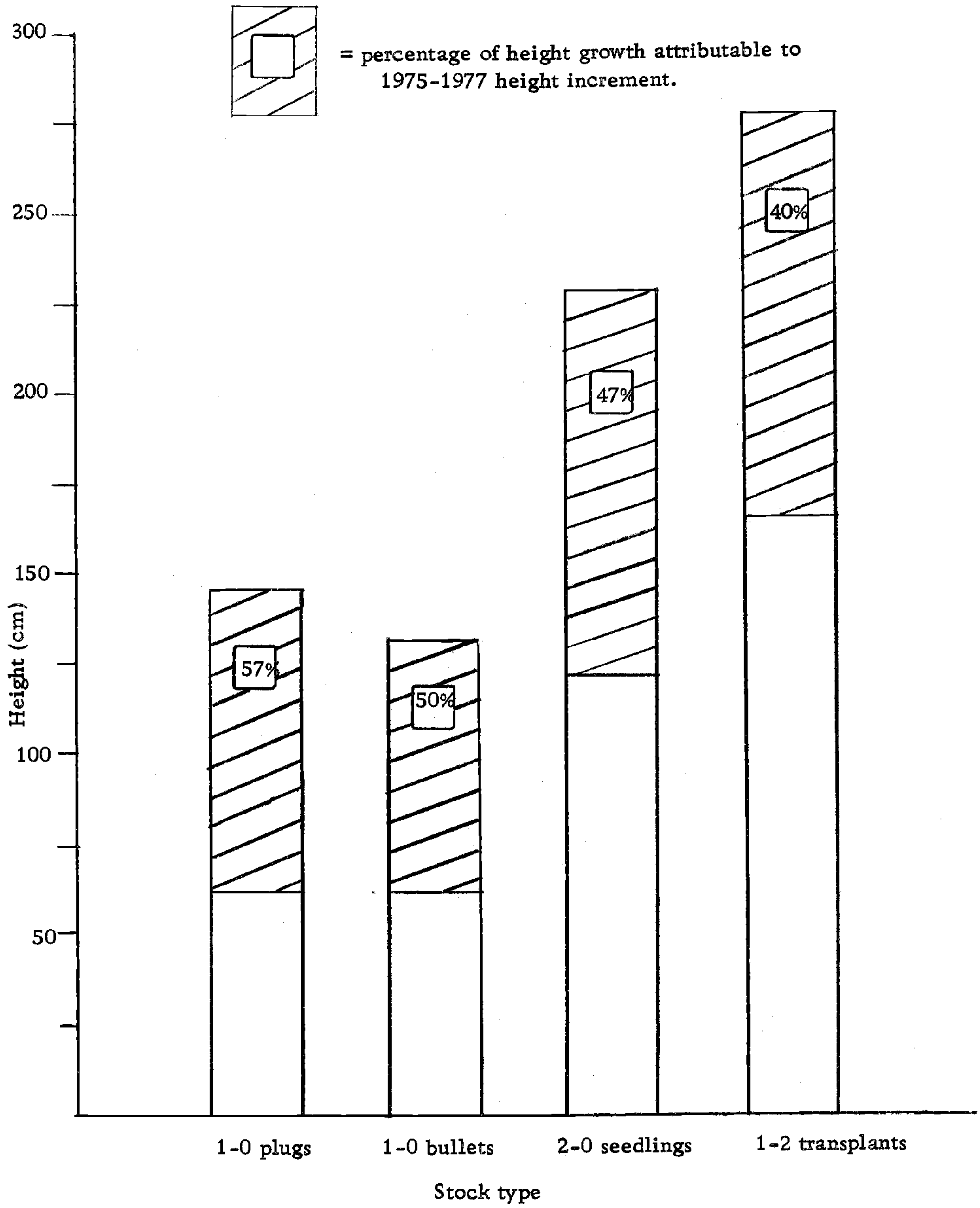

Figure 18. Adjusted mean height 1977 partitioned into percentage attributable to mean 1975-1977 height increment. 1970 tree data averaged over all vegetation groups and sites.

also significant for the latter two. As a general trend for 1971 trees, site was often non-significant in explaining variation in seedling growth. This pattern is explored further in the Discussion.

Stock contrasts for 1971 trees were identical to those obtained for 1970 trees (Tables 48, 51 and 52, Appendix B). While the patterns of vegetation contrasts for M4 were similar to results with 1970 trees, the patterns of vegetation contrasts for M6 and 71INC were somewhat different. Comparisons in these instances showed significant differences between the average of all groups with vegetation present (groups 1, 2, 3, 4 and 5) compared with group 6 which had no notable vegetation. This was the only instance where this comparison was significant (Tables 49 and 50, Appendix B).

Table 8 summarizes the significance of independent variables and contrasts in regressions with 1971 trees, all dependent variables.

Figure 19 illustrates the adjusted mean 1975 and 1977 heights, as well as the adjusted mean 1975-1977 height increment for each vegetation group, averaged over all stock types and sites. Figure 20 partitions the mean height in 1977 for each stock type into the percentage that cen be attributed to the 1975-1977 height increment.

Analysis IX - Regression Models with Density Classes

Results from Analysis VIII indicated that there were no consistent significant differences among vegetation in groups 1, 2 and 3 or groups 4, 5 and 6 in terms of their influence on tree height growth. There were significant differences, however, in most analyses between

TABLE 8. Summary of the significance of independent variables and contrasts in regressions with 1971 trees, all dependent variables.

Independent Variables and Contrasts (Models One and Two)	Dependent Variables: Mean Height 1975 (four-year height)	Mean Height 1977 (six-year height)	Mean 1975-1977 Height Increment
Site	NS	NS	NS
Stock	S	S	S
linear	S	S	S
quadratic	NS	NS	NS
1-0 plugs vs. 1-0 bullets	NS	NS	NS
1-0 plugs + bullets vs. 2-0 seedlings	S	S	S
Vegetation	NS	S	S
groups 1 vs. 2	S	NS	NS
1 vs. 3	NS	NS	NS
2 vs. 3	S	NS	NS
4 vs. 6	NS	NS	S
5 vs. 6	NS	NS	NS
1 + 2 vs. 3	NS	NS	NS
1 + 2 + 3 vs. 4	NS	NS	NS
1 + 2 + 3 + 4 vs. 5	NS	NS	NS
1 + 2 + 3 + 4 + 5 vs. 6	NS	S	S
1 + 2 + 3 vs. 4 + 5 + 6	NS	S	S
Vegetation * stock	NS	NS	NS

S = Significant at 0.05 level or above.
NS = Not Significant at 0.05 level.

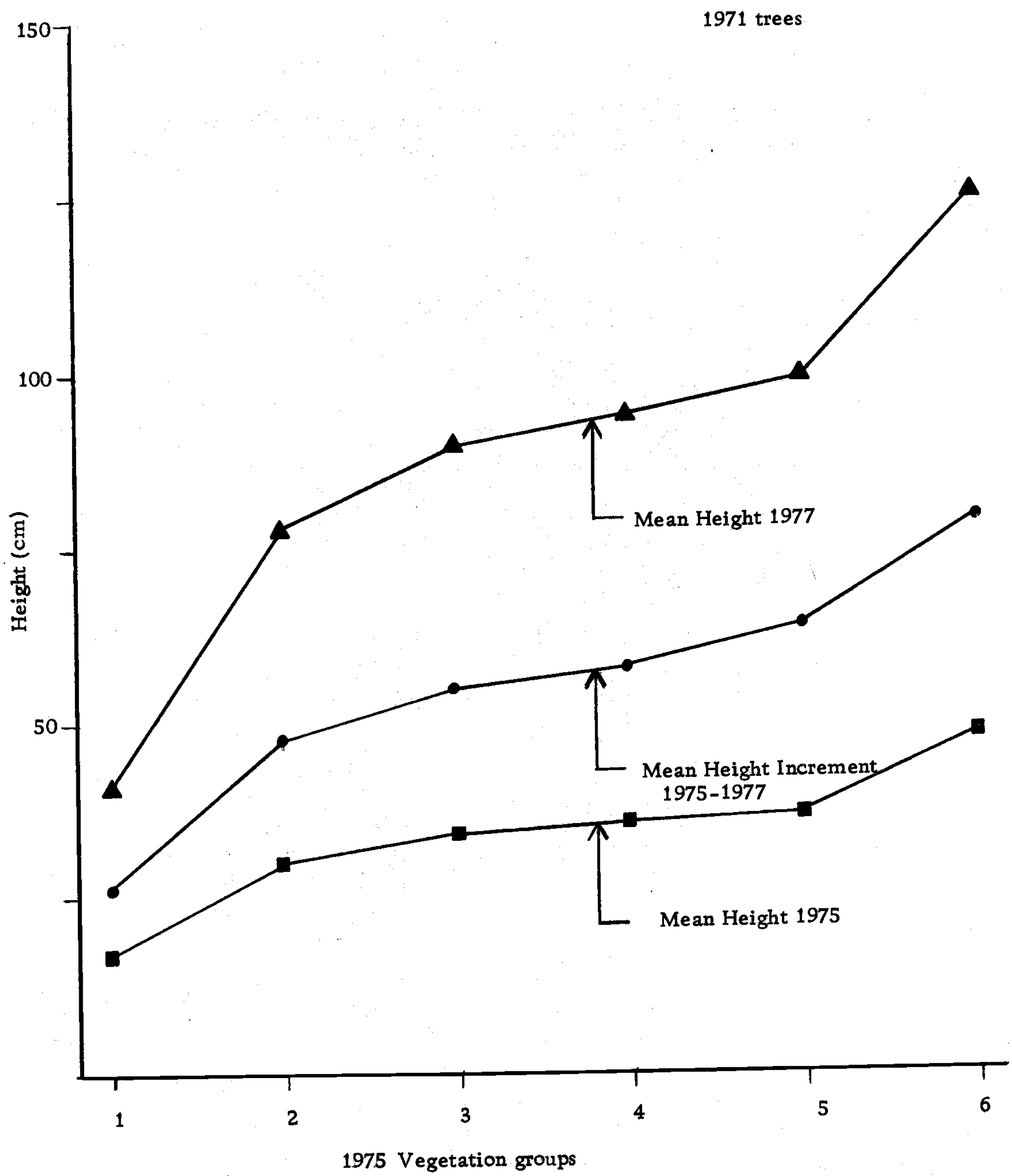

Figure 19. Mean height 1975, mean height 1977 and mean height increment 1975-1977 (adjusted for missing data) against 1975 vegetation groups. 1971 tree data averaged over all stock types and sites.

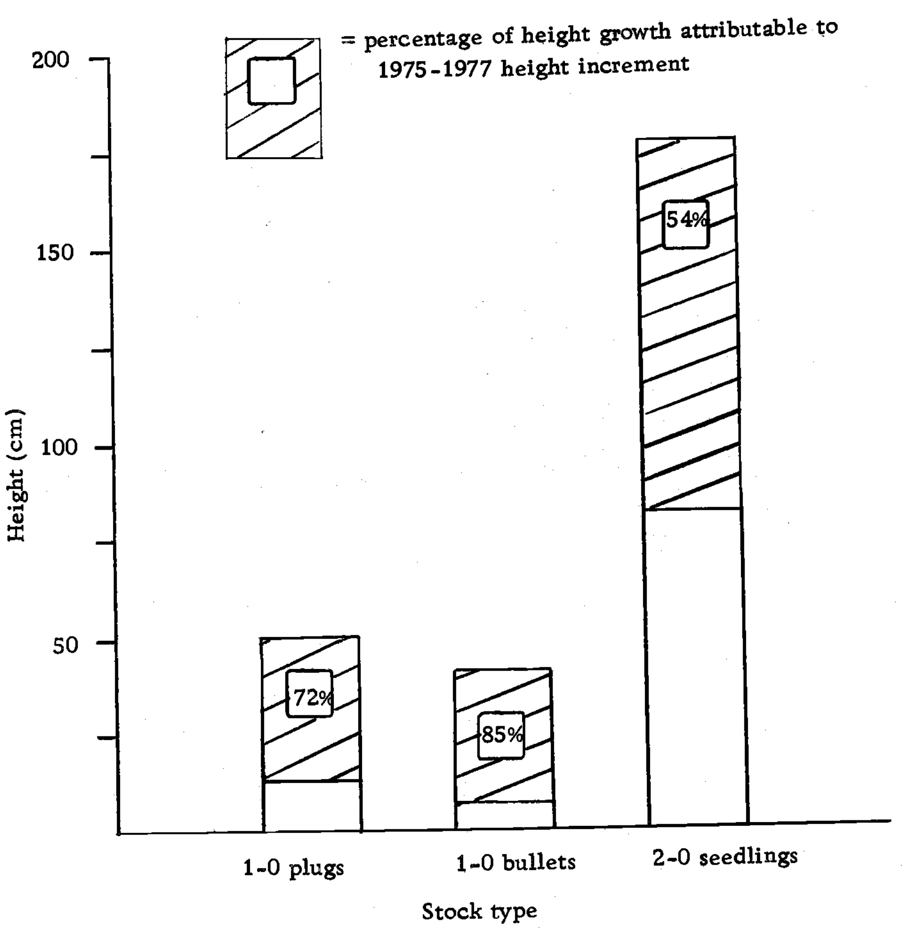

Figure 20. Adjusted mean height 1977 partitioned into percentage attributable to mean 1975-1977 height increment. 1971 tree data averaged over all vegetation groups and sites.

the average of groups 1, 2 and 3 contrasted with the average of groups 4, 5 and 6.

To explore differences in these vegetation groups, a new procedure divided seedlings into five density classes, based on competing vegetation. These classes were expressions of the overtop, encroachment and ground cover. Density classes are summarized in Table 9.

Analysis VIII was then repeated, with density class replacing vegetation group as an independent variable. Sums of squares subdivisions were modified as appropriate.

Results from these regressions analyses are discussed by establishment year, with emphasis on the ability of density class to explain variation in seedling heights.

For 1970 trees, differences in all three dependent variables, M5, M7 and 70INC, could be partially explained by density class, although density class was less significant than stock type or site. The density class by stock type interaction was non-significant in all Analysis IX regressions for 1970 trees, but was significant in analyses for 1971 trees.

Stock type subdivisions in these regressions indicated that the linear term was most important in explaining differences in growth between stock types, although the quadratic term was also significant. This result is interesting in that of all regressions performed with density classes, only in these instances were the quadratic terms significant in the models.

Density class contrasts show that for all dependent variables,

TABLE 9. Density Class Criteria

Class One:	Seedlings overtopped; cone occlusion $\geqslant$ 70%.
Class Two:	Seedlings overtopped; cone occlusion $<$ 70%.
Class Three:	Seedlings encroached; percentage encroachment $\geqslant$ 70%.
Class Four:	Seedlings encroached; percentage encroachment $<$ 70%.
Class Five:	Seedlings associated with herbaceous ground cover or bare ground.

there were significant differences between the average of density classes 1 and 2 (≥70% overtop and <70% overtop, respectively) and density class 3 (≥70% encroachment). Significant differences also appeared between classes 2 and 3 (<70% overtop and ≥70% encroachment, respectively), as well as between classes 3 and 4 (≥70% encroach and <70% encroach, respectively). In addition, for 70INC, classes 4 (<70% encroach) and 5 (ground cover or bare ground) were significantly different. No other density contrasts were significant (Tables 53, 54, 55, 56, 57 and 58, Appendix B).

Table 10 summarizes the significance of independent variables and contrasts in regressions with 1970 trees, all dependent variables.

Figure 21 illustrates the adjusted mean 1975 height, adjusted mean 1977 height and adjusted mean height increment for each density group averaged over all stock types and sites.

For 1971 trees, stock type and density class were important in explaining variation in M4, M7 and 71INC, although stock type explained more variation than density class.

Density class contrasts for 1971 trees were similar to those for 1970 trees, and showed significant differences in all dependent variables between the averages of overtopping density classes (1 and 2) when compared with density class 3 (≥70% encroach). There were also significant differences in all the dependent variables between tree seedlings in class 2 (<70% overtop) and class 3 (≥70% encroach) as well as between class 4 (<70% encroach) and class 5 (ground cover or bare ground), for M6 and 71INC. All other contrast terms were

TABLE 10. Summary of the significance of independent variables and contrasts in regressions with 1970 trees, all dependent variables.

Independent Variables and Contrasts (Models One and Two)	Dependent Variables		
	Mean Height 1975 (five-year height)	Mean Height 1977 (seven-year height)	Mean 1975-1977 Height Increment
Site	S	S	S
Stock	S	S	S
linear	S	S	S
quadratic	S	S	S
lack of fit	NS	NS	NS
1-0 plug vs. 1-0 bullet	NS	NS	NS
2-0 seedling vs. 1-2 transplant	S	S	NS
1-0 plug + bullet vs. 2-0 seedlings and 1-2 transplants	S	S	S
Density	S	S	S
groups 1 vs. 2	NS	NS	NS
2 vs. 3	S	S	S
3 vs. 4	S	S	S
4 vs. 5	NS	NS	S
1 + 2 vs. 3	S	S	S
1 + 2 + 3 vs. 4	S*	S*	S*
1 + 2 + 3 + 4 vs. 5	NS	NS	S*
Density * stock	NS	NS	NS

S = Significant at 0.05 level or above.
NS = Not Significant at 0.05 level.
* = Not interpretable.

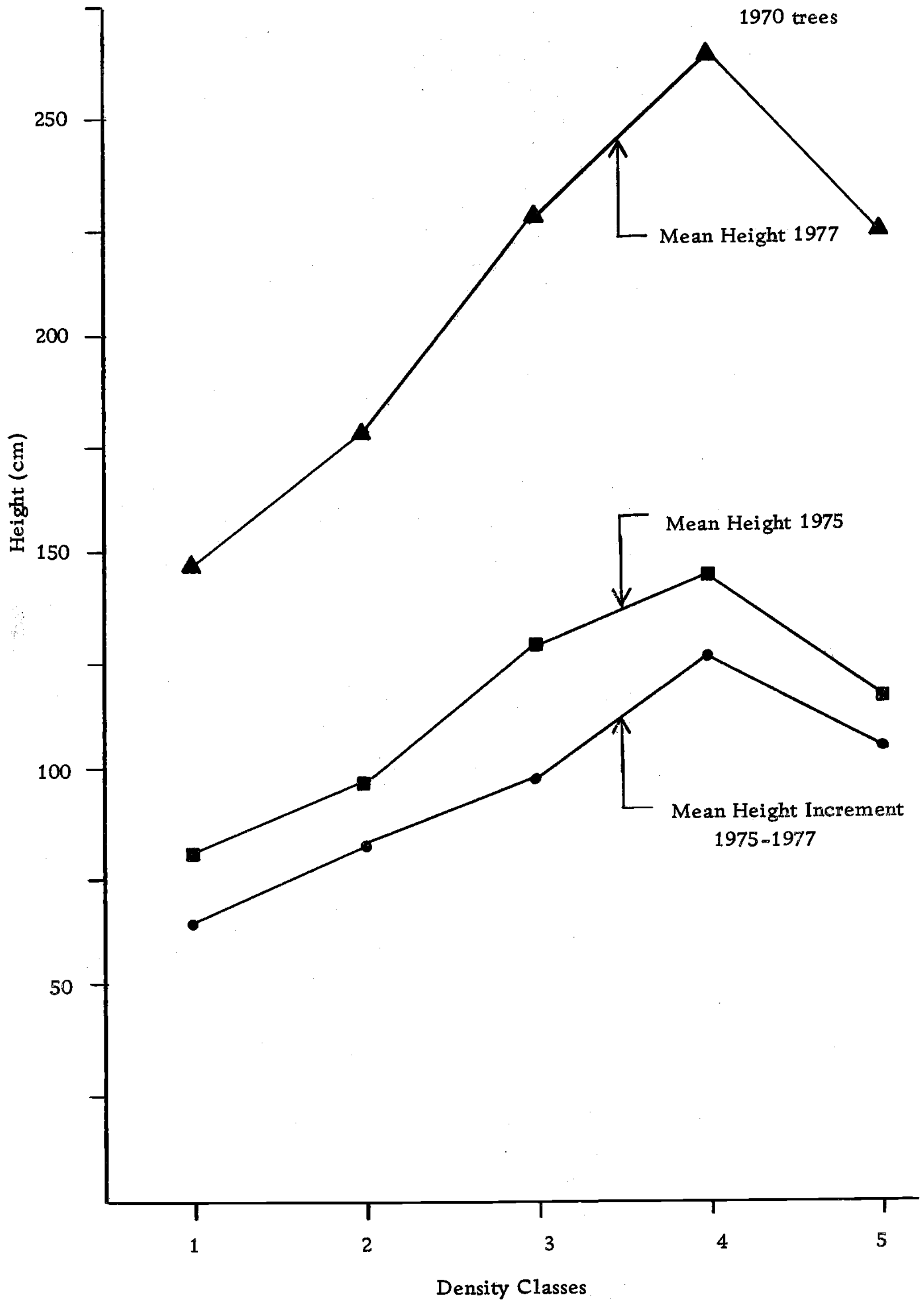

Figure 21. Mean height 1975, mean height 1977 and mean height increment 1975-1977 (adjusted for missing data) against density classes. 1970 tree data averaged over all stock types and sites.

non-significant or not interpretable (Tables 59, 60, 61, 62, 63 and 64, Appendix B).

Table 11 summarizes the significance of independent variables and contrasts in regressions with 1971 trees, all dependent variables.

Figure 22 illustrates the adjusted mean 1975 and 1977 heights, as well as the adjusted mean height increment for each density class averaged over all stock types and sites.

