ESTIMATION OF SEEDLING DENSITY AND EVALUATION OF WOODY COMPETITION IN YOUNG LOBLOLLY PINE PLANTATIONS USING 35mm COLOR AERIAL PHOTOGRAPHY

by

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Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
in
Forestry

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September, 1986

Blacksburg, Virginia

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(ABSTRACT)

The potential for using large scale, small format aerial photography to obtain seedling density and woody competition information was investigated. Factors affecting photo interpretation of seedlings were examined and equations to predict seedling density and woody competition levels were developed and evaluated. Two scales of imagery, 1:4000 and 1:6000 were considered to compare their relative merits for these purposes.

Greater age of the seedlings and their inherent development generally served to improve photo interpretation. The amount of woody competition present in the plots tended to hinder seedling identification at the 1:4000 scale, while enhancing it when 1:6000 scale data was used. Seedling density estimation and evaluation of competition through Free-To-Grow classification predictions

yielded results comparable to ground surveys. Estimation of total groundline basal area in all woody competition, and classification of the plots by the amount of hard-to-control competition they contained, were less successful. These results may have been due in part to the partial leaf fall that occurred prior to obtaining the imagery. Many of the results found in this study favored the larger scale (1:4000) imagery, and its use for the procedures described is recommended.

ACKNOWLEDGEMENTS

I would like to thank the members of my committee for their continued interest and support. Dr. Harold Burkhart and Dr. Shepard Zedaker unhesitatingly provided useful advice and guidance as the work progressed. A special thanks goes to my chairman, Dr. James Smith, for his unflagging assistance and encouragement on this project. I feel that I have not only developed a strong professor-student relationship with him, but made a good friend in the process.

Lastly, I would like to thank my wife Kathy, whose endurance, patience and love helped me through it all.

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INTRODUCTION

Establishing and maintaining a pine stand is a substantial economic undertaking. Investments made for site preparation, planting and release work must often be carried through to the end of the planned rotation, typically 25-30 years, before any profit from their implementation can be realized. Plantation establishment efforts and treatments applied early in a rotation must accomplish their objectives efficiently and economically. Proper monitoring and timely decision-making, however, can require information not always easily or adequately obtainable on the ground. In this research, the potential of large scale, small format aerial photography to supplement, or perhaps replace current ground-based plantation assessment methods was explored in an effort to improve the management of loblolly pine (*Pinus taeda* L.) plantations.

As part of a management program, plantations are normally evaluated for seedling survival/density after an initial establishment period of one to two years. A decision to replant poorly stocked areas must be made early in the life of a plantation to minimize the extent and cost of re-preparing the site and to keep the land as fully productive as possible. Assessments of this type are typically made by sampling a small portion of the plantation and tallying established pine stems within plots of a predetermined area. The number of trees recorded in the sample area can then be converted to an estimate of the number of seedlings established per acre. If the number of pines per unit area falls below some recognized minimum, the plantation would be considered for re-site preparation and replanting.

Once a stand of pine seedlings has become established, it is rare for optimal development to continue unimpeded. Competition from woody and herbaceous vegetation on the site can frequently be serious enough to require some form of release treatment. A needs determination of this type has often been qualitative in nature, with an ocular estimation of the competing vegetation made in a separate examination, or as part of the density assessment. Only recently has an effort been made to quantify the level of competing vegetation. Identification of the competing species, various measurements of the woody stems, their distances and relative positions with regard to the planted pines, and the type and density of herbaceous ground cover have all been used alone, and in combination, to better describe the level of competition [Bacon and Zedaker 1984]. Since the stocking of desirable species must first be deemed adequate before determining whether a release treatment would be required, both a density assessment and a competition level evaluation should be part of a forest manager's comprehensive decision-making process.

Due to recent economic trends and general budgetary limitations within the forest industry, there has been a corresponding reduction in available manpower. As a result, such labor-intensive activities as the procedures described have been scrutinized, with other possible alternative methods being investigated. One feasible option may be the use of aerial photography in lieu of, or in conjunction with, ground based methods of assessment. Of all the photographic formats available, large scale 35mm aerial photography may hold the most promise for versatile and economical forest industry applications.

To the cost-concious resource manager, the economic aspect of obtaining and maintaining aerial photography equipment is an important consideration. The low initial purchase price of the basic 35mm camera system, compared with the popular 70mm or 23cm x 23cm (9"x9") formats, makes the 35mm format initially more attractive [Goba et al. 1982]. Features for suitable cameras of this type include a wide range of affordable lenses, motor drives and optional large film capacity backs available on some units. The popularity of the 35mm format among recreational users as well as professionals suggests an ease of operation combined with highly satisfactory results. In addition, virtually all 35mm films, with the possible exception of infrared, can be processed quickly and professionally at any number of commercial photo centers. This important factor contributes greatly to the short turnaround time of photography of this type, and it makes it especially attractive for timely forest survey purposes.