Figure 23 graphs mean initial height against mean final height, by stock type, for 1970 and 1971 trees to illustrate the linear and quadratic influences in growth between the stock types. In all instances the linear trend was most significant although for 1970 trees, the quadratic influence for M5 and M7 accounted for only a small proportion of the variation in growth between stock types (6% and 13%, respectively). For 70INC, the quadratic term accounted for 38% of this variation. The deviation from the linear trend occurs at the upper range of initial heights, or in the range occupied by 1-2 transplant stock. One might speculate that the deviation from linear is due to some characteristic of the transplant stock (not just size effect) which distinguishes it from the other stock types, all of which were not transplanted.

It should also be noted that the limited number of stock types (data points on the graph) undoubtedly influenced the fit of the linear and quadratic terms. The relevance of these trends, therefore, may be limited in the present analyses.

TABLE 11. Summary of the significance of independent variables and contrasts in regressions with 1971 trees, all dependent variables.

Independent Variables and Contrasts (Models One and Two)	Dependent Variables: Mean Height 1975 (four-year height)	Mean Height 1977 (six-year height)	Mean 1975-1977 Height Increment
Site	NS	NS	NS
Stock	S	S	S
linear	S	S	S
quadratic	NS	NS	NS
1-0 bullets vs. 1-0 plugs	NS	NS	NS
1-0 bullets + 1-0 plugs vs. 2-0 seedlings	S	S	S
Density	S	S	S
groups 1 vs. 2	NS	NS	NS
2 vs. 3	S	S	S
3 vs. 4	NS	NS	NS
4 vs. 5	NS	S	S
1 + 2 vs. 3	S	S	S
1 + 2 + 3 vs. 4	NS	NS	NS
1 + 2 + 3 + 4 vs. 5	NS	S*	S*
Density * stock	S	S	S

S = Significant at 0.05 level or above.
NS = Not Significant at 0.05 level.
* = Not interpretable.

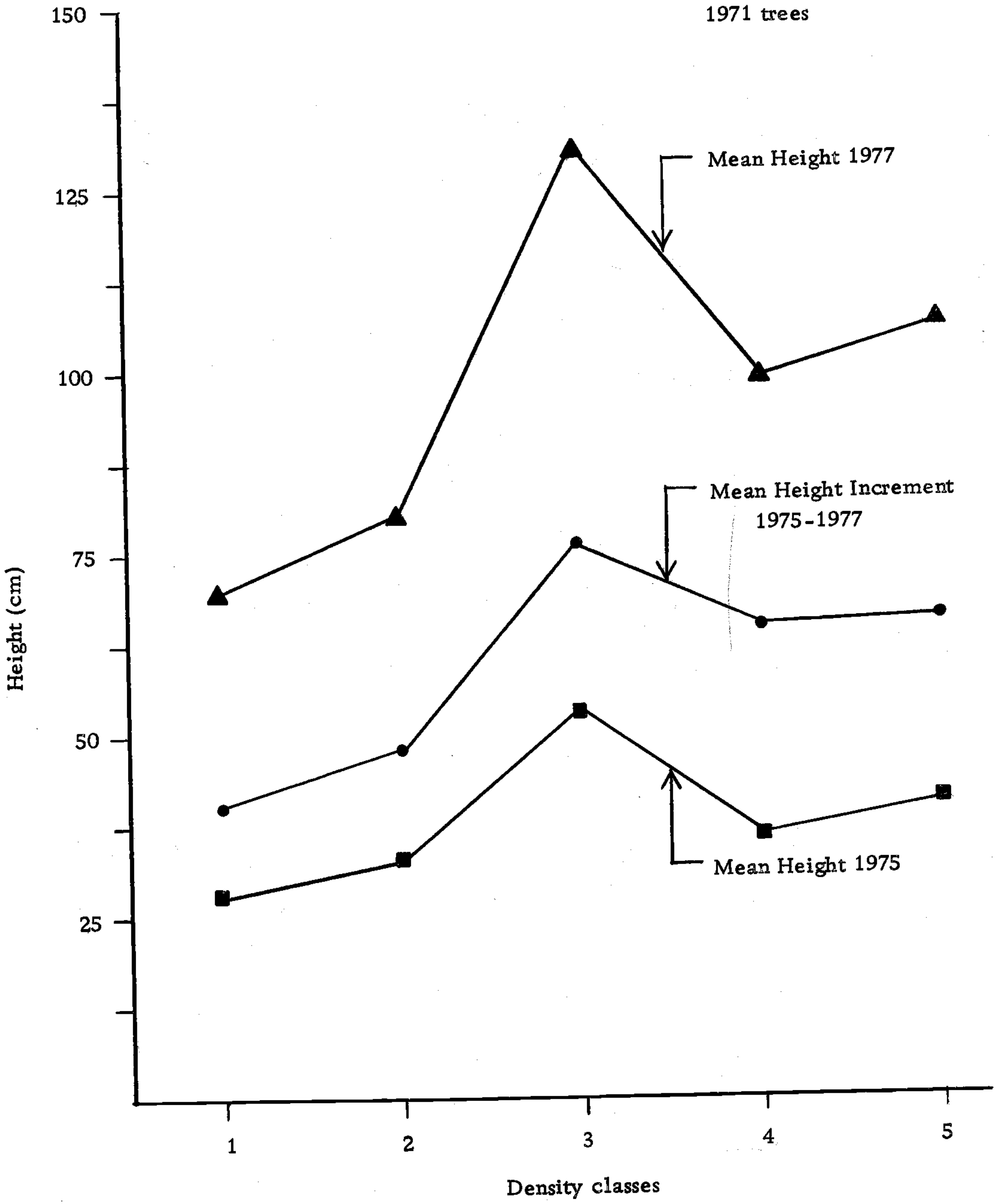

Figure 22. Mean height 1975, mean height 1977 and mean height increment 1975-1977 (adjusted for missing data) against density classes. 1971 tree data averaged over all stock types and sites.

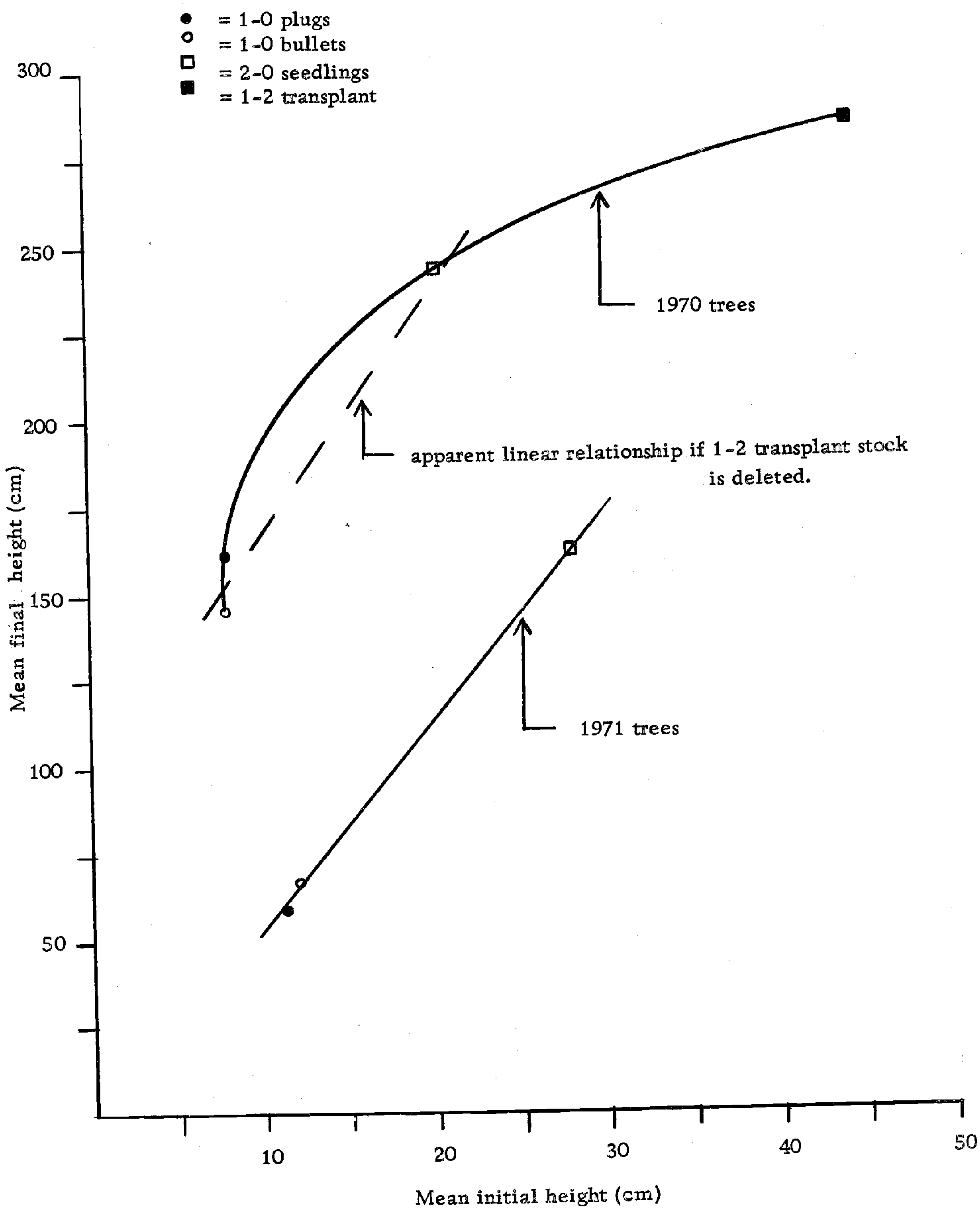

Figure 23. Mean initial height against mean final height by stock type. 1970 + 1971 trees illustrating linear and quadratic relation between stock type growth.

Analysis X - Changes in Competitive Status

To determine how the competitive status of individual tree seedlings had changed from 1975 to 1977, brush group criteria were devised. The six vegetation groups in 1975 were recombined into two brush groups depending on their influence. Overtopping influences in vegetation groups 1, 2 and 3 were combined into brush group 1; encroaching, ground-cover influence and bare ground (vegetation groups 4, 5 and 6) were combined into brush group 2.

An analysis was then designed to determine if trees had remained in the same brush group or if the status of the vegetation has changed from a higher competitive influence (brush group 1) to a lower competitive influence (brush group 2) or vice-versa.

Actual and expected frequencies of tree seedlings in each brush group were calculated. In addition, a regression analysis was conducted which regressed height in 1977, 1975-1977 height increment, diameter in 1977, 1975-1977 diameter increment, volume in 1977 and 1975-1977 volume increment on the independent variables for 1970 trees: site, stock type, brush group 1975, brush group 1977 and stock type by brush group interaction terms. For 1971 trees, independent variables included stock type, site, 1975 and 1977 brush groups.

Results are discussed by establishment year.

Table 12 illustrates the actual and expected frequencies, and the deviations between the two for 1970 trees in brush groups 1 and 2 in 1975 and 1977. From a significant chi-square test, it can be concluded that the brush category a tree seedling is in during 1977 is not independent of the brush category it was in during 1975. In fact, the frequency table shows a tendency for trees to remain under either a high competition (group 1) or low competition influence (group 2) both years. The number of trees changing their brush group status was relatively small. The frequency table also shows that the greater percentage of trees were associated with non-overtopping, less competitive vegetation both in 1975 and 1977 (72.84 and 79.20%, respectively).

Results from regressions for 1970 trees were similar for all dependent variables. In all instances, both 1975 and 1977 brush groups could partially explain variations, with 1975 brush group usually being more significant. Differences in dependent variables: 1977 diameter, 1977 volume and 1975-1977 volume increment could also be explained by the stock type by 1975 brush group interaction term (Tables 65, 66, 67, 68, 69 and 70, Appendix B).

Figure 24 illustrates mean diameters in 1977 by 1975 brush group and stock type, averaged over all sites, while figure 25 illustrates mean diameter increments by 1975 brush group, averaged over all sites and stock types. Consistently, measurements for trees associated with a lower competition influence are greater than those associated with a high competition influence, as expected.

Figures 26 and 27 illustrate adjusted mean volumes in 1975 and adjusted mean 1975-1977 volume increments, respectively, by 1975 brush group and stock type, averaged over all sites.

TABLE 12. Actual and expected frequencies, and deviations between the two, for trees in Brush Groups 1 and 2 in 1975 and 1977. 1970 trees.

actual frequency expected frequency deviation		Brush Group 1977 1	2	
Brush Group 1975	1	192.0 69.3 122.7	141.0 263.7 -122.7	n = 333 27.16%
	2	63.0 185.7 -122.7	830.0 707.3 122.7	893 72.84%
		n = 255 20.80%	971 79.20%	1226 100.00%

Chi-square = 377.03   df = 1   prob = 0.0001

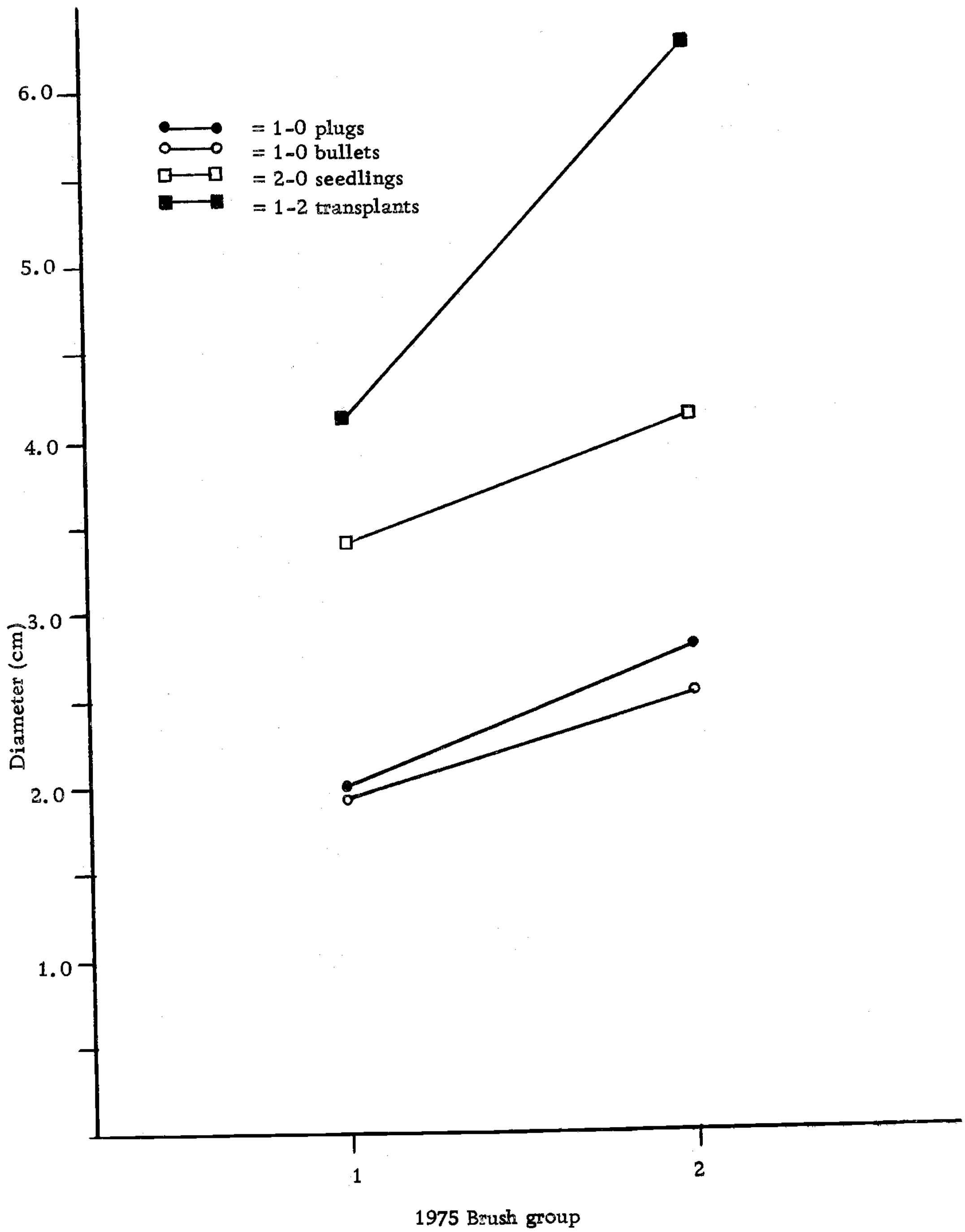

Figure 24. Mean diameter in 1977 against 1975 brush groups by stock type, averaged over all sites. 1970 trees.

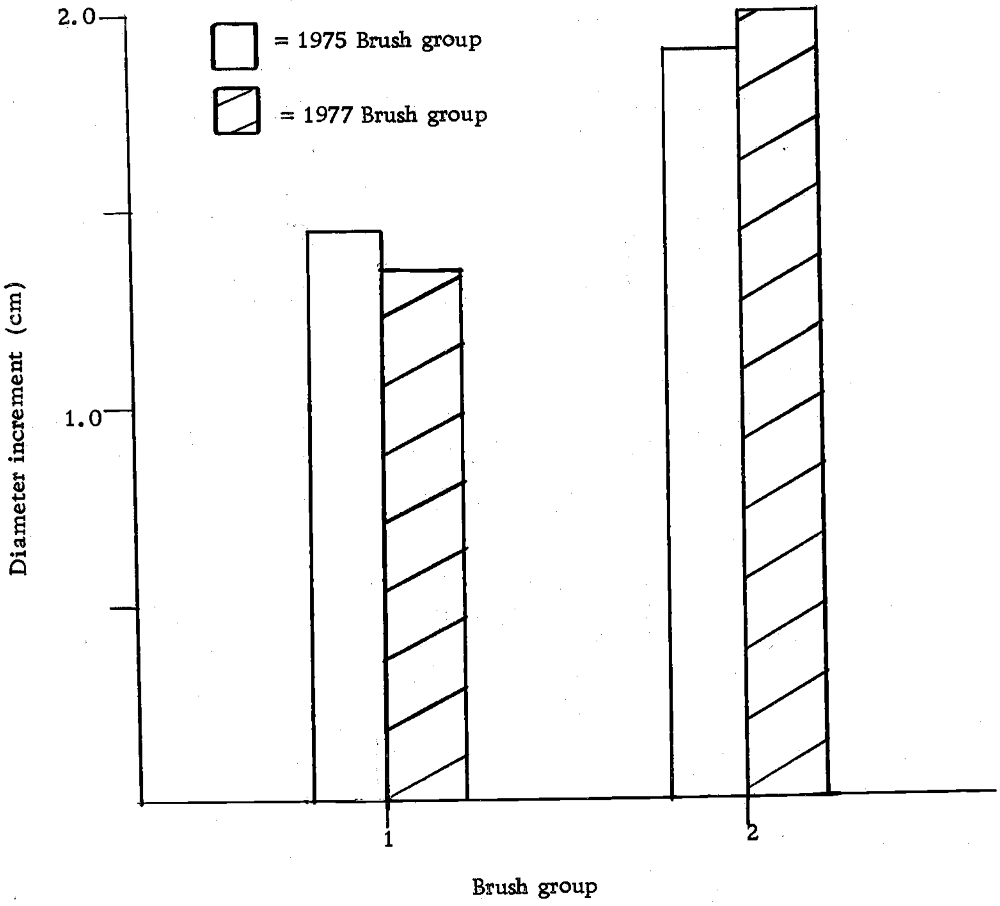

Figure 25. Mean 1975-1977 diameter increment by 1975 and 1977 brush groups. 1970 tree data averaged over all stock types and sites.

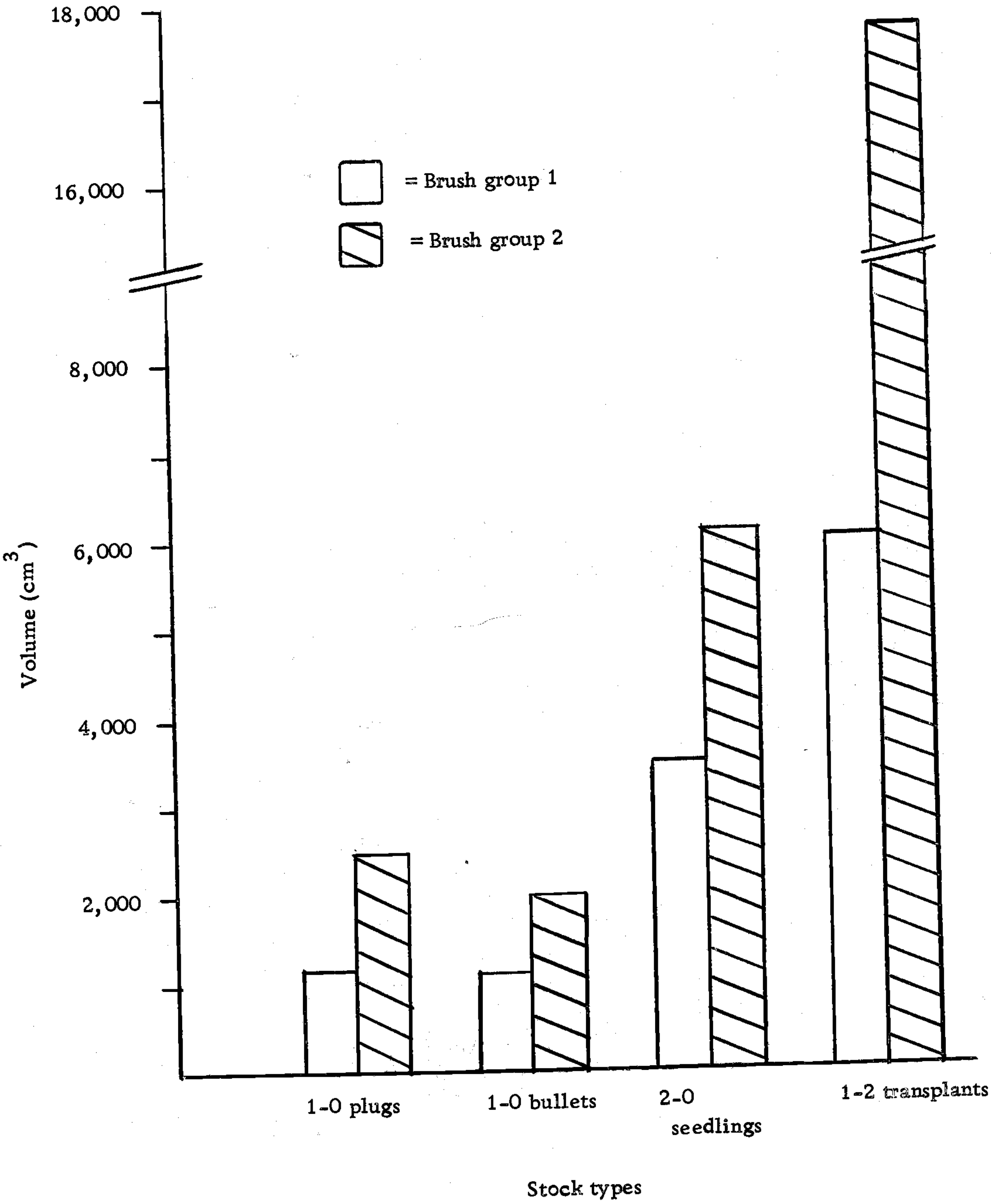

Figure 26. Mean volume 1977 by 1975 brush group and stock type, averaged over all sites. 1970 trees.

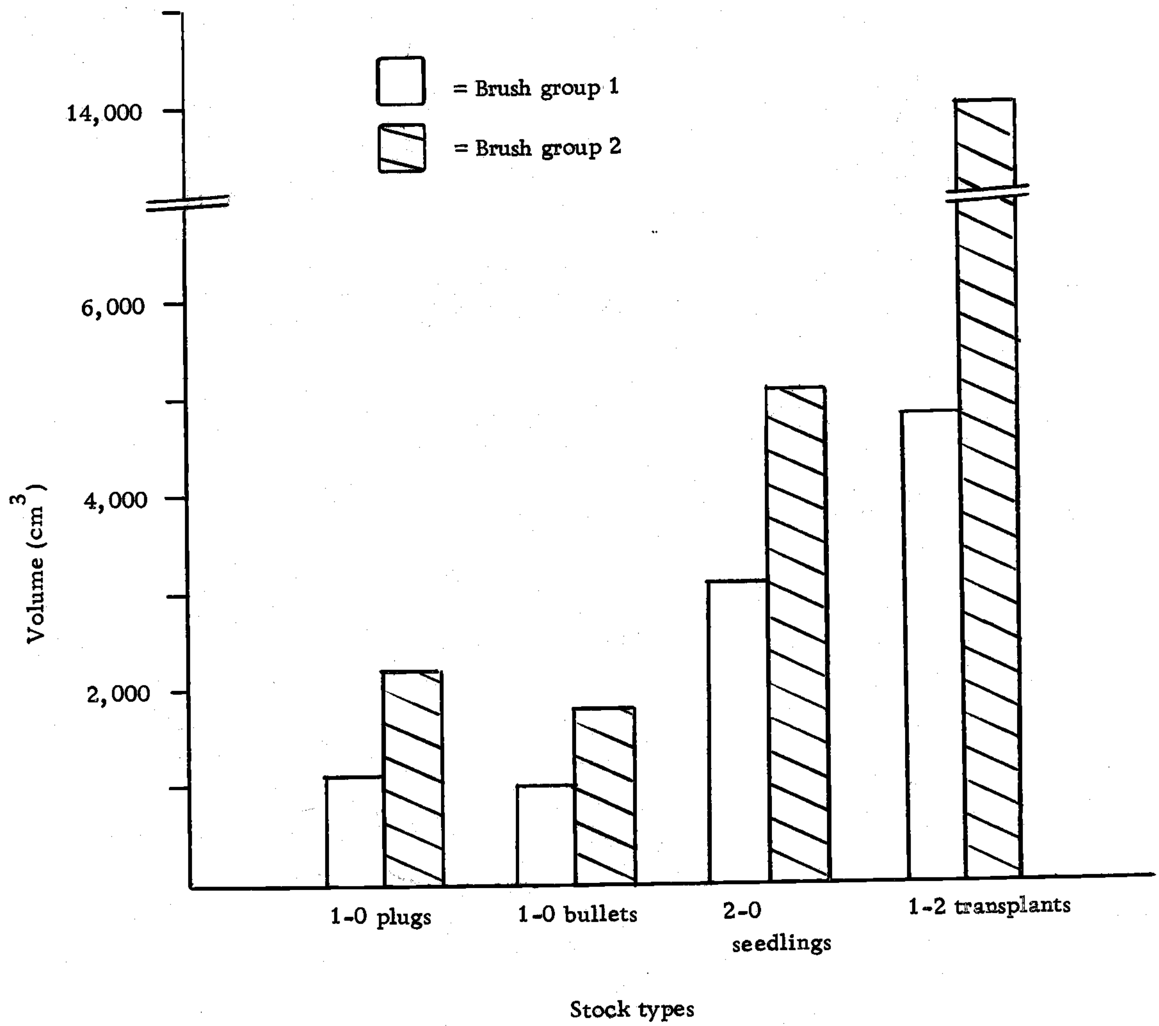

Figure 27. Mean 1975-1977 volume increment by 1975 brush group and stock type, averaged over all sites. 1970 trees.

Table 13 summarizes the significance of independent variables in regressions with 1970 trees, all dependent variables.

Table 14 illustrates the actual and expected frequencies, for 1971 trees in brush groups 1 and 2 in 1975 and 1977. Like 1970 trees, brush categories in 1975 and 1977 are not independent, and there is a greater tendency for trees to remain under either high competition or low competition influences. Unlike 1970 trees, however, there were more trees associated with overtopping vegetation in 1975 (55.25%) than with the lower competition group, which may reflect their having been planted later into vegetation which was one year older.

Results from regressions with dependent variables: 1977 height, 1977 diameter, and 1975-1977 height and diameter increments were similar. Differences in these variables could be explained in part by stock type, brush group in 1975 and brush group in 1977. In all instances, stock explained the most variation followed by brush group in 1975 and brush group in 1977 (Tables 71, 72, 73 and 74, Appendix B).

Results from regressions with 1977 volume and 1975-1977 volume increment again show that stock type and 1975 brush groups were important in explaining differences, with stock type explaining more variation than brush groups. Neither 1977 brush group nor any interaction terms were important in explaining differences (Tables 75 and 76, Appendix B).

Figure 28 illustrates adjusted mean diameter and diameter increments by brush group present in 1975 and 1977. Figure 29 illustrates

TABLE 13. Summary of the significance of independent variables in regressions with 1970 trees, all dependent variables.

Independent Variables	Dependent Variables					
	Height in 1977	1975-1977 Height Increment	Diameter in 1977	1975-1977 Diameter Increment	Volume in 1977	1975-1977 Volume Increment
Site	S	S	S	S	S	S
Stock	S	S	S	S	S	S
Brush Group 1975	S	S	S	S	S	S
Brush Group 1977	S	S	S	S	S	S
Brush Group 1975 * Brush Group 1977	NS	NS	NS	NS	NS	NS
Stock * Brush 1975	NS	NS	S	NS	S	S
Stock * Brush 1977	NS	NS	NS	NS	NS	NS
Stock * Brush 1975 * Brush 1977	NS	NS	NS	NS	NS	NS

S = Significant at 0.05 level or above.

NS = Not Significant at 0.05 level.

TABLE 14. Actual and expected frequencies, and deviation between the two, for trees in Brush Groups 1 and 2 in 1975 and 1977. 1971 trees.

actual frequency expected frequency deviation		Brush Group 1977 1	2	
Brush Group 1975	1	84.0 66.3 17.7	95.0 112.7 -17.7	179 55.25%
	2	36.0 53.7 -17.7	109.0 91.3 17.7	145 44.75%
		120 37.04%	204 62.96%	324 100.00%

Chi-square = 16.778 df = 1 prob = .0001

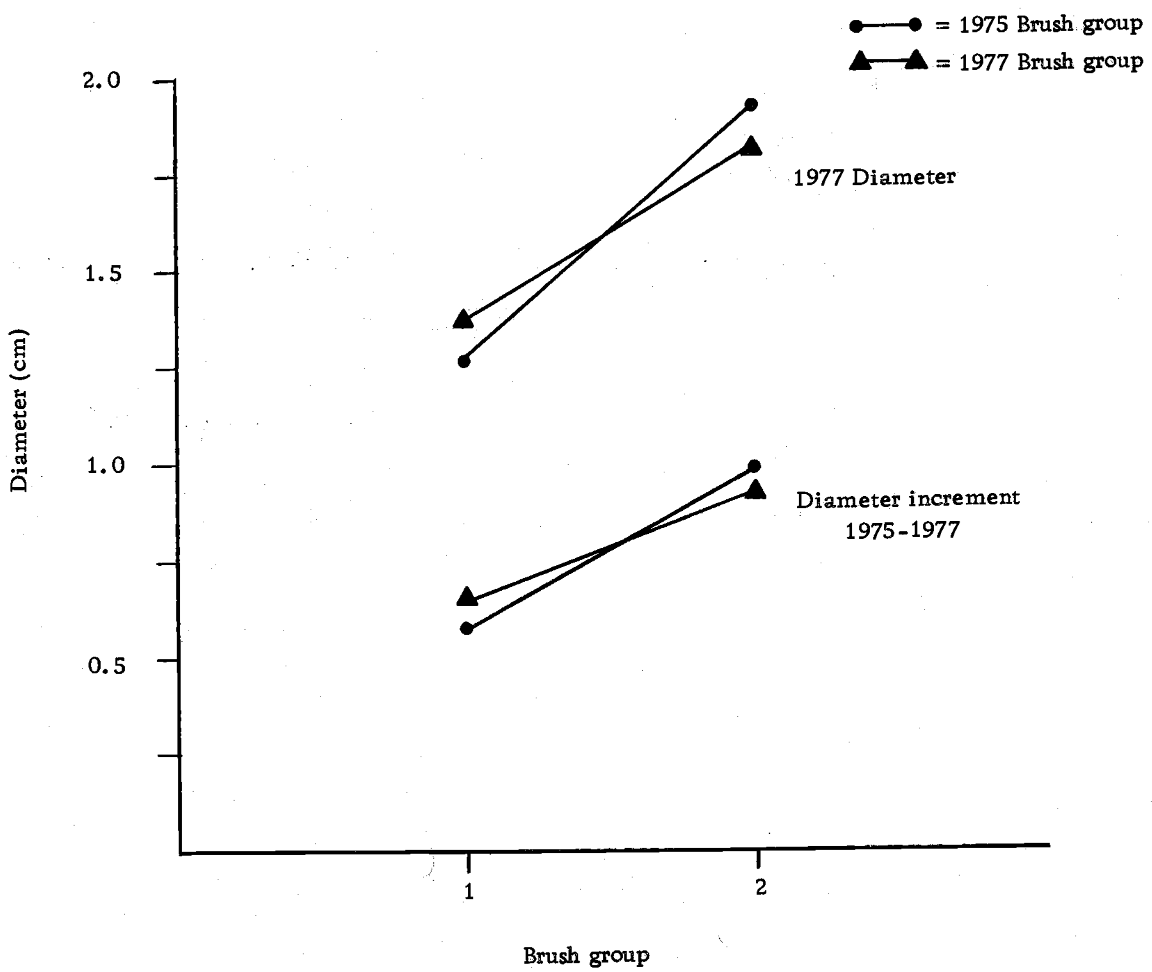

Figure 28. Mean diameter 1977 and mean 1975-1977 diameter increment (adjusted for missing data), by brush groups present in 1975 and 1977. 1971 tree data averaged over all stock types and sites.

adjusted mean volume and volume increments by brush group present in 1975. As expected, volumes, diameters and increments are greater when the tree was associated with vegetation of a lower competitive influence (group 2).

Table 15 summarizes the significance of independent variables in regressions with 1971 trees, all dependent variables.

Section D. Examination of Damage Sustained by Stock Types

An analysis was performed which partitioned trees into groups corresponding to damage estimates recorded during the 1977 field season. Results were tabulated by stock type, and the percentage occurrence for each damage group was calculated. Damage groups are summarized in Table 16.

Tables 17 and 18 illustrate the actual and expected frequencies of different types of damage to each stock type established in 1970 and 1971, respectively. Figure 30 illustrates deviations between the actual and expected frequencies. Chi-square tests reveal that for both 1970 and 1971 trees, damage frequency is not independent of stock type. Examining the deviations for 1970 trees reveals that 1-0 plugs and 1-0 bullets sustained more damage than expected at seven years, while 2-0 seedlings and 1-2 transplants experienced less damage than expected. For 1971 trees, 1-0 plugs, 1-0 bullets and 1-1 transplants sustained more damage than expected at six years, while 2-0 seedlings and 2-1 transplants had less.

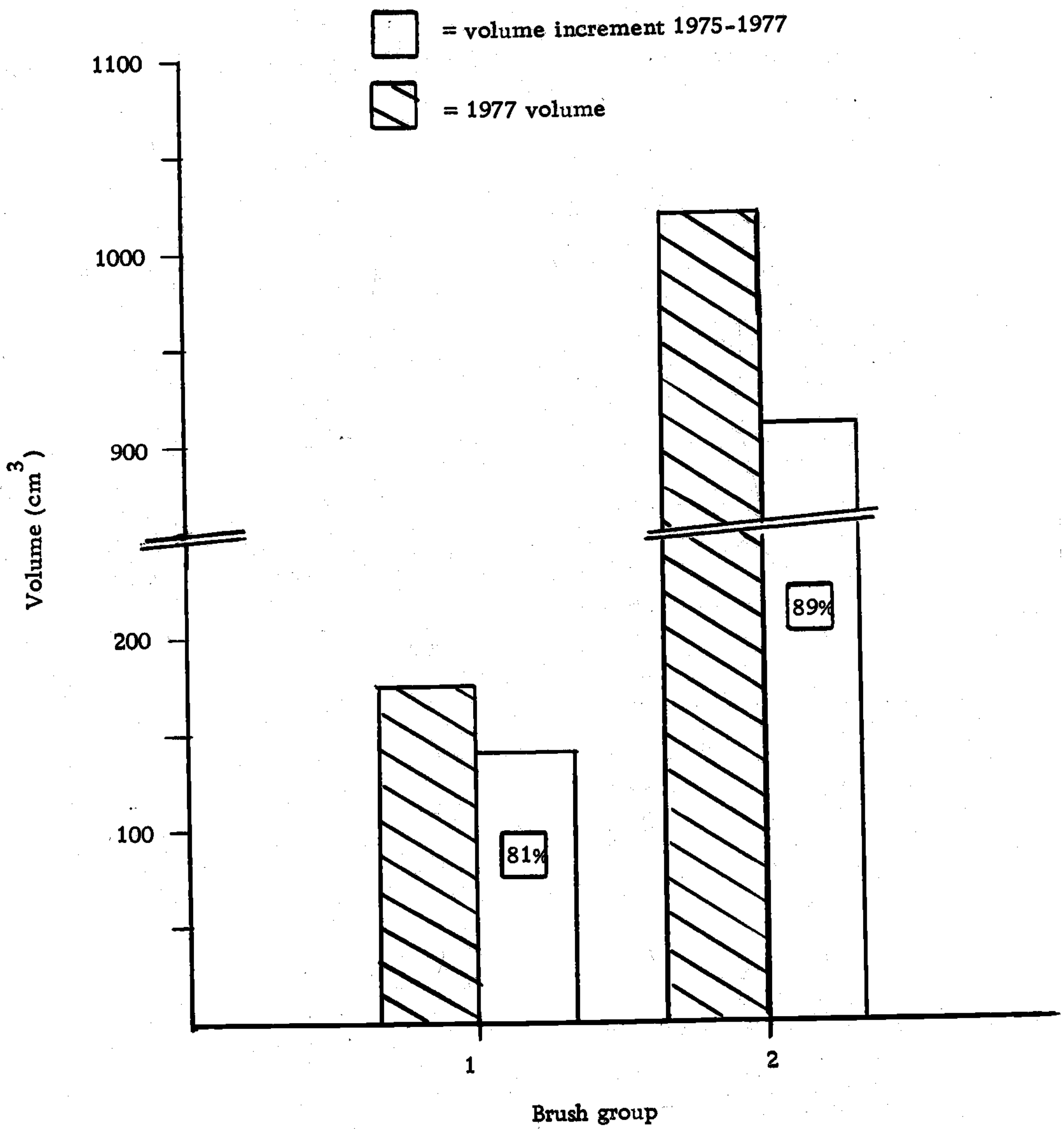

Figure 29. Mean volume 1977 and mean 1975-1977 volume increment (adjusted for missing data), by 1975 brush group. 1971 trees averaged over all stock types and sites.

TABLE 15. Summary of the significance of independent variables in regressions with 1971 trees, all dependent variables.

Independent Variables	Dependent Variables: Height in 1977	1975-1977 Height Increment	Diameter in 1977	1975-1977 Diameter Increment	Volume in 1977	1975-1977 Volume Increment
Site	NS	NS	NS	NS	NS	NS
Stock	S	S	S	S	S	S
Brush Group 1975	S	S	S	S	S	S
Brush Group 1977	S	S	S	S	NS	NS
Brush Group 1975 * Brush Group 1977	NS	NS	NS	NS	NS	NS
Stock * Brush 1975	NS	NS	NS	NS	NS	NS
Stock * Brush 1977	NS	NS	NS	NS	NS	NS
Stock * Brush 1975 * Brush 1977	NS	NS	NS	NS	NS	NS

S = Significant at 0.05 level or above.

NS = Not Significant at 0.05 level.

TABLE 16. Damage Group Criteria

Group One:	No observable damage.
Group Two:	Top die-back attributed to frost, herbicide injury or other physiological factors.
Group Three:	Mechanical damage due to soil ravelling, or accumulation of debris or slash on seedlings.
Group Four:	Animal damage from clipping by rodents, and/or terminal browse or rubbing by big-game.

TABLE 17. Actual and expected frequencies, and the deviation between the two, for damage occurring to stock types, 1970 trees.

actual frequency expected frequency deviation	Damage Type: undamaged	top-dieback	mechanical	animal		% DAMAGE
Stock Type: 1-0 plugs	279.0 296.0 -17.0	10.0 7.8 2.2	21.0 11.5 9.5	16.0 10.7 5.3	n = 326 22.19%	14.4%
1-0 bullets	224.0 235.2 -11.2	8.0 6.2 1.8	13.0 9.2 3.8	14.0 8.5 5.5	259 17.63%	13.5%
2-0 seedlings	355.0 344.2 10.8	8.0 9.0 -1.0	8.0 13.4 -5.4	8.0 12.4 -4.4	379 25.80%	6.3%
1-2 transplants	476.0 458.6 17.4	9.0 12.0 -3.0	10.0 17.9 -7.9	10.0 16.5 -6.5	505 34.38%	5.7%
	n = 1334 90.81%	35 2.38%	52 3.54%	48 3.27%	1469 100.0%	

Chi-square = 30.016 df = 9 prob. = 0.0004

% refers to percentage of row or column totals.

TABLE 18. Actual and expected frequencies, and the deviation between the two, for damage occurring to stock types, 1971 trees.