There are already many established uses for large scale, small format 35mm aerial photography in forest management. The purpose of this study was to investigate its potential for providing accurate and reliable density and competition information affecting decisions typically made in the management of young pine plantations. Specifically, this research had the following objectives:

1) To investigate and identify factors that influence the accuracy and precision of photo-obtained pine density estimates, and

2) To develop and evaluate a prediction/correction equation to obtain pine density estimates from 35mm aerial photography, and

3) To develop and evaluate prediction equations to assess the level of hardwood competition directly, by predicting actual groundline basal area, and indirectly, by determining the number of trees in acceptable Free-To-Grow classes, from 35mm aerial photography, and

4) To develop and evaluate a photo interpretation method to classify plots regarding the level of hard-to-control woody competition they contain.

LITERATURE REVIEW

Estimating Seedling Density

The substantial costs incurred in establishing a stand of forest trees has caused resource managers to become increasingly concerned with the outcome of investments. The measure of a planting success has often been represented by a count of the number of trees surviving on the planting site compared to the total number of trees originally planted [Swinford 1965]. A ratio of these values has frequently been expressed as a survival percentage. Comparisons have also been made between the number of pines established per acre and the optimal density created by systematic spacing [Loetsch _et_ _al._ 1973]. Regardless of the form of the final result, all are attempts at describing the number of seedlings in a plantation.

An alternative to counting pine seedlings is to assess the stocking level found in plantations or naturally regenerated stands. Since the early 1930's, a 6.6 foot square unit of space, called a milacre [Lowdermilk 1921 as cited by Haig 1931] has been the basis for regeneration assessment in the Western U.S. [Stein 1973]. Whether a seedling was successfully established in a given milacre, and the percentage of units so stocked, indicated the proportion of land area that was being utilized for tree growth [Loetsch et al. 1973]. This method has also been referred to as the stocked-quadrat method. As the size of the young growth to be assessed increases, plot sizes of one-fourth to one-half chain square have been used [Loetsch et al. 1973]. In the distance method, linear measurements have been made between adjacent stems or between a sample point and the nearest stem, to shift the focus from seedling presence to the openings or spacings between them [Stein 1973]. A comparison study of the distance method to the standard stocked plot method showed the distance method providing more consistent and accurate stocking percentages [MacLeod and Chaudhry 1979].

In order to gain useful information on the density of pine stems, it might seem that an exhaustive 100 percent tally of all seedlings established on the site would be required. Fortunately, time and monetary limitations aside, studies have shown that samples in established plantations amounting to intensities of only 3-5 percent of the total area provide reliable regeneration estimates while keeping error below 10 percent [Swinford 1965]. In contast, many industrial forestry concerns have established their own sampling levels, a typical scheme checking only 1 milacre plot every 2 acres [Campbell 1981]. Certain governments, notably the U.S.S.R., have established regulations for sampling intensities based on the size of the planting. These guidelines call for 2 percent samples for plantings exceeding 10 hectares (24.7 acres), to samples of greater than 5 percent for plantings less than 3 hectares (7.4 acres) [Isaev 1975].

Estimating Competition Levels

During the early stages of development within a forest plantation, seedlings contend with intra- as well as interspecific competition. Competition within a species can be modified by the initial spatial arrangement of the planting [Smith 1962]. Currently accepted "optimal" spacing arrangements and ongoing research dealing with this question [Amateis *et al.* 1983] should provide the best guidelines for addressing this problem. Uncontrolled interspecific competition, however, differentially utilizing the site's available light, moisture and nutrients, may be the more significant detriment to optimal plantation development prior to crown closure [Zedaker 1982].

While the importance of competition is undisputed, universally accepted methods of evaluation have not been established. As early as 1926, there were efforts to develop competition models to quantify the zone of influence around developing trees [Aaltonen 1926]. This concept has been defined as the area over which a tree obtains or competes for site factors [Opie 1968]. Another basic relationship felt to underlie most competition from woody vegetation was that basal area of the competing stems is a critical factor in the amount of stress the crop tree experiences [Stenaker and Jarvis 1963]. Although hardwood basal area can be measured directly, a strong association between basal area and crown volume has been established [Zedaker _et_ _al._ 1985], with crown volumes calculated from the more easily obtained measurements of crown height and crown diameter.

The use of basal area alone as a competition measure has tended to ignore other potentially useful factors such as competition tree size, crown class and the spatial distribution of the competition [Opie 1968]. This feeling has led other researchers to investigate variations on the zone of influence idea and other, more original approaches. Gerrard [1969] evaluated what he termed a competition quotient, relating the amount of influence zone overlap to the total influence zone of the subject tree. His approach ignored the size difference between the subject tree and its competitors as it was felt to have no effect on the competition interaction. Bella [1969,1971], however, hypothesized that the contribution of each competitor tree to the total influence zone overlap should be weighted exponentially based on the relative size of the competitor and the crop tree. Evaluating interspecific competition