Stock Type (actual frequency / expected frequency / deviation)	Damage Type: undamaged	top-dieback	mechanical	animal	
1-0 plugs	79.0 96.0 -17.0	0.0 0.2 -0.2	16.0 8.6 7.4	23.0 13.1 9.9	n = 118 19.60%
1-0 bullets	45.0 47.2 -2.2	0.0 0.1 -0.1	5.0 4.2 0.8	8.0 6.5 1.5	58 9.63%
2-0 seedlings	229.0 221.4 7.6	1.0 0.5 -0.5	23.0 19.9 3.1	19.0 30.3 -11.3	272 45.18%
1-1 transplants	27.0 33.4 -6.4	0.0 0.1 -0.1	0.0 3.0 -3.0	14.0 4.6 9.4	41 6.81%
2-1 transplants	110.0 92.0 18.0	0.0 0.2 -0.2	0.0 8.3 -8.3	3.0 12.6 -9.6	113 18.77%
	n = 490 81.40%	1 0.17%	44 7.31%	67 11.13%	602 100.0%

Chi-square = 66.33 df = 12 prob. = 0.0001

% refers to percentage of row or column totals

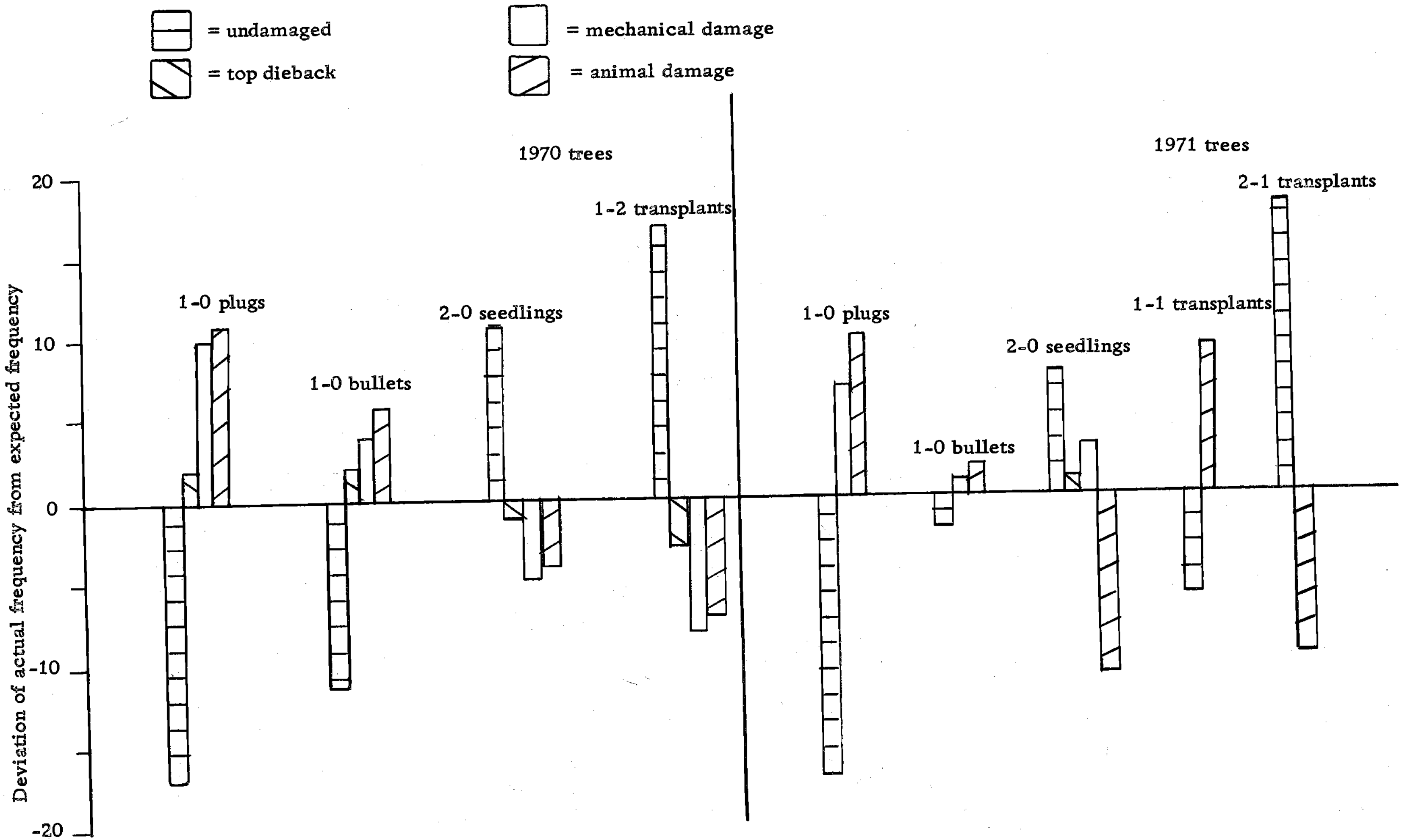

Figure 30. Deviations of actual damage type frequency from expected damage type frequency. 1970 and 1971 trees.

Comparing overall percentages of undamaged trees for 1970 and 1971 reveals that in both years, the numbers of undamaged trees were high, but there were fewer undamaged trees in 1971 plantings than in 1970. Undamaged percentages were 81.4 and 90.8%, respectively. Therefore, even though damage to trees after five and seven years is limited, results from these analyses are still useful in that they illustrate how smaller seedlings remain more vulnerable to damage for a longer period of time.

Table 77 and 78 (Appendix B) list the percentages of each damage type sustained by all stock types in 1970 and 1971 respectively. Figure 31 illustrates this same information graphically.

Figure 32 illustrates antler rubbing damage to a sapling by big-game.

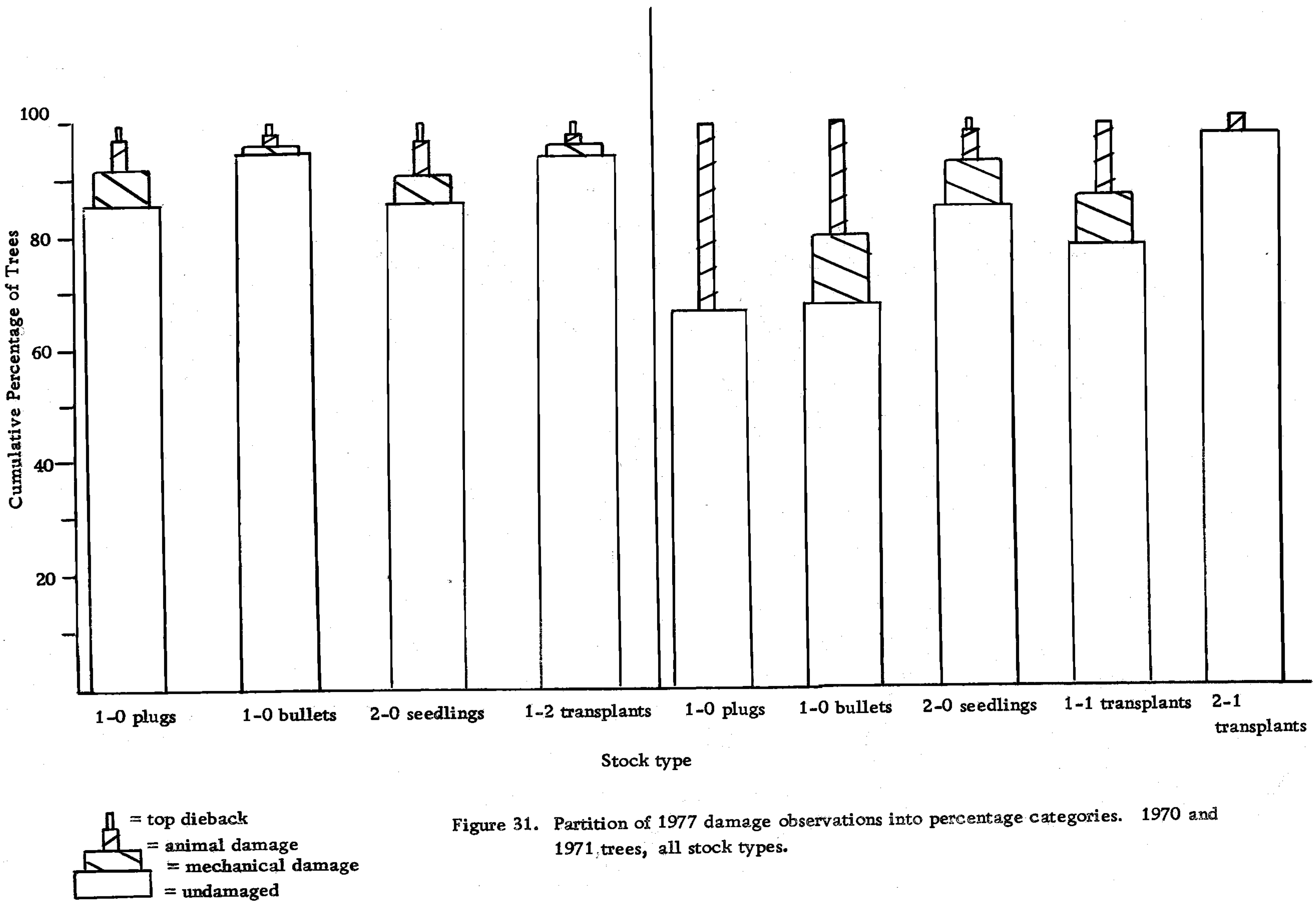

Figure 31. Partition of 1977 damage observations into percentage categories. 1970 and 1971 trees, all stock types.

Figure 32. Antler rubbing damage to a sapling by big-game.

V. DISCUSSION

A. Comparisons Between Stock Types: Absolute and Relative Growth, Growth Rates and Susceptibility to Damage.

Results from the various statistical analyses serve as a basis for comparing differences in stock type performance.

The covariance analyses provide highly significant information relating the importance of initial size, vegetation density and stock type in explaining variation in seven-year tree growth. The unexplained variation in these models, however, which averages 70% indicates that there is still much uncertainty in regard to the performance of tree seedlings within the different vegetation groups. Further, when results of the present analyses are compared with Iverson's (1976), it can be seen that unexplained variation is greater for seven-year growth than five-year growth. This suggests that variables not included in the regression model are now more important in explaining total growth variation.

While results differ slightly between the two covariance procedures (i.e. correlating seven-year growth with 1975 vegetation and 1977 vegetation), both provide relevant information. In fact, the competition analyses in Section C have indicated that, in most instances, both dominant competitors present in 1975 and in 1977 are important in explaining variation in tree growth response.

In general, correlations of seven-year growth in all 1975 vegetation groups have shown that initial seedling height was most important in explaining growth variations. An exception is in vegetation group 2, where density of the competing vegetation, rather than initial seedling height or stock type, is most significant.

These results are in good agreement with Iverson's findings in 1976 which indicated that seedling size explained most of the variation in growth in vegetation groups 1, 3, 5 and 6, and that density was most significant in group 2. The only discrepancy is in regard to vegetation group 4. Stock type was more significant in 1975, while initial height was most significant in 1977.

Overall, stock type was less important in explaining variations in growth than initial seedling height, when both were included in the regression model. As Analysis IV has shown, there was a wide range in the initial heights (and presumably other seedling characteristics such as diameter, root development, etc.) within stock types, hence it is not unexpected that a measurable characteristic such as height, rather than a stock type designation is more highly correlated with and a better predictor of seedling growth, when growth is expressed as height.

Results from covariance analyses with seven-year growth on 1977 vegetation group are somewhat different than those from the previous analyses. While variations in the growth of seedlings associated with a lower competitive influence (groups 4 and 5) are still explained most completely by initial height, density explains more of the variation in growth of overtopped seedlings in groups 2 and 3. Also, in vegetation group 1 (overtopping competitors with high dominance potential), stock type designation is most significant.

The importance of vegetation density, in explaining growth of overtopped trees at seven years suggests that the ability of shrubby overtoppers to utilize light resources has increased since 1975. Reduced levels of radiation may now be more limiting to tree growth.

The importance of stock type in explaining growth variations at the upper extreme of competition, suggests that there are stock type characteristics other than initial height which contribute to divergent growth. Whether this is diameter, shoot-root ratio or some other factor cannot be determined in this analysis. Figure 33 illustrates tree seedlings under this extreme of competitive influence.

It is noteworthy that vegetation density was most significant in explaining growth variation in 1975 and 1977 for trees in group 2. The vegetation in this group, bracken and thimbleberry, are unique in that not only are they light limiting, but bracken is also capable of producing substances thought to be toxic to conifer seedlings. Several studies have indicated reduced height growth of two year-old Douglas-fir seedlings planted on sites dominated by bracken, when compared with growth on sites when bracken was absent (Dimock 1964, Worthington 1955). While the allelopathic influences were not directly investigated in this analysis, the low growth rates and negative initial height regression coefficients associated with trees in this group suggest some type of interaction is occurring that is not obvious in the other vegetation groups.

When initial height is not included in regression models, but site and vegetation group or density classes are, as in Analyses VIII and IX, the ability of different independent variables to explain variation in mean height and height increments changes slightly.

Figure 33. Tree seedlings overtopped by Big leaf maple. Vegetation group one, brush group 1.

Figure 34 illustrates the percentages of total variation that can be explained by regression models when analyzing mean heights in 1975 and 1977, as well as mean height increment from 1975 to 1977 for trees established in 1970 and 1971.

Stock type is consistently most important in explaining mean height variation in 1975 and 1977 for all trees. In general, the importance of stock decreases with increasing age of the trees, but still explains more than 40% of the total variation in height. In this comparison, stock type embodies a substantial effect of seedling height.

Site is also important in explaining variations, and contrary to stock, the importance of site increases with increasing age of the trees. The site variable is the most difficult to interpret as it may be confounded with other influences. Not only are sites located on different aspects and slopes, and with different elevations and topography, Analysis IV has also shown that initial seedling height is confounded with site. In addition, the overall vegetation varies among sites and plots and thus, vegetation is certain to be confounded with site as well. The combination of these interacting influences may help to explain why site becomes increasingly important as trees age.

The importance of 1975 vegetation group to seven-year height growth varies with the time of establishment and the number of years of growth. The present study shows that at seven-years, vegetation group never explains more than 8% of the total variation, and at best is not consistent. For trees established in 1971, vegetation

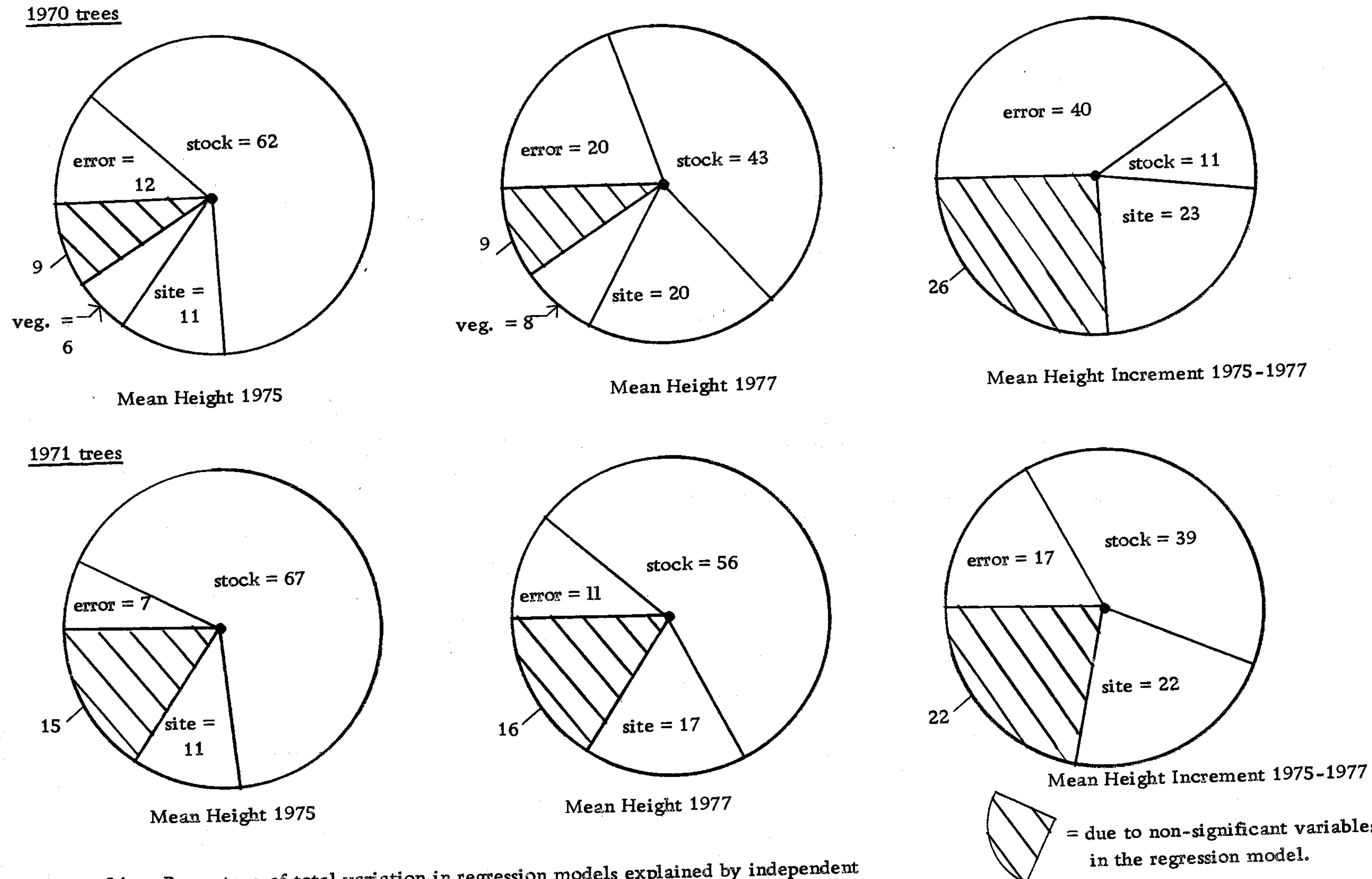

Figure 34. Percentage of total variation in regression models explained by independent variables. 1970 and 1971 trees; regressions with vegetation groups.

group is no longer significant at either four or six years.

The amount of residual variation that cannot be explained by regression models, increases with increasing age of the trees. Unexplained variation for 1975-1977 height increments is consistently greater than for mean heights in 1975 and 1977, and is also greater for trees established in 1970 than 1971. This suggests that microsite influences begin to mask macrosite and stock factors between the fifth and seventh year.

Figure 35 illustrates the percentages of total variation that are explained by regression when analyzing mean height in 1975 and 1977 with density classes. In general, the results from regressions with density classes are quite similar to regressions with vegetation groups. As in earlier comparisons, stock consistently explains the largest amount of variation between mean heights in 1975 and 1977, the amount decreasing with the increasing age of the trees. Also, site becomes more important as the trees age, and the unexplained proportion of variation increases. Unlike vegetation groups, however, the ability of density classes to explain variation in absolute height also increases as the trees age.

In general, the amount of unexplained variation in the absolute and relative growth at six and seven years, indicates that other factors not included in the model are becoming increasingly more important. These factors could include microsite variation, genetic characteristics of the trees, increasing size of trees (hence increasing absolute magnitude of proportional differences) or a combination of environmental interactions. This increase in unexplained variation

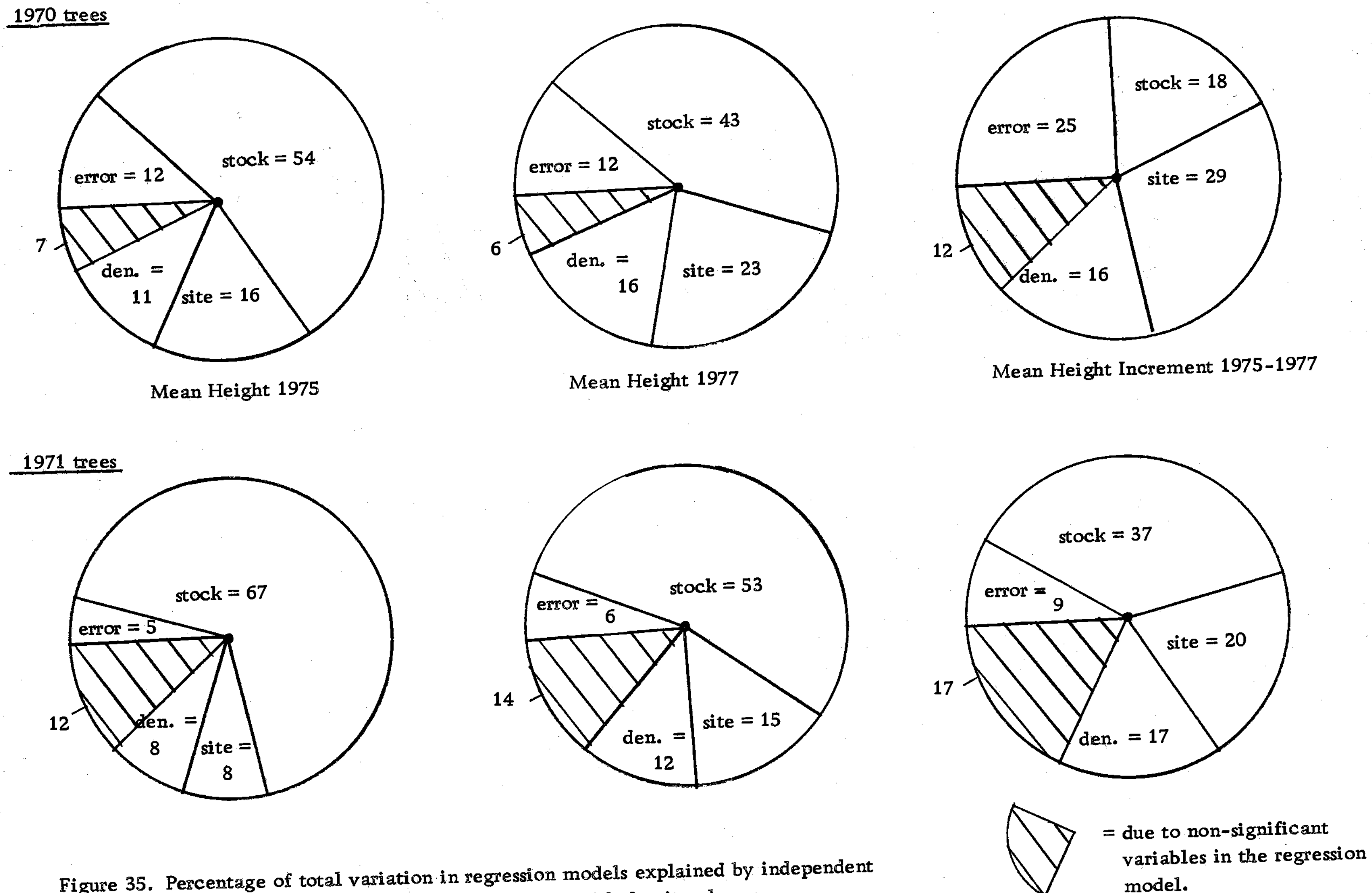

Figure 35. Percentage of total variation in regression models explained by independent variables. 1970 and 1971 trees; regressions with density classes.

also indicates that the growth performance of seedlings at six and seven years cannot be precisely predicted by characteristics such as stock type and height which are present at the seedling stage. In other words, the effectiveness of proper stock selection may be overcome by random occurrence of both biotic and abiotic factors which contribute additional uncertainty.

Another result of the covariance analyses was that only at the mid-range of competitive influences (groups 3, 4 and 5) were there significant differences between growth rates of the various stock types. The lack of significant growth differences between stock types at the upper and lower extremes of competitive influence suggest that either all trees grow comparatively well (group 6), or all are limited to some extent (groups 1 and 2) as was proposed earlier in this thesis. It should be noted however, that when seven-year growth was correlated with 1977 vegetation, there were significant differences between growth for stock types associated with vegetation in group 1. The number of trees still surviving under this high competitive influence was low (containerized=13, transplants=24 and seedlings=13), and this may have influenced the results to some extent. Even though the transplants and seedlings had considerably better growth than the containerized seedlings, the high mortality in this environment reduced the dependability of the observation of survivors.

Analyses VIII and IX have also shown that 1-0 plugs are not significantly different from 1-0 bullets in terms of absolute heights and mean increments. Also, the relative growth of 2-0 seedlings and

1-2 transplants are not significantly different, although their absolute growths are. In addition, containerized seedlings are significantly different from the larger seedlings and transplants in terms of both absolute and relative growth.

In spite of these differences, results from Analysis VI have shown that the mean absolute growth rates for seedlings at seven years are not significantly different between sites, between stock types, or except for one uncertain instance (group 2), between vegetation groups. In other words, seedlings with a greater initial height at time of planting maintain their height advantage but after seven years do not have greater current growth rates. Therefore, a reasonably precise estimate of the time-gain from stock selection becomes possible because stock types have become parallel in development at seven-years.

Figure 36 illustrates the cumulative height growth for trees established in 1970. Only trees which had not sustained damage detrimental to their growth were included in this analysis, hence the growth curves represent only trees which continually increased in height all years in the field.

As discussed by Iverson (1976), a tree is often considered established under natural field conditions once it reaches 4-1/2 feet (app. 137 cm.) in height. At this time, a tree's susceptibility to adverse influences such as animal damage and vegetative competition is reduced, thus differences in stock type performance may be evaluated by comparing the average number of years it takes each to reach 4-1/2 feet.

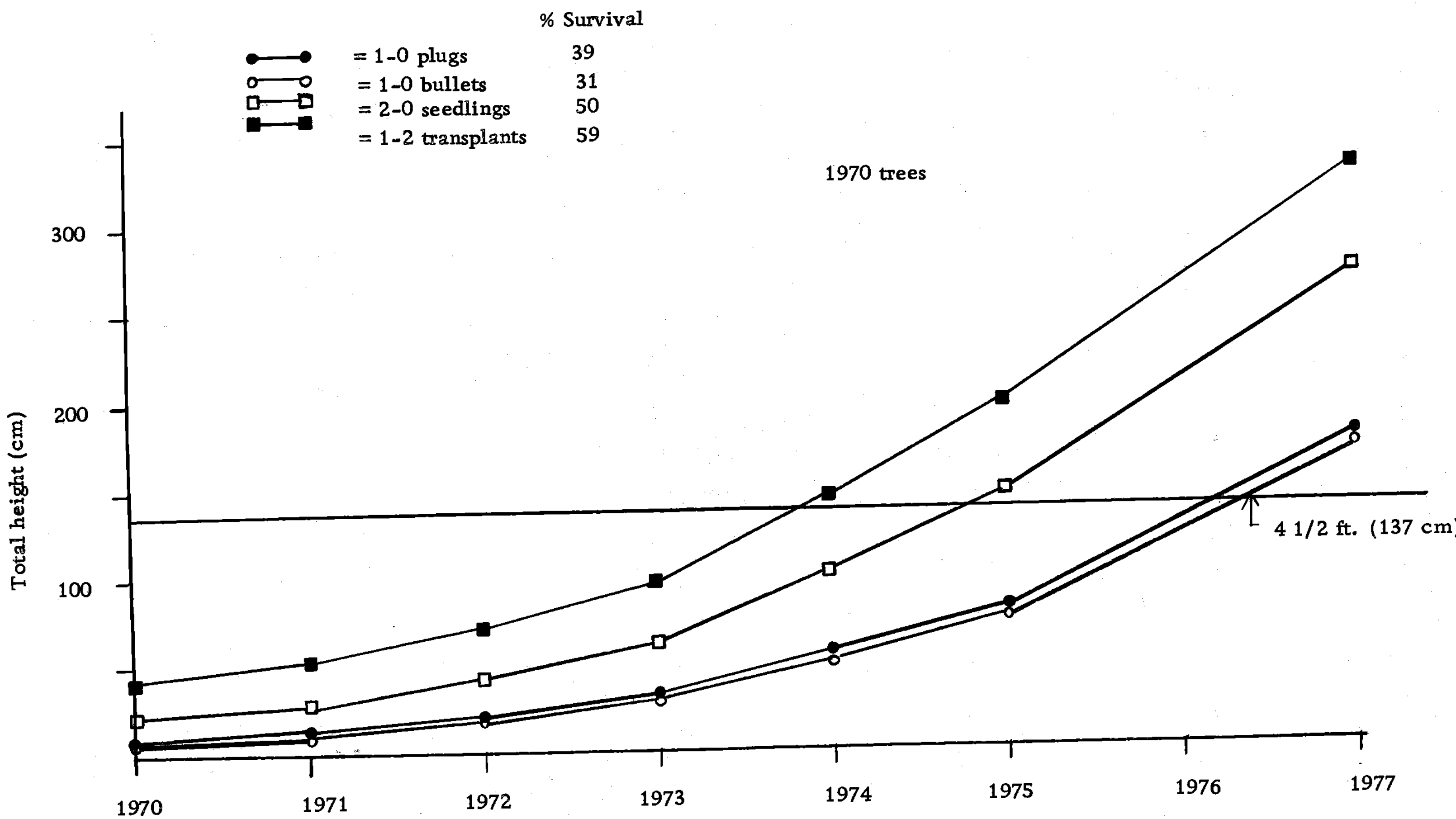

Figure 36. Cumulative height growth of undamaged seedlings, by stock type.

As Figure 36 illustrates, all stock types established in 1970 have now passed the establishment mark. As was noted by Iverson (1976) the establishment time for 1-2 transplant stock in this study was four years. He also predicted that establishment time for 2-0 and containerized seedlings would be six and eight years, respectively although the present evaluation indicates these are actually five and seven years. In general, the larger the stock, the less time is needed for establishment. Approximately three years time-gain is likely to be attained by using 44 cm. stock in preference to 8 cm. seedlings.

Plantation stocking rates are of interest also in plantation evaluation. The combination of stocking and growth in the long run will help to estimate plantation yields and rotation lengths.

Initially, 700 trees of each stock type were planted in 1970. After eliminating mortality and damaged seedlings over the seven years in the field, Figure 36 indicates that the percentages of surviving, established trees for 1-2 transplants, 2-0 seedlings and containerized seedlings are 59, 50 and 35%, respectively. Therefore, despite the exhibition of currently similar growth rates for all 1970 stock types that have reached 4-1/2 feet, the differences in survival alone are worthy of economic consideration. Understocked stands obviously have lower production rates, and plantations started from smaller trees have less stocking.

Results from trees established in 1971 are similar to the above (Figure 37), although only two of the five stock types (2-1 transplants and 2-0 seedlings) can be considered established at six-years. Also

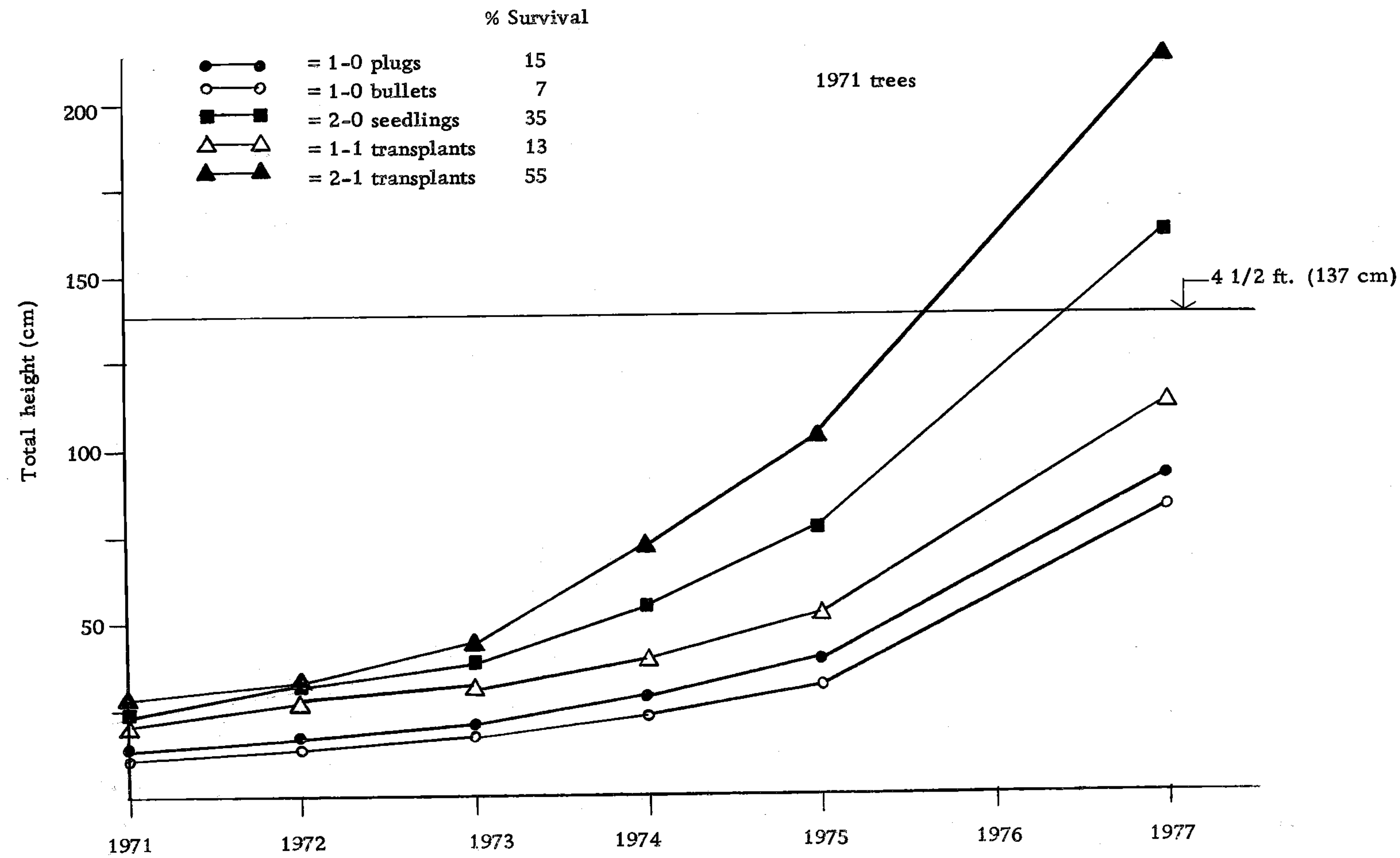

Figure 37. Cumulative height growth of undamaged seedlings, by stock type.

mortality was much greater for 1971 trees, and at the present, survival for 2-1 transplants, 2-0 seedlings, 1-1 transplants and containerized seedlings are 55,35, 13 and 11%, respectfully.

Additional advantages of using larger stock are evident after considering results from the damage survey. Although damage detrimental to growth for seven and six-year old trees was limited (usually less than 20%), there was still a significant tendency for the smaller stock types (1-0 plugs and bullets, and 1-1 transplants) to be damaged more often. This includes all types of damage, and is complied from tree data on all sites and associated with all vegetation groups. It is definitive evidence that small seedlings have prolonged exposure to mechanically injurious events.

In summary, the primary practical advantage of the large stock types over small are that they are less prone to animal damage and mortality, are established earlier, and have an initial height advantage that is maintained at seven years. These advantages will have a large influence on plantation success, and a later appraisal of stock type performance would most likely reaffirm these early trends. As shown by Iverson (1976), while the planting costs for larger stock are initially greater, the cost per established tree is lower over the long-run for large stock than small stock. In addition, the updated observations on the performance of various stock types would tend to increase the differential value of larger stock over smaller stock. The economic efficiency of smaller stock types may be less than figures calculated by Iverson (1976), as results now show that through seven years their susceptibility to injury is greater and differences in absolute height are still apparent even after all stock types are established.

B. The Influence of Seral Vegetation on Tree Growth: Ecological Patterns and Biological Interpretation.

A primary reason for studying competitive interactions between coniferous crop trees and seral vegetation in natural field situations, is to gain an understanding of how these interactions influence reforestation success. A continuum of vegetation types can be found on cutover sites in the Oregon Coast Range, and evaluations of tree and brush growth over this continuum can provide insight into how competition for limited resources modifies both individual conifer growth and the overall successional picture.

Of the six vegetation groups developed by Iverson (1976), it is interesting to note that at seven-years the influence of this vegetation on the absolute and relative height of seedlings was not consistently or significantly different between overtopping groups (1, 2 and 3) or between groups with encroachment, ground cover and bare ground (4, 5 and 6).[1] Possible explanations for this apparent lack of differences are discussed below.

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[1]This is not to say that there were never significant differences between these groups. As in several instances bracken influence (group 2) was significantly different from other woody overtoppers (group 3) or overtopping in groups 2 and 3 was significantly different from encroaching in group 4. Overall though, the general trend above was more apparent than these individual instances.

Overtopping vegetation groups were distinguished from each other primarily by differences in the dominance potential of the vegetation in these groups. The lack of significant differences between these groups, suggests that, at seven years, the differences in dominance potential are not yet apparent, and that the primary influence of this vegetation on tree seedlings is to limit the amount of incoming solar radiation available for photosynthesis and growth. In all instances, the crown of tree seedlings was below the crowns of the surrounding vegetation.

Initially one would not expect the influences from encroaching vegetation to be similar to influences from low-lying vegetation or bare ground. However, in all these instances, tree seedling crowns were above the upper level of the surrounding vegetation, hence light interception was not an important limiting factor. Furthermore, because low light levels are probably most limiting to tree growth on otherwise favorable sites in the Coast Range, other differences between encroaching, herbaceous vegetation and bare ground are less important.

In general then, two types of brush influence were examined in this study: high competition for light (vegetation groups 1, 2 and 3 or brush group 1) and low competition for light (vegetation groups 4, 5 and 6 or brush group 2). Results from regressions with density classes also verify these two brush group influences. Significant differences appeared most often in these regressions, between classes with overtopping influence (1 and 2) and classes with encroaching influence (3). Again this suggests that seral vegetation has a greater influence through a reduction in available light if it overtops seedlings.

Two years of competition estimates were used to evaluate changes in competitive status of vegetation surrounding tree seedlings. In light of the above findings, it was of interest to determine how this vegetation had influenced growth patterns from 1975 to 1977.

In general, analyses indicated that there was a greater tendency for trees to remain under either high competition or low competition influences in both 1975 and 1977. This suggests that after four and five field seasons, for trees established in 1971 and 1970 respectively, the competitive status of the juvenile tree seedlings had already been determined, and the tendency for change either to a more favorable or less favorable competitive environment is small without interference. The importance of this observation in determining reforestation success will be evaluated later.

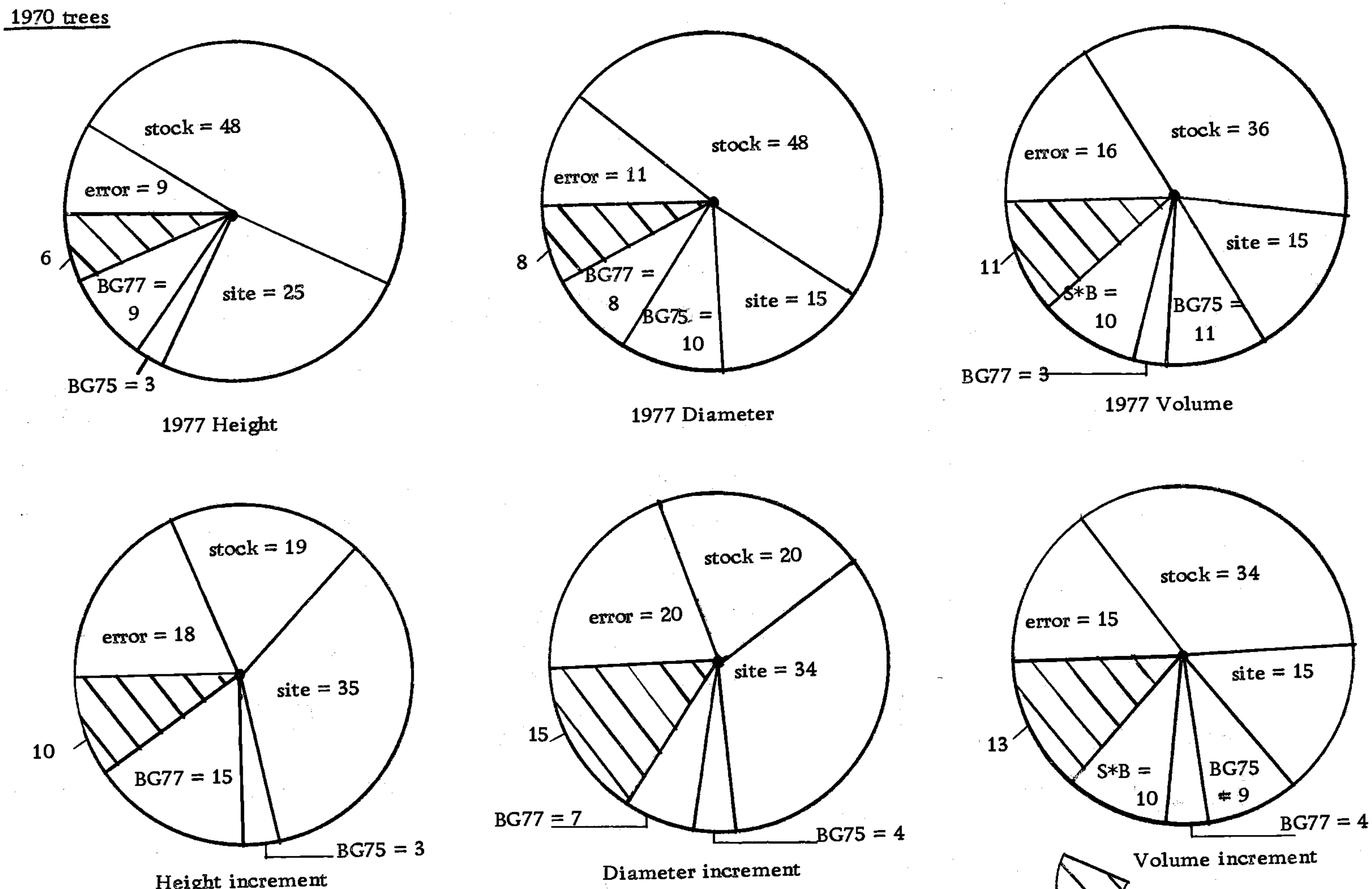
Regression analyses for a number of different response variables (height, diameter, volume, etc.) on brush group in 1975 and 1977, helped to eludicate which variables were most significant in explaining variations at six and seven-years. Both height, diameter and their increments are to some extent indicators of how site resources are distributed. As noted by Preest (1975) however, early volume increments provide a more integrated response to resource distribution, as both height and diameter measurements are needed for its determination. Hence, volume in 1977 and volume increment from 1975-1977 were evaluated as well.

Figures 38 and 39 illustrate the percentage of total variation for each of the six response variables, explained by different independent variables. The following trends are apparent in the data.

Stock type consistently explains most of the variation in diameter and volume as well as height, for trees established in 1970 and 1971. Site is more closely related to height than diameter or volume. For 1971 trees, site was not significant in explaining differences. Brush group present in 1975 almost always explained more variation than brush group present in 1977 for height, diameter and volume. It is also interesting to note that a stock type by 1975 brush group interaction explained almost as much variation as 1975 brush group, for 1970 tree volumes. This interaction was not significant in the 1971 trees, however.

These trends suggest that over the long run, stock selection still has a large bearing on response trends at six and seven years. The ability of brush group present in 1975 to explain more variation than 1977 brush group suggests that the present morphological status of the tree is determined more by past competitive interactions than by the present. Gross morphological characteristics do not respond instantaneously, thus the time delay allows competitive influences to be expressed.

The ability of the stock type by 1975 brush group interaction term to explain variations in volume, suggests that volume may represent a more integrated measure of environmental influences. Volume and volume increments are correlated with a number of differ-



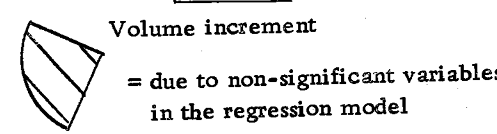


Figure 38. Percentage of total variation in regression models explained by independent variables. 1970 trees; BG = brush group, S*B = stock types by brush interaction.

1971 trees

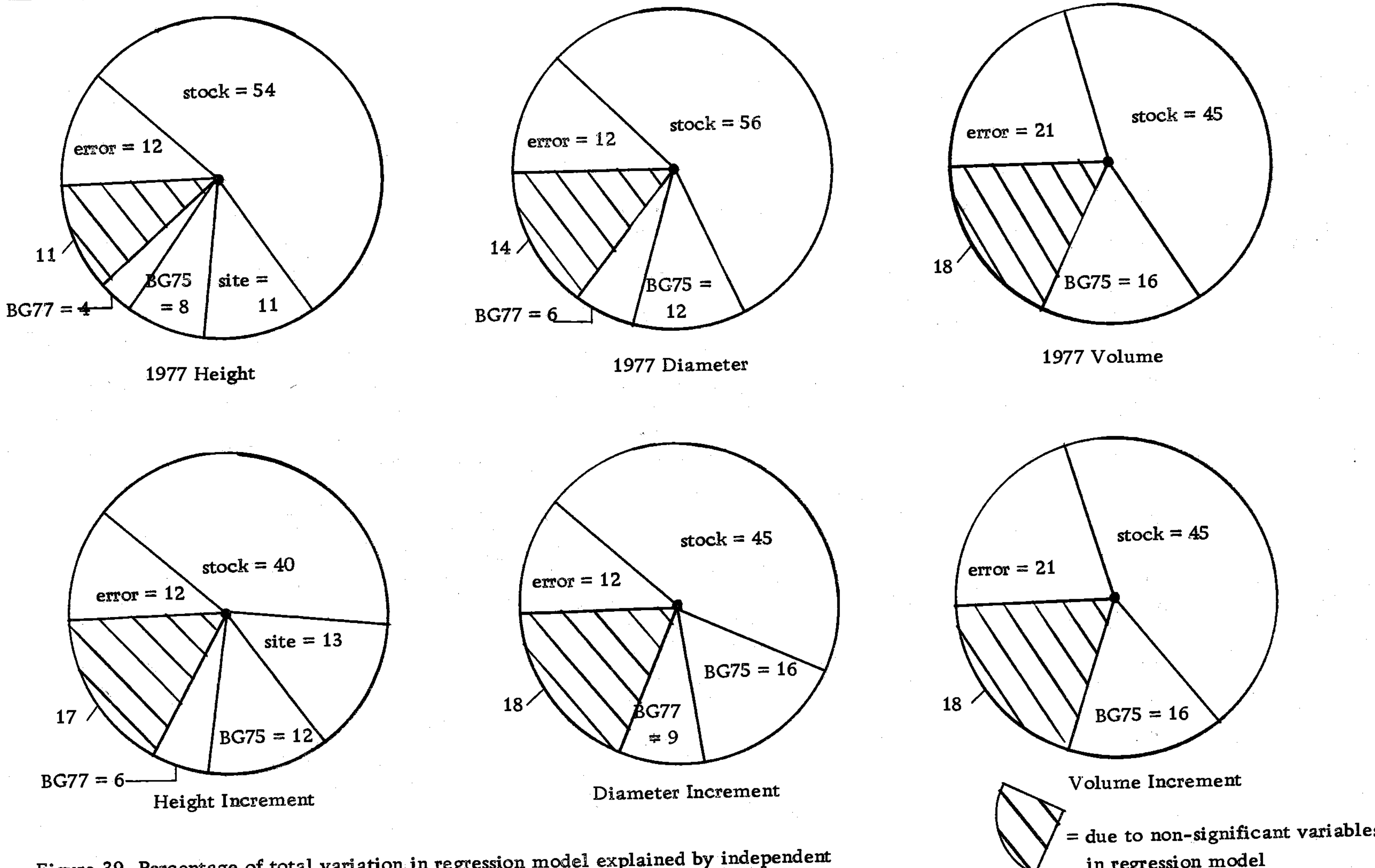


Figure 39. Percentage of total variation in regression model explained by independent variables. 1971 trees; BG = brush group.

ent variables, yet total variation is not explained which again indicates that important variables were not included in the regression models.

Unexplained variation in incremental growth was at least as great and usually greater than unexplained variation in absolute growth. Stock type was also less important, while site was more important in determining 1975-1977 height and diameter increments for 1970 trees. It is not clear how much contribution was made to site effects by stock size and vegetation confounding.

These data suggest that over a limited time period, growth response is less predictable than over a longer time period. Trends of influence are not as obvious, although stock type and site continued to explain most of the variation. Unexplained variation in relative seedling growth may be due to short-term fluctuations in microsite conditions or weather patterns, or perhaps may reflect inherent differences between individual tree seedlings (i.e. genetic characteristics, seed source, etc.). Unexplained variation may be less for absolute growth, as long-term responses are a cumulative expression of these more subtle, finite influences.

It is interesting to note that variations in response variables could not be explained by interactions between 1975 and 1977 brush groups. As was shown earlier, 1975 brush groups were not independent of 1977 brush groups, hence the vegetative influences in 1975 and 1977 were similar. Interactions between brush groups from year to year may not have been significant as often influences were the same.

In spite of this finding, all absolute and relative measurements of growth were always largest when competition influences in 1975 and 1977 were low (brush group 2) and were smallest when competitive influences were high (brush group 1). Measurements for seedlings which had changed brush groups were always intermediate.

In conclusion, vegetation groups serve as valuable indicators of differences and similarities in habitats. Competition for limited light resources operates vertically, thus tree seedlings with crowns in the upper-most strata are less influenced by surrounding vegetation.

At six and seven years, vegetation on cutover land in this area explains only a limited amount of variation in several measures of growth. Vegetation effects on tree seedlings appear to be cumulative, however, with past competitive interactions highly correlated with the present status of tree seedlings. Therefore, seral vegetation on early cutover sites undoubtedly has an influence on individual tree growth and overall reforestation success extending beyond survival.

Vegetation present on a site is fundamentally a product of chance and interactions between a number of environmental variables. The more complex the community, the less variation that can be explained in terms of conventional parameters.

C. Relevance of Findings to Forest Regeneration Practice

The rate of succession in Coastal brushfields is so rapid that striking differences in vegetation are obvious in a few years time. Study of succession and competitive interactions increases the ability of foresters to predict natural trends of development after disturbance, and thus formulate feasible strategies for modifying these trends. A knowledge of ecological processes in disturbed and undisturbed communities is essential for successful vegetation management on forested lands.

The present study has shown that the relative performance of coniferous trees is a function of the combined effects of competition for limited resources and other environmental factors. There is an upper limit of competitive influence that inhibits all seedlings, and a lower limit where most seedlings do reasonably well. Establishment rates and seedlings growth are lowest on sites with a prevalent brush problem, and in general competition from brush decreases seedling survival and growth, as well as delays establishment and reduce stocking. By seven years, trees are less responsive to the surrounding vegetation which suggests that it is the early periods in the regeneration cycle which are most critical in determining later outcomes.

With vegetation management, seral vegetation can be reduced to a less competitive state. The allocation of site resources among primary producers can thus be modified to favor crop trees at the expense of seral vegetation. Not only can the dominance of crop trees be increased by release from competitors, but the resulting increase in survival and growth rates can alter the entire successional picture on regeneration sites.

The importance of brush control, therefore, cannot be overlooked.

The present study has indicated that the largest stock studied is consistently the best economic investment on brushy sites. In addition to better initial survival and growth, they require less protection from animals and brush. The use of vegetation management techniques to control seral vegetation, however, can help to insure positive growth trajectories for all stock types. Enhanced growth of crop trees in early years thus allows for early establishment and thus for increased and more dependable yields in subsequent years.

In conclusion, the potential return from reforested sites can be controlled to some extent by management strategies. Effective and efficient reforestation can increase the amount, the rate and the quality of yields. Therefore, investments in the early stages of tree rotations are of utmost importance.

VI. CONCLUSIONS

A detailed study was conducted which evaluated the juvenile growth of several Douglas-fir stock types on Coastal sites occupied by a variety of seral vegetation.

Conclusions which can be drawn from this study, both direct and inferred, are as follows:

1. Covariance analysis techniques used to evaluate five-year growth are still applicable at seven-years. Similar growth trends are apparent, although unexplained variation of total growth is increased.

2. Stock type designation, which embodies the effect of initial seedling height is a good predictor of seedling performance on brushy sites.

3. Larger stock types (1-2 transplants and 2-0 seedlings, in this study) are a better economic investment than smaller stock on brushy sites. They are influenced less by biological constraints (competing vegetation, animal damage), maintain their superior height advantage, are established on a number of sites and perform better without maintenance.

4. At seven years, there is no significant differences in seedling growth between sites, stock types or vegetation groups. The use of larger seedlings, however, can provide up to three years height growth advantage.

5. On otherwise favorable Coast Range sites, overtopping vegetation which reduces incoming solar radiation is an important factor limiting seedling growth. The vertical position of coniferous seedlings in relation to surrounding vegetation, is a prime determinant of subsequent growth.

6. Bracken fern is a particularly tough competitor on Coast Range sites. Not only is it light limiting, but may also produce substances toxic to Douglas-fir. Of all vegetation examined, growth was always lowest for trees associated with bracken.

7. Data suggest that after four or five field seasons, the competitive status of juvenile seedlings has already been determined. There is little tendency for seedlings to

change to either a more favorable or less favorable competitive situation after this time, without interference.

8. The importance of stock type in explaining current growth variations decreases as the trees age, while site increases. The importance of vegetation groups at seven-years varies, although 1975 brush group is more highly correlated with response variables than 1977 brush group.

9. Unexplained growth variation increases as trees age. This variation may be due to microsite variations or genetic characteristics of tree seedlings. Physiological condition of seedlings and treatment at time of planting may also influence results to some extent.

10. Vegetation management on brushy sites can help to insure positive growth trajectories of all stock types. The allocation of site resources can be modified to favor crop trees, thus allowing for increased yields from greater stocking in subsequent years.

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APPENDICES

APPENDIX A. Plant Species List - Scientific names, common names, plant species code and vegetation group classification. Nomenclature follows Hitchcock and Cronquist (1973) and Garrison et al. (1976).

Scientific Name	Common Name	Species Code	Vegetation Group
Acer circinatum	Vine Maple	ACCI	3 or 4
Acer macrophyllum	Big leaf Maple	ACMA	1
Adiantum sp.	Maidenhair Fern	ADIAN	5
Alnus rubra	Red Alder	ALRU	1
Arctostaphylos columbiana	Hairy Manzanita	ARCO	3 or 4
Baccharis pilularis	Baccharis	BAPI	3 or 4
Berberis nervosa	Cascade Hollygrape	BENE	3 or 4
Berberis repens	Creeping Hollygrape	BERE	3 or 4
Carex sp.	Sedge	CAREX	5
Castanopsis chrysophylla	Golden Chinquapin	CACH	3 or 4
Ceanothus sanguineus	Redstem Ceanothus	CESA	3 or 4
Ceanothus velutinus	Snowbrush Ceanothus	CEVE	3 or 4
Cornus nuttallii	Pacific Dogwood	CONU	1
Cornus occidentalis	Western Dogwood	COOC	1
Corylus cornuta californica	California Hazel	COCO	3 or 4
Forbs	Forb Species	FOsp	5
Gaultheria shallon	Salal	GASH	3 or 4

APPENDIX A. continued

Scientific Name	Common Name	Species Code	Vegetation Group
Grass	Grass Species	GRsp	5
Holodiscus discolor	Ocean Spray	HODI	3 or 4
Polystichum munitum	Sword Fern	POMU	5
Prunus emarginata	Bitter Cherry	PREM	3 or 4
Pseudotsuga menziesii	Douglas-fir	PSME	1
Pteridium aquilinum	Bracken Fern	PTAQ	2 or 5
Rhamnus purshiana	Cascara Buckthorn	RHPU	3 or 4
Rhus diversiloba	Sumac	RHDI	3 or 4
Ribes sanguineum	Winter Currant	RISA	3 or 4
Rosa gymnocarpa	Baldhip Rose	ROGY	3 or 4
Rubus laciniatus	Evergreen Blackberry	RULA	3 or 4
Rubus leucodermis	Blackcap	RULE	3 or 4
Rubus parviflorus	Thimbleberry	RUPA	2 or 4
Rubus spectabilis	Salmonberry	RUSP	3 or 4
Rubus ursinus	Trailing Blackberry	RUUR	3 or 4
Salix sp.	Willow Species	SALIX	3 or 4
Sambucus glauca	Blue Elderberry	SAGL	3 or 4

APPENDIX A. continued

Scientific Name	Common Name	Species Code	Vegetation Group
Symphoricarpos albus	Common Snowberry	SYAL	3 or 4
Vaccinium ovatum	Box Blueberry	VAOV	3 or 4
Vaccinium parvifolium	Red Whortleberry	VAPA	3 or 4

APPENDIX B

TABLE 1. Analysis of covariance for seedlings in vegetation group one in 1977. Seven-year growth on stock type, adjusted for initial seedling height and density; $r^2 = .32$.[1]

Source	Sums of Squares	df	Mean Square	F	Significance of F
Covariables					
Initial seedling height	70165.30	1	70165.30	9.43	0.01**
Density	676.74	1	676.74	0.09	0.76
Main effects					
Stock	85156.31	3	28385.44	3.81	0.02 *
Error	327448.29	44	7442.01		

[1] Note - when a series of similar analyses were conducted, the first results table shows the complete analysis, as above, and subsequent results are reported in an abbreviated form.

* Significant at the 0.05 level.

** Significant at the 0.01 level.

TABLE 2. Analysis of covariance for seedlings in vegetation group two in 1977. Seven year growth on stock type, adjusted for initial seedling height and density; $r^2 = .27$.

Source	df	Mean Square	F
Covariables			
Initial seedling height	1	252.39	0.23
Density	1	19696.23	17.65**
Main effects			
Stock	3	1924.43	1.72
Error	62	1116.23	

** Significant at the .01 level

TABLE 3. Analysis of covariance for seedlings in vegetation group three in 1977. Seven year growth on stock type, adjusted for initial seedling height and density; $r^2 = .19$.

Source	df	Mean Square	F
Covariables			
Initial seedling height	1	78075.84	14.11**
Density	1	90484.55	16.35**
Main effects			
Stock	3	3005.94	0.54
Error	131	5531.87	

** Significant at the .01 level

TABLE 4. Analysis of covariance for seedlings in vegetation group four in 1977. Seven-year growth on stock type, adjusted for initial seedling height and density; $r^2 = .33$.

Source	df	Mean Square	F
Covariables			
Initial seedling height	1	1031587.98	128.53**
Density	1	892268.77	111.17**
Main effects			
Stock	3	90236.95	11.24**
Error	562	8025.92	

** Significant at the .01 level

TABLE 5. Analysis of covariance for seedlings in vegetation group five in 1977. Seven-year growth on stock type, adjusted for initial seedling height and density; $r^2 = .19$.

Source	df	Mean Square	F
Covariables			
Initial seedling height	1	378435.07	73.79**
Density	1	54444.44	10.62**
Main effects			
Stock	3	15063.81	2.94*
Error	377	5128.25	

** Significant at the .01 level

TABLE 6. Analysis of covariance for seedlings in vegetation group one in 1975. Seven-year growth on stock type, adjusted for initial seedling height and density; $r^2 = .47$.

Source	df	Mean Square	F
Covariables			
Initial seedling height	1	86052.24	14.34**
Density	1	74359.90	12.39**
Main effects			
Stock	3	11638.29	1.94
Error	36	6001.23	

** Significant at the .01 level

TABLE 7. Analysis of covariance for seedling in vegetation group two in 1975. Seven-year growth on stock type, adjusted for initial seedling height and density; $r^2 = .34$.

Source	df	Mean Square	F
Covariables			
Initial seedling height	1	40387.07	14.10**
Density	1	135370.50	47.26**
Main effects			
Stock	3	4298.49	1.50
Error	126	2864.34	

** Significant at the .01 level.

TABLE 8. Analysis of covariance for seedlings in vegetation group three in 1975. Seven-year growth on stock type, adjusted for initial seedling height and density; $r^2 = .44$.

Source	df	Mean Square	F
Covariables			
Initial seedling height	1	387250.87	74.37**
Density	1	138567.47	26.61**
Main effects			
Stock	3	23661.32	4.54**
Error	147	5207.19	

** Significant at the .01 level.

TABLE 9. Analysis of covariance for seedlings in vegetation group four in 1975. Seven-year growth on stock type, adjusted for initial seedling height and density; $r^2 = .30$.

Source	df	Mean Square	F
Covariables			
Initial seedling height	1	148214.15	17.93**
Density	1	12058.61	1.46
Main effects			
Stock	3	49353.34	5.97**
Error	89	8266.24	

** Significant at the .01 level.

TABLE 10. Analysis of covariance for seedlings in vegetation group five in 1975. Seven-year growth on stock type, adjusted for initial seedling height and density; $r^2 = .20$.

Source	df	Mean Square	F
Covariables			
Initial seedling height	1	1623114.23	160.38**
Density	1	44430.82	4.39*
Main effects			
Stock	3	47391.46	4.68**
Error	737	10120.54	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 11. Analysis of covariance for seedlings in vegetation group six in 1975. Seven-year growth on stock type, adjusted for initial seedling height; $r^2 = .38$.

Source	df	Mean Square	F
Covariables			
Initial seedling height	1	33171.46	3.44
Main effects			
Stock	3	3106.63	0.32
Error	37	9650.87	

TABLE 12. Analysis of covariance for seedling planted in 1971. Six-year growth on stock type and site, adjusted for initial seedling height, $r^2 = .38$.

Source	df	Mean Square	F
Covariables			
Initial seedling height	1	265937.92	92.55**
Main effects			
Stock	4	109586.21	38.14**
Site	3	21061.30	7.33**
Error	437	2873.43	

** Significant at the .01 level.

TABLE 13. Analysis of variance for 1-0 plug seedlings established in 1970. Initial seedling height on site and plot adjusted for site.

Source	Sums of Squares	df	Mean Square	F	Significance of F
Site	694.39	4	173.60	7.95	0.01**
Plot (site)	501.61	23	21.81	4.03	0.01**
Error	3623.21	671	5.40		

** Significant at 0.01 level.

TABLE 14. Analysis of variance for 1-0 bullet seedlings established in 1970. Initial seedling height on site and plot adjusted for site.

Source	df	Mean Square	F
Site	4	355.19	19.84**
Plot (site)	23	17.90	3.44**
Error	672	5.21	

** Significant at the .01 level.

TABLE 15. Analysis of variance for 2-0 seedlings established in 1970. Initial seedling height on site and plot adjusted for site.

Source	df	Mean Square	F
Site	4	1326.31	13.07**
Plot (site)	23	101.51	3.57**
Error	671	28.47	

** Significant at the .01 level.

TABLE 16. Analysis of variance for 1-2 transplant seedlings established in 1970. Initial seedling height on site and plot adjusted for site.

Source	df	Mean Square	F
Site	4	560.72	1.01
Plot (site)	23	554.93	2.58**
Error	671	215.04	

** Significant at the .01 level.

TABLE 17. Analysis of variance for 1-0 plug seedlings established in 1971. Initial seedling height on site and plot adjusted for site.

Source	df	Mean Square	F
Site	3	1883.62	16.56**
Plot (site)	18	113.77	9.22**
Error	521	12.34	

** Significant at the .01 level.

TABLE 18. Analysis of variance for 1-0 bullet seedlings established in 1971. Initial seedling height on site and plot adjusted for site.

Source	df	Mean Square	F
Site	3	58.06	1.09
Plot (site)	18	53.11	3.20**
Error	521	16.00	

** Significant at the .01 level.

TABLE 19. Analysis of variance for 2-0 seedlings established in 1971. Initial seedling height on site and plot adjusted for site.

Source	df	Mean Square	F
Site	3	3034.99	27.08**
Plote (site)	18	112.06	2.26**
Error	521	49.57	

** Significant at the .01 level.

TABLE 20. Analysis of variance for 1-1 transplant seedlings in 1971. Initial seedling height on plot (one site).

Source	df	Mean Square	F
Plot	5	129.70	5.65**
Error	142	22.97	

** Significant at the .01 level.

TABLE 21. Analysis of variance for 2-1 transplant seedlings established in 1971. Initial seedling height on plot (one site).

Source	df	Mean Square	F
Plot	5	237.55	8.20**
Error	142	28.98	

** Significant at the .01 level.

TABLE 22. Initial height regression coefficients (slopes) from regressions with height in 1977 on initial seedling height and plot. 1970 trees, 1-0 plug stock.

Height in 1977			Vegetation Group			
Site	1	2	3	4	5	6
2		-1.67	-3.99	biased	11.80	biased
3	biased[1]	-2.81	biased	12.60	-0.17	biased
4	5.77	-33.86	3.18		8.74	biased
5	-5.31	-2.80	0.87	8.66	5.64	biased
6	-10.83	biased	biased		biased	

[1] 'Biased' refers to the fact that there were too few data points to determine a regression line. Blank spaces indicate no observations.

TABLE 23. Initial height regression coefficients (slopes) from regressions with 1975-1977 height increment on initial seedling height and plot. 1970 trees, 1-0 plug stock.

1975-1977 Height Increment			Vegetation Group			
Site	1	2	3	4	5	6
2		-1.09	-1.18	biased	5.42	biased
3	biased	-8.34	biased	4.60	-1.82	biased
4	6.44	-24.36	-0.40		5.53	biased
5	-2.81	-1.90	1.27	-2.84	1.41	biased
6	-4.83	biased	biased		biased	

TABLE 24. Initial height regression coefficients (slopes) from regressions with height in 1977 on initial seedling height and plot. 1970 trees, 2-0 seedling stock.

Height in 1977			Vegetation Group			
Site	1	2	3	4	5	6
2		4.17	biased	14.30	6.59	biased
3		biased	biased	0.00	1.85	biased
4	53.54		5.84	8.69	6.05	17.85
5	11.08		4.39	0.30	2.51	6.17
6	biased				biased	

TABLE 25. Initial height regression coefficients from regressions with 1975-1977 height increment on initial seedling height and plot. 1970 trees, 2-0 seedling stock.

1975-1977 Height Increment			Vegetation Group			
Site	1	2	3	4	5	6
2		0.66	biased	5.30	2.42	biased
3		biased	biased	9.00	0.23	biased
4	18.54		0.81	2.12	1.39	8.51
5	5.01		7.53	0.01	0.88	2.17
6	biased				biased	

TABLE 26. Initial height regression coefficients (slopes) from regressions with height in 1977 on initial seedling height and plot. 1970 trees; 1-0 bullet stock.

Height in 1977						
	Vegetation Group					
Site	1	2	3	4	5	6
2		9.91	22.83	biased	11.33	biased
3		-7.93	1.77	-4.92	14.45	biased
4		biased	1.67	0.39	1.21	
5	biased	-12.60	-0.98	-3.55	9.15	biased
6	biased			biased		

TABLE 27. Initial height regression coefficients (slopes) from regressions with 1975-1977 height increment on initial seedling height and plot. 1970 trees, 1-0 bullet stock.

1975-1977 Height Increment						
	Vegetation Group					
Site	1	2	3	4	5	6
2		5.61	14.83	biased	7.18	biased
3		-5.01	-7.73	4.08	2.46	biased
4		biased	-0.83	-8.61	0.52	
5	biased	-8.60	0.52	-2.69	3.81	biased
6	biased			biased		

TABLE 28. Initial height regression coefficients (slopes) from regressions with height in 1977 on initial seedling height and plot. 1970 trees, 1-2 transplant stock.

Height in 1977	Vegetation Group					
Site	1	2	3	4	5	6
2	0.70	-0.33	2.37	biased	2.17	
3	-3.99		biased	biased	2.67	
4	2.54		3.53	0.98	2.21	biased
5	-17.72		-15.04	0.67	1.04	1.08
6	biased		biased	-1.44	0.24	-2.66

TABLE 29. Initial height regression coefficients (slopes) from regressions with 1975-1977 height increment on initial seedling height and plot. 1970 trees, 1-2 transplant stock.

1975-1977 Height Increment	Vegetation Group					
Site	1	2	3	4	5	6
2	0.82	-0.0003	1.35	biased	0.84	
3	-3.36		biased	biased	0.37	
4	0.98		0.62	-1.14	0.38	biased
5	-14.38		-2.64	0.11	-0.56	-0.39
6	biased		biased	3.89	-0.66	-2.16

TABLE 30. Analysis of variance for initial height regression coefficients (slopes) from Analysis V (height in 1977 on initial height and plot) on site, stock type, 1975 vegetation group and stock type by vegetation group interaction term. 1970 trees; vegetation groups one and six and site 6 deleted.

Source	Sums of Squares	df	Mean Square	F	Significance of F
Site	338.69	3	112.90	1.63	0.26
Stock	180.57	3	60.19	0.87	0.47
Error (a)	624.59	9	69.40		
Vegetation	891.18	3	297.06	5.28	0.01**
Stock * Vegetation	299.11	9	33.23	0.59	0.79
Error (b)	1125.57	20	56.28		

** Significant at 0.01 level.

TABLE 31. Analysis of variance for initial height regression coefficients (slopes) from Analysis V (height in 1977 on initial height and plot) on independent variables with sums of squares subdivided (model one). 1970 trees; vegetation groups one and six and site 6 deleted.[1]

Source	Sums of Squares	df	Mean Square	F	Significance of F
Site	338.69	3	112.90	1.71	0.29
Stock	180.57	3	60.19	0.91	
linear	24.68	(1)	24.68	0.37	0.60
quadratic	110.06	(1)	110.06	1.67	0.25
lack of fit	45.83	(1)	45.83	0.69	0.41
Error (a)	594.10	9	66.01		
Vegetation	932.16	3			
2 vs. 3	352.52	(1)	352.52	6.51	0.02*
2 + 3 vs. 4	254.58	(1)	254.88	4.70	0.04*
2 + 3 + 4 vs. 5	325.06	(1)	325.06	6.00	0.02*
Stock * vegetation	322.34	9	35.82	0.66	0.73
Error (b)	1091.84	20	54.17		

[1] See note on following page.

* Significant at 0.05 level.

TABLE 31. continued

[1] A difficulty in calculating the sums of squares in Table 31 occurred when the subdivision of the source due to stock was desired. Ordinarily the 3 degrees of freedom could be subdivided into sources due to linear, quadratic and lack of fit (or cubic). However in this case, the initial heights for both stock types 1-0 plugs and 1-0 bullets are nearly equal (7.98 and 7.99 cm, respectively) so that inclusion of the cubic term leads to extreme non-orthogonality. Thus this term was omitted from the analysis and then re-introduced as the difference between the total stock and the linear plus quadratic sums of squares. The end result of this computational strategy was that the total sums of squares due to Error (a), Error (b), Vegetation and Stock * Vegetation differ slightly between Tables 31 and 32. This difference was judged to be unimportant to the overall inferences. A similar computational strategy was adopted for all other regressions where stock had three degrees of freedom and was subdivided in this manner. Statistical consultation and procedure by Dr. Paul Hinz, 1978, Forest Research Laboratory, Oregon State University.

TABLE 32. Analysis of variance for initial height regression coefficients (slopes) from Analysis V (height in 1977 on initial height and plot) on independent variables with sums of squares subdivided (model two). 1970 trees; vegetation groups one and six and site 6 deleted.

Source	Sums of Squares	df	Mean Square	F	Significance of F
Site	338.69	3	112.90	1.63	0.26
Stock	180.57	3			
plugs vs. bullets	44.99	(1)	44.99	0.65	0.41
2-0 vs. 1-2	133.39	(1)	133.38	1.92	0.13
plug + bullet vs. 2-0 + 1-2	2.19	(1)	2.19	0.03	0.84
Error (a)	624.59	9	69.40		
Vegetation	891.18	3			
veg. 2 + 3 vs. 4 + 5	430.80	(1)	430.80	7.65	0.01**
2 vs. 3	449.90	(1)	449.91	7.99	0.01**
4 vs. 5	10.48	(1)	10.48	0.19	0.67
Stock * vegetation	299.11	9	33.23	0.59	0.79
Error (b)	1125.57	20	56.28		
Total	3459.70	47			

** Significant at 0.01 level.

TABLE 33. Analysis of variance for initial height regression coefficients (slopes) from Analysis V (1975-1977 height increment on initial height and plot) on site, stock type, 1975 vegetation group and stock type by vegetation group interaction term. 1970 trees; vegetation groups one and six and site 6 deleted.

Source	Sums of Squares	df	Mean Square	F	Significance of F
Site	194.92	3	64.97	2.70	0.11
Stock	130.87	3	43.62	1.81	0.24
Error (a)	216.59	9	24.07		
Vegetation	316.16	3	105.39	3.78	0.03 *
Stock * vegetation	119.60	9	13.29	0.48	0.87
Error (b)	557.69	20	27.88		

* Significant at 0.05 level.

TABLE 34. Analysis of variance for initial height regression coefficients (slopes) from Analysis V (1975-1977 height increment on initial height and plot) on independent variables with sums of squares subdivided (model one). 1970 trees; vegetation groups one and six and site 6 deleted.

Source	Sums of Squares	df	Mean Square	F	Significance of F
Site	194.92	3	64.97	2.87	0.09
Stock	130.87	3			
linear	3.41	(1)	3.41	0.15	0.73
quadratic	89.86	(1)	89.86	3.97	0.08
lack of fit	37.60	(1)	37.60	1.66	0.35
Error (a)	203.47	9	22.61		
Vegetation	339.23	3			
2 vs. 3	188.63	(1)	188.63	6.81	0.02*
2 + 3 vs. 4	76.34	(1)	76.34	2.76	0.11
2 + 3 + 4 vs. 5	74.26	(1)	74.26	2.68	0.12
Stock * vegetation	123.38	9	13.71	0.49	0.86
Error (b)	543.97	20	27.69		

* Significant at 0.05 level.

TABLE 35. Analysis of variance for initial height regression coefficients (slopes) from Analysis V (1975-1977 height increment on initial height and plot) on independent variables with sums of squares subdivided (model two). 1970 trees; vegetation groups one and six and site 6 deleted.

Source	Sums of Squares	df	Mean Square	F	Significance of F
Site	194.92	3	64.97	2.70	0.11
Stock	130.87	3			
plugs vs. bullets	36.02	(1)	36.02	1.50	0.28
2-0 vs. 1-2	49.92	(1)	49.93	2.07	0.22
plugs + bullets vs. 2-0 +1-2	44.93	(1)	44.93	1.87	0.24
Error (a)	216.59	9	24.07		
Vegetation	316.16	3			
Veg. 2 + 3 vs. 4 + 5	99.62	(1)	99.62	3.57	0.07
2 vs. 3	215.66	(1)	215.66	7.73	0.02*
4 vs. 5	0.88	(1)	0.88	0.031	0.86
Stock * vegetation	119.60	9	13.29	0.48	0.87
Error (b)	557.70	20	27.88		

* Significant at 0.05 level.

TABLE 36. Analysis of variance for initial height regression coefficients (slopes) from Analysis V (height in 1977 on initial height and plot) on site, stock type, vegetation group and stock type by vegetation group interaction term. 1970 trees; vegetation groups one, two and six and site 6 deleted.

Source	df	Mean Square	F
Site	3	85.48	2.29
Stock	3	59.45	1.59
Error (a)	9	37.40	
Vegetation	2	33.68	1.07
Stock * Vegetation	6	46.92	1.49
Error (b)	15	31.40	

TABLE 37. Analysis of variance for initial height regression coefficients (slopes) from Analysis V (1975-1977 height increment on initial height and plot) on site, stock, vegetation group and stock type by vegetation group interaction term. 1970 trees; vegetation groups one, two and six and site 6 deleted.

Source	df	Mean Square	F
Site	3	37.38	1.91
Stock	3	16.11	0.82
Error (a)	9	19.55	
Vegetation	2	0.99	0.06
Stock * Vegetation	6	10.90	0.62
Error (b)	15	17.72	

TABLE 38. Analysis of variance for mean five-year height (1975) on site, stock type, 1975 vegetation group and vegetation * stock interaction term; 1970 trees.

Source	Sums of Squares	df	Mean Square	F	Significance of F
Site	34710.07	4	8677.52	9.48	0.01**
Stock	198324.65	3	66108.22	72.2	0.01**
Error (a)	10985.44	12	915.45		
Vegetation	20048.44	5	4009.68	5.36	0.01**
Vegetation * stock	14499.79	15	966.65	1.29	0.24
Error (b)	39681.33	53	748.70		

** Significant at 0.01 level.

TABLE 39. Analysis of variance for mean seven-year height (1977) on site, stock type, 1975 vegetation group and vegetation * stock interaction term; 1970 trees.

Source	df	Mean Square	F
Site	4	42050.38	15.51**
Stock	3	121458.43	44.79**
Error (a)	12	2711.51	
Vegetation	5	14132.61	4.46**
Vegetation * Stock	15	3243.88	1.02
Error (b)	53	3168.87	

** Significant at the .01 level.

TABLE 40. Analysis of variance for mean five-year height (1975) on site, stock type, 1975 vegetation group and vegetation * stock interaction term; 1970 trees. Stock and vegetation sums of squares subdivided (model one); vegetation groups 1 and 6 deleted.

Source	df	Mean Square	F
Site	4	6714.47	5.82**
Stock	3	45253.26	39.25**
linear	(1)	130615.15	113.30**
quadratic	(1)	4825.62	4.19
lack of fit	(1)	319.01	0.28
Error (a)	12	1152.81	
Vegetation	3	5574.57	10.83**
group 2 vs. 3	(1)	1173.33	2.28
2 + 3 vs. 4	(1)	12107.28	23.52**
2 + 3 + 4 vs. 5	(1)	3443.11	6.69*
Vegetation * stock	9	413.81	0.80
Error (b)	33	514.83	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 41. Analysis of variance for mean seven-year height (1977) on site, stock type, 1975 vegetation group and vegetation * stock interaction term; 1970 trees. Stock and vegetation sums of squares subdivided (model one); vegetation groups 1 and 6 deleted.

Source	df	Mean Square	F
Site	4	27056.92	10.67**
Stock	3	96287.07	37.97**
linear	(1)	270962.57	106.85**
quadratic	(1)	17407.44	6.86**
lack of fit	(1)	491.19	0.19
Error (a)	12	2536.03	
Vegetation	3	20485.94	9.95**
group 2 vs. 3	(1)	8800.22	4.28*
2 + 3 vs. 4	(1)	34005.40	16.52**
2 + 3 + 4 vs. 5	(1)	18652.20	9.06**
Vegetation * stock	9	1649.21	0.80
Error (b)	33	2057.97	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 42. Analysis of variance for mean five-year height (1975) on site, stock type, 1975 vegetation group and vegetation * stock interaction term; 1970 trees. Stock and vegetation sums of squares subdivided (model two); vegetation groups 1 and 6 deleted.

Source	df	Mean Square	F
Site	4	6714.47	5.35*
Stock	3	45253.26	36.04**
1-0 plug vs. 1-0 bullet	(1)	1279.69	1.02
2-0 seedling vs. 1-2 transplant	(1)	22935.77	18.27**
1-0 plug + 1-0 bullet vs. 2-0 seedling + 1-2 transplant	(1)	111544.31	88.84**
Error (a)	12	1255.59	
Vegetation	3	5237.90	10.49**
groups 2 + 3 vs. 4 + 5	(1)	14191.83	28.42**
2 vs. 3	(1)	125.78	0.25
4 vs. 5	(1)	1396.08	2.80
Vegetation * stock	9	445.60	0.89
Error (b)	33	499.39	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 43. Analysis of variance for mean seven-year height (1977) on site, stock type, 1975 vegetation group and vegetation * stock interaction term; 1970 trees. Stock and vegetation sums of squares subdivided (model two); vegetation groups 1 and 6 deleted.

Source	df	Mean Square	F
Site	4	27056.92	10.76**
Stock	3	21407.07	8.51**
1-0 plug vs. 1-0 bullet	(1)	2346.18	0.93
2-0 seedling vs. 1-2 transplant	(1)	36918.36	14.68**
1-0 plug + 1-0 bullet vs. 2-0 seedling + 1-2 transplant	(1)	249596.66	99.25**
Error (a)	12	2514.85	
Vegetation	3	20450.58	9.87**
groups 2 + 3 vs. 4 + 5	(1)	57138.32	27.58**
2 vs. 3	(1)	2311.50	1.12
4 vs. 5	(1)	1901.92	0.92
Vegetation * stock	9	11.47	0.79
Error (b)	33	2072.04	

** Significant at the .01 level.

TABLE 44. Analysis of variance for mean 1975-1977 height increment on site, stock type, 1975 vegetation group and vegetation * stock interaction term; 1970 trees.

Source	df	Mean Square	F
Site	4	14446.39	7.00**
Stock	3	9230.56	4.47*
Error (a)	12	2064.11	
Vegetation	5	3243.07	1.70
Vegetation * Stock	15	1671.06	0.87
Error (b)	53	1911.58	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 45. Analysis of variance for mean height increment 1975-1977 on site, stock type, 1975 vegetation group and vegetation * stock interaction term; 1970 trees. Stock and vegetation sums of squares subdivided (model one); vegetation groups 1 + 6 deleted.

Source	df	Mean Square	F
Site	4	8429.26	7.71**
Stock	3	9909.90	9.06**
linear	(1)	25894.21	23.67**
quadratic	(1)	3814.28	3.49
lack of fit	(1)	21.20	0.02
Error (a)	12	1093.99	
Vegetation	3	4832.03	5.32**
group 2 vs. 3	(1)	3438.57	3.79
2 + 3 vs. 4	(1)	5148.07	5.67*
2 + 3 + 4 vs. 5	(1)	5909.44	6.51*
Vegetation * stock	9	650.02	0.72
Error (b)	33	908.23	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 46. Analysis of variance for mean height increment 1975-1977 on site, stock type, 1975 vegetation group and vegetation * stock interaction term; 1970 trees. Stock and vegetation sums of squares subdivided (model two); vegetation groups 1 and 6 deleted.

Source	df	Mean Square	F
Site	4	8429.26	7.41**
Stock	3	9909.90	8.71**
1-0 plug vs. 1-0 bullet	(1)	170.04	0.15
2-0 seedling vs. 1-2 transplant	(1)	1789.33	1.57
1-0 plug + 1-0 bullet vs. 2-0 seedlings + 1-2 transplant	(1)	27770.33	24.41**
Error (a)	12	1137.80	
Vegetation	3	5028.17	5.75**
groups 2 + 3 vs. 4 + 5	(1)	13730.40	15.69**
2 vs. 3	(1)	1330.19	1.52
4 vs. 5	(1)	23.92	0.03
Vegetation * stock	9	648.64	0.74
Error (b)	33	874.84	

** Significant at the .01 level.

TABLE 47. Analysis of variance for mean four-year height (1975) on site, stock type, 1975 vegetation group and vegetation * stock interaction term; 1971 trees. Stock and vegetation sums of squares subdivided (model one); 1-1 and 2-1 transplant stock deleted.

Source	Sums of Squares	df	Mean Square	F	Significance of F
Site	3251.31	3	1083.77	1.92	0.37
Stock	19272.90	2	9636.45	17.03	0.02*
linear	19213.50	(1)	19213.50	33.96	0.01**
quadratic	59.40	(1)	59.40	0.10	0.89
Error (a)	2263.39	4	565.85		
Vegetation	1394.03	5	278.81	2.52	0.06
group 1 vs. 2	925.41	(1)	925.41	8.37	0.01**
1 + 2 vs. 3	138.09	(1)	138.09	1.24	0.28
1 + 2 + 3 vs. 4	104.52	(1)	104.52	0.95	0.34
1 + 2 + 3 + 4 vs. 5	4.64	(1)	4.64	0.04	0.84
1 + 2 + 3 + 4 + 5 vs. 6	221.37	(1)	221.37	2.00	0.17
Vegetation * stock	556.09	7	79.44	0.72	0.66
Error (b)	2100.52	19	110.55		

* Significant at 0.05 level ** Significant at 0.01 level.

TABLE 48. Analysis of variance for mean four-year height (1975) on site, stock type, 1975 vegetation group and vegetation * stock interaction term; 1971 trees. Stock and vegetation sums of squares subdivided (model two); 1-1 and 2-1 transplant stock deleted.

Source	df	Mean Square	F
Site	3	1083.77	1.92
Stock	2	9636.45	17.03*
1-0 plugs + bullets vs. 2-0 seedlings	(1)	17233.51	30.46**
1-0 plugs vs. 1-0 bullets	(1)	2039.40	3.60
Error (a)	4	565.85	
Vegetation	5	278.81	2.52
groups 1 + 2 + 3 vs. 4 + 5 + 6	(1)	477.18	4.32
group 1 vs. 3	(1)	300.02	2.71
2 vs. 3	(1)	493.55	4.46*
4 vs. 6	(1)	31.11	0.28
5 vs. 6	(1)	92.17	0.83
Vegetation * stock	7	79.44	0.72
Error (b)	19	110.55	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 49. Analysis of variance for mean six-year height (1977) on site, stock type, 1975 vegetation group and vegetation * stock interaction term; 1971 trees; stock and vegetation sums of squares subdivided (model one); 1-1 and 2-1 transplant stock deleted.

Source	df	Mean Square	F
Site	3	6379.06	3.27
Stock	2	31892.02	16.36*
linear	(1)	62857.31	32.25**
quadratic	(1)	926.72	0.48
Error (a)	4	1949.33	
Vegetation	5	1859.27	2.96*
group 1 vs. 2	(1)	1166.76	1.85
1 + 2 vs. 3	(1)	6.98	0.01
1 + 2 + 3 vs. 4	(1)	900.03	1.43
1 + 2 + 3 + 4 vs. 5	(1)	1300.99	2.07
1 + 2 + 3 + 4 + 5 vs. 6	(1)	5921.59	9.43**
Vegetation * stock	7	143.36	0.23
Error (b)	19	627.35	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 50. Analysis of variance for mean 1975-1977 height increment on site, stock type, 1975 vegetation group and vegetation * stock interaction term; 1971 trees; stock and vegetation sums of squares subdivided (model one); 1-1 and 2-1 transplant stock deleted.

Source	df	Mean Square	F
Site	3	2550.01	6.02
Stock	2	6987.59	16.48*
linear	(1)	13416.61	31.65**
quadratic	(1)	558.57	1.32
Error (a)	4	423.91	
Vegetation	5	1079.98	3.48*
group 1 vs. 2	(1)	9.59	0.03
1 + 2 vs. 3	(1)	168.02	0.54
1 + 2 + 3 vs. 4	(1)	467.81	1.51
1 + 2 + 3 + 4 vs. 5	(1)	1091.35	3.52
1 + 2 + 3 + 4 + 5 vs. 6	(1)	3663.14	11.81**
Vegetation * stock	7	112.00	0.36
Error (b)	19	310.09	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 51. Analysis of variance for mean six-year height (1977) on site, stock type, 1975 vegetation group and vegetation * stock interaction term; 1971 trees; stock and vegetation sums of squares subdivided (model two); 1-1 and 2-1 transplant stock deleted.

Source	df	Mean Square	F
Site	3	6379.06	3.27
Stock	2	31892.02	16.36*
1-0 plugs vs. 1-0 bullets	(1)	9518.01	4.88
1-0 plugs + bullets vs. 2-0 seedlings	(1)	54266.02	27.84**
Error (a)	4	1949.33	
Vegetation	5	1859.27	2.96*
groups 1 + 2 + 3 vs. 4 + 5 + 6	(1)	6126.22	9.77**
1 vs. 3	(1)	20.98	0.03
2 vs. 3	(1)	375.58	0.60
4 vs. 6	(1)	2299.65	3.67
5 vs. 6	(1)	473.91	0.76
Vegetation * stock	7	143.36	0.23
Error (b)	19	627.35	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 52. Analysis of variance for mean 1975-1977 height increment on site, stock type, 1975 vegetation group and vegetation * stock interaction term; 1971 trees; stock and vegetation sums of squares subdivided (model two); 1-1 and 2-1 transplant stock deleted.

Source	df	Mean Square	F
Site	3	2550.01	6.02
Stock	2	6987.59	16.48*
1-0 plugs vs. 1-0 bullets	(1)	2946.45	6.95
1-0 plugs + bullets vs. 2-0 seedlings	(1)	11028.73	26.01**
Error (a)	4	423.91	
Vegetation	5	1079.98	3.48*
groups 1 + 2 + 3 vs. 4 + 5 + 6	(1)	3200.97	10.32**
1 vs. 3	(1)	430.59	1.39
2 vs. 3	(1)	15.21	0.05
4 vs. 6	(1)	1590.46	5.13*
5 vs. 6	(1)	162.69	0.52
Vegetation * stock	7	112.00	0.36
Error (b)	19	310.09	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 53. Analysis of variance for mean five-year height (1975) on site, stock type, density class and density class * stock interaction term. 1970 trees, stock and density sums of squares subdivided (model one).

Source	Sums of Squares	df	Mean Square	F	Significance of F
Site	52692.30	4	13173.08	9.44	0.01**
Stock	181032.03	3	60344.01	43.25	0.01
linear	171139.66	(1)	171139.66	122.66	0.01**
quadratic	9885.31	(1)	9885.31	7.08	0.02*
lack of fit	7.06	(1)	7.06	0.01	0.90
Error (a)	16742.30	12	1395.19		
Density	36488.16	4	9122.04	11.32	0.01**
groups 1 vs. 2	1512.89	(1)	1512.89	1.88	0.18
1 + 2 vs. 3	17015.50	(1)	17015.50	21.11	0.01**
1 + 2 + 3 vs. 4	17524.27	(1)	17524.27	21.74	0.01**
1 + 2 + 3 + 4 vs. 5	435.50	(1)	435.50	0.54	0.47
Density * stock	5944.22	12	495.35	0.61	0.82
Error (b)	39488.97	48	805.89		

* Significant at 0.05 level. ** Significant at 0.01 level.

TABLE 54. Analysis of variance for mean seven-year height (1977) on site, stock type, density class and density class * stock interaction term. 1970 trees; stock and density sums of squares subdivided (model one).

Source	df	Mean Square	F
Site	4	45730.94	21.22**
Stock	3	114717.14	53.24**
linear	(1)	300441.89	139.44**
quadratic	(1)	43410.80	20.15**
lack of fit	(1)	298.73	0.14
Error (a)	12	2154.58	
Density	4	31580.83	15.14**
groups 1 vs. 2	(1)	8175.25	3.92
1 + 2 vs. 3	(1)	47146.14	23.00**
1 + 2 + 3 vs. 4	(1)	63759.67	30.56**
1 + 2 + 3 + 4 vs. 5	(1)	7242.26	3.47
Density * stock	12	1628.16	0.78
Error (b)	48	2086.24	

** Significant at the .01 level.

TABLE 55. Analysis of variance for mean 1975-1977 height increment on site, stock type, density class and density class * stock interaction term. 1970 trees; stock and density sums of squares subdivided (model one).

Source	df	Mean Square	F
Site	4	12525.14	17.40**
Stock	3	10277.19	14.28**
linear	(1)	18747.41	26.06**
quadratic	(1)	11714.23	16.28**
lack of fit	(1)	369.93	0.51
Error (a)	12	719.53	
Density	4	7106.81	7.69**
group 1 vs. 2	(1)	2746.28	2.97
1 + 2 vs. 3	(1)	7122.83	7.71**
1 + 2 + 3 vs. 4	(1)	14514.08	15.40**
1 + 2 + 3 + 4 vs. 5	(1)	4044.04	4.37*
Density * stock	12	1038.75	1.14
Error (b)	48	924.44	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 56. Analysis of variance for mean five-year height (1975) on site, stock type, density class and density class * stock interaction term. 1970 trees; stock and density sums of squares subdivided (model two).

Source	df	Mean Square	F
Site	4	13173.07	9.34**
Stock	3	60344.01	42.80**
1-0 plug vs. 1-0 bullet	(1)	5.73	0.004
2-0 seedling vs. 1-2 transplant	(1)	30812.33	21.86**
1-0 plug + 1-0 bullet vs. 2-0 seedling + 1-2 transplant	(1)	150213.97	106.55**
Error (a)	12	1409.82	
Density	4	9078.66	11.05**
group 1 vs. 2	(1)	1571.18	1.91
2 vs. 3	(1)	16831.92	20.48**
3 vs. 4	(1)	17469.39	21.26**
4 vs. 5	(1)	442.14	0.54
Density * stock	12	498.52	0.61
Error (b)	48	821.85	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 57. Analysis of variance for mean seven-year height (1977) on site, stock type, density class and density class * stock interaction term. 1970 trees; stock and density sums of squares subdivided (model two).

Source	df	Mean Square	F
Site	4	45730.94	21.04**
Stock	3	114717.14	52.78**
1-0 plug vs. 1-0 bullet	(1)	614.14	0.28
2-0 seedlings vs. 1-2 transplant	(1)	29636.74	13.64**
1-0 plug + 1-0 bullet vs. 2-0 seedlings + 1-2 transplant	(1)	313900.54	144.44**
Error (a)	12	2173.18	
Density	4	31797.67	15.39**
group 1 vs. 2	(1)	7986.33	3.87
2 vs. 3	(1)	47809.72	23.15**
3 vs. 4	(1)	64621.14	31.29**
4 vs. 5	(1)	6773.49	3.27
Density * stock	12	1620.52	0.78
Error (b)	48	2065.43	

** Significant at the .01 level.

TABLE 58. Analysis of variance for mean 1975-1977 height increment on site, stock type, density class and density class * stock interaction term. 1970 trees; stock and density sums of squares subdivided (model two).

Source	df	Mean Square	F
Site	4	12525.14	15.77**
Stock	3	10277.19	12.93**
1-0 plug vs. 1-0 bullet	(1)	470.77	0.59
2-0 seedling vs. 1-2 transplant	(1)	1.71	0.002
1-0 plug + 1-0 bullet vs. 2-0 seedling + 1-2 transplant	(1)	30359.09	38.22**
Error (a)	12	794.39	
Density	4	7177.86	8.02**
group 1 vs. 2	(1)	2565.55	2.87
2 vs. 3	(1)	7494.79	8.37**
3 vs. 4	(1)	14967.01	16.72**
4 vs. 5	(1)	3684.08	4.12*
Density * stock	12	1058.04	1.18
Error (b)	48	894.98	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 59. Analysis of variance for mean height in 1975 on site, stock type, density class and density class* stock interaction term. 1971 trees; stock and density sums of squares subdivided (model one); 1-1 and 2-1 transplant stock deleted.

Source	Sums of Squares	df	Mean Square	F	Significance of F
Site	1925.29	3	641.76	1.76	0.44
Stock	15408.38	2	7704.19	21.14	0.01**
linear	15237.88	(1)	15237.88	41.80	0.01**
quadratic	170.50	(1)	170.50	0.47	0.56
Error (a)	1457.99	4	364.50		
Density	1887.84	4	471.96	7.32	0.01**
group 1 vs. 2	212.14	(1)	212.14	3.29	0.09
1 + 2 vs. 3	1494.42	(1)	1494.42	23.19	0.01**
1 + 2 + 3 vs. 4	56.57	(1)	56.57	0.88	0.36
1 + 2 + 3 + 4 vs. 5	124.71	(1)	124.71	1.93	0.18
Density * stock	1228.49	6	204.75	3.18	0.03*
Error (a)	1095.64	17	64.45		

* Significant at 0.05 level. ** Significant at 0.01 level.

TABLE 60. Analysis of variance for mean height in 1977 on site, stock type, density class and density class * stock interaction term. 1971 trees; stock and density sums of squares subdivided (model one); 1-1 and 2-1 transplant stock deleted.

Source	df	Mean Square	F
Site	3	4515.60	3.44
Stock	2	24114.84	18.38**
linear	(1)	48204.26	36.74**
quadratic	(1)	25.42	0.19
Error (a)	4	1312.04	
Density	4	2832.86	8.84**
group 1 vs. 2	(1)	1126.11	3.51
1 + 2 vs. 3	(1)	7357.47	22.95**
1 + 2 + 3 vs. 4	(1)	831.32	2.59
1 + 2 + 3 + 4 vs. 5	(1)	2016.55	6.29*
Density * stock	6	1174.66	3.66**
Error (b)	17	320.56	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 61. Analysis of variance for mean 1975-1977 height increment on site, stock type, density class and density class * stock interaction term. 1971 trees; stock and density sums of squares subdivided (model one); 1-1 and 2-1 transplant stock deleted.

Source	df	Mean Square	F
Site	3	1722.41	4.49
Stock	2	4890.94	12.75*
linear	(1)	9708.16	25.30**
quadratic	(1)	73.72	0.19
Error (a)	4	383.69	
Density	4	1122.69	7.73**
group 1 vs. 2	(1)	511.55	3.52
1 + 2 vs. 3	(1)	2392.84	16.48**
1 + 2 + 3 vs. 4	(1)	535.36	3.69
1 + 2 + 3 + 4 vs. 5	(1)	1050.63	7.23*
Density * stock	6	462.19	3.18*
Error (b)	17	145.27	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 62. Analysis of variance for mean height in 1975 on site, stock type, density class and density class * stock interaction term. 1971 trees; stock and density sums of squares subdivided (model two); 1-1 and 2-1 transplanted stock deleted.

Source	df	Mean Square	F
Site	3	641.76	1.76
Stock	2	7704.19	21.14**
1-0 bullet vs. 1-0 plug	(1)	56.14	0.15
1-0 bullet + 1-0 plug vs. 2-0 seedling	(1)	15352.25	42.12**
Error (a)	4	364.50	
Density	4	471.96	7.32**
group 1 vs. 2	(1)	212.14	3.29
2 vs. 3	(1)	1494.42	23.19**
3 vs. 4	(1)	56.57	0.88
4 vs. 5	(1)	124.71	1.93
Density * stock	6	204.75	3.18*
Error (b)	17	64.45	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 63. Analysis of variance for mean height in 1977 on site, stock type, density class and density class * stock interaction term. 1971 trees; stock and density sums of squares subdivided (model two); 1-1 and 2-1 transplant stock deleted.

Source	df	Mean Square	F
Site	3	4515.60	3.44
Stock	2	24114.84	18.38**
1-0 plug vs. 1-0 bullet	(1)	977.13	0.74
1-0 plug + 1-0 bullet vs. 2-0 seedling	(1)	47252.55	36.01**
Error (a)	4	1312.04	
Density	4	2832.86	8.84**
group 1 vs. 2	(1)	1126.11	3.51
2 vs. 3	(1)	7357.47	22.95**
3 vs. 4	(1)	831.32	2.59
4 vs. 5	(1)	2016.55	6.29*
Density * stock	6	1174.66	3.66*
Error (b)	17	320.56	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 64. Analysis of variance for mean 1975-1977 height increment on site, stock type, density class and density class * stock interaction term. 1971 trees; stock and density sums of squares subdivided (model two); 1-1 and 2-1 transplant stock deleted.

Source	df	Mean Square	F
Site	3	1722.41	4.49
Stock	2	4890.94	12.75*
1-0 plug vs. 1-0 bullet	(1)	611.48	1.59
1-0 plug + 1-0 bullet vs. 2-0 seedling	(1)	9170.40	23.90**
Error (a)	4	383.69	
Density	4	1122.85	7.73**
group 1 vs. 2	(1)	511.55	3.52
2 vs. 3	(1)	2393.84	16.48**
3 vs. 4	(1)	535.36	3.69
4 vs. 5	(1)	1050.63	7.23*
Density * stock	6	462.19	3.18*
Error (b)	17	145.27	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 65. Analysis of variance for height in 1977 on site, stock type, brush group and stock by brush group interaction terms; 1970 trees.

Source	Sums of Squares	df	Mean Square	F	Significance of F
Site	146929.14	4	36732.29	23.07	0.01**
Stock	277592.87	3	92530.96	58.12	0.01**
Error (a)	19106.34	12	1592.20		
Brush 75	18802.29	1	18802.29	14.45	0.01**
Brush 77	53115.01	1	53115.01	40.83	0.01**
Brush 75 * Brush 77	186.22	1	186.22	0.14	0.71
Stock * Brush 75	4329.22	3	1443.07	1.11	0.36
Stock * Brush 77	5414.32	3	1804.77	1.39	0.26
Stock * Brush 75 * Brush 77	2119.56	3	706.52	0.54	0.66
Error (b)	582236.41	73	1300.99		

** Significant at 0.01 level.

TABLE 66. Analysis of variance for 1975-1977 height increment on site, stock type, brush group and stock by brush group interaction terms; 1970 trees.

Source	df	Mean Square	F
Site	4	10932.34	14.89**
Stock	3	8055.02	10.97**
Error (a)	12	734.15	
Brush 75	1	4352.86	8.22**
Brush 77	1	18691.13	35.29**
Brush 75 * Brush 77	1	702.01	1.33
Stock * Brush 75	3	367.85	0.69
Stock * Brush 77	3	460.26	0.87
Stock * Brush 75 * Brush 77	3	516.71	0.33
Error (b)	42	529.57	

** Significant at the .01 level.

TABLE 67. Analysis of variance for 1977 diameter on site, stock type, brush group and stock by brush group interaction terms; 1970 trees.

Source	df	Mean Square	F
Site	4	8.06	11.51**
Stock	3	35.30	50.43**
Error (a)	12	0.70	
Brush 75	1	21.61	38.09**
Brush 77	1	16.74	29.52**
Brush 75 * Brush 77	1	0.001	0.003
Stock * Brush 75	3	2.57	4.53**
Stock * Brush 77	3	0.28	0.50
Stock * Brush 75 * Brush 77	3	0.43	0.76
Error (b)	42	0.57	

** Significant at the .01 level.

TABLE 68. Analysis of variance for 1975-1977 diameter increment on site, stock type, brush group and stock by brush group interaction terms; 1970 trees.

Source	df	Mean Square	F
Site	4	7.26	11.52**
Stock	3	5.76	9.14**
Error (a)	12	0.63	
Brush 75	1	3.74	9.06**
Brush 77	1	6.05	14.69**
Brush 75 * Brush 77	1	0.21	0.52
Stock * Brush 75	3	0.82	1.99
Stock * Brush 77	3	0.15	0.37
Stock * Brush 75 * Brush 77	3	0.15	0.37
Error (b)	42	0.41	

** Significant at the .01 level.

TABLE 69. Analysis of variance for 1977 volume on site, stock type, brush group and stock by brush group interaction terms; 1970 trees.

Source	df	Mean Square	F
Site	4	130259522.68	4.53*
Stock	3	427889097.30	14.88**
Error (a)	12	28758483.87	
Brush 75	1	327029676.24	23.93**
Brush 77	1	120044942.84	8.78**
Brush 75 * Brush 77	1	3468252.00	0.25
Stock * Brush 75	3	120621589.50	8.83**
Stock * Brush 77	3	8245821.94	0.60
Stock * Brush 75 * Brush 77	3	7230991.91	0.53
Error (b)	42	13665832.29	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 70. Analysis of variance for 1975-1977 volume increment on site, stock, brush group and stock by brush group interaction terms; 1970 trees.

Source	df	Mean Square	F
Site	4	86514546.83	4.23*
Stock	3	258681636.20	12.65**
Error (a)	12	20442372.41	
Brush 75	1	202001059.51	25.11**
Brush 77	1	94638328.58	11.77**
Brush 75 * Brush 77	1	2051754.12	0.26
Stock * Brush 75	3	72967890.83	9.07**
Stock * Brush 77	3	5709990.24	0.71
Stock * Brush 75 * Brush 77	3	3459403.88	0.43
Error (b)	42	8042969.62	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 71. Analysis of variance for height in 1977 on site, stock type, brush group and stock by brush group interaction terms; 1971 trees.

Source	Sums of Squares	df	Mean Square	F	Significance of F
Site	8906.92	3	2968.97	2.43	0.30
Stock	45839.74	2	22919.87	18.75	0.01**
Error (a)	4892.77	4	1223.19		
Brush 75	6379.77	1	6379.77	8.30	0.01**
Brush 77	3740.48	1	3740.48	4.87	0.05 *
Brush 75 * Brush 77	312.41	1	312.41	0.41	0.53
Stock * Brush 75	2231.24	2	1115.62	1.45	0.27
Stock * Brush 77	1738.20	2	869.10	1.13	0.35
Stock * Brush 75 * Brush 77	408.24	2	204.12	0.27	0.77
Error (b)	9988.05	13	768.31		

* Significant at 0.05 level.

** Significant at 0.01 level.

TABLE 72. Analysis of variance for 1975-1977 height increment on site, stock type, brush group and stock by brush group interaction terms; 1971 trees.

Source	df	Mean Square	F
Site	3	1112.92	2.77
Stock	2	4991.47	12.43*
Error (a)	4	401.68	
Brush 75	1	2934.17	12.51**
Brush 77	1	1534.84	6.55*
Brush 75 * Brush 77	1	51.01	0.22
Stock * Brush 75	2	650.94	2.78
Stock * Brush 77	2	551.74	2.35
Stock * Brush 75 * Brush 77	2	146.43	0.62
Error (b)	13	234.45	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 73. Analysis of variance for 1977 diameter on site, stock type, brush group and stock by brush group interaction terms; 1971 trees.

Source	df	Mean Square	F
Site	3	0.26	0.79
Stock	2	6.44	19.52**
Error (a)	4	0.33	
Brush 75	1	2.67	13.05**
Brush 77	1	1.47	7.17*
Brush 75 * Brush 77	1	0.33	1.63
Stock * Brush 75	2	0.25	1.23
Stock * Brush 77	2	0.21	0.51
Stock * Brush 75 * Brush 77	2	0.06	0.15
Error (b)	13	0.20	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 74. Analysis of variance for 1975-1977 diameter increment on site, stock type, brush group and stock by brush group interaction terms; 1971 trees.

Source	df	Mean Square	F
Site	3	0.09	0.69
Stock	2	1.41	10.85*
Error (a)	4	0.13	
Brush 75	1	0.97	16.89**
Brush 77	1	0.58	10.07**
Brush 75 * Brush 77	1	0.06	1.09
Stock * Brush 75	2	0.08	1.31
Stock * Brush 77	2	0.06	0.97
Stock * Brush 75 * Brush 77	2	0.02	0.26
Error (b)	13	0.06	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 75. Analysis of variance for 1977 volume on site, stock type, brush groups and stock by brush group interaction terms; 1971 trees.

Source	df	Mean Square	F
Site	3	268582.91	0.80
Stock	2	6919314.71	20.70**
Error (a)	4	334325.27	
Brush 75	1	4738737.33	9.77**
Brush 77	1	625058.09	1.29
Brush 75 * Brush 77	1	675210.38	1.39
Stock * Brush 75	2	1094113.17	2.26
Stock * Brush 77	2	77.44	0.0002
Stock * Brush 75 * Brush 77	2	20958.11	0.04
Error (b)	13	484871.35	

** Significant at the .01 level.

TABLE 76. Analysis of variance for 1975-1977 volume increment on site, stock type, brush group and stock by brush group interaction terms; 1971 trees.

Source	df	Mean Square	F
Site	3	231960.06	.80
Stock	2	5467493.14	18.80**
Error (a)	4	290888.96	
Brush 75	1	3899925.03	10.04**
Brush 77	1	500917.16	1.29
Brush 75 * Brush 77	1	503352.87	1.29
Stock * Brush 75	2	878830.67	2.26
Stock * Brush 77	2	290.15	0.0008
Stock * Brush 75 * Brush 77	2	9493.45	0.02
Error (b)	13	388259.56	

** Significant at the .01 level.

TABLE 77. Damage percentages by stock type; 1970 trees.

Stock Type	Damage Type			
	Undamaged	Top-dieback	Mechanical	Animal
1-0 plugs	86	3	6	5
1-0 bullets	86	3	5	6
2-0 seedlings	94	2	2	2
1-2 transplants	94	2	2	2

TABLE 78. Damage percentages by stock type; 1971 trees.

Stock Type	Damage Type			
	Undamaged	Top-dieback	Mechanical	Animal
1-0 plugs	67	0	14	19
1-0 bullets	77	0	9	14
2-0 seedlings	84	1	8	7
1-1 transplants	66	0	0	34
2-1 transplants	97	0	0	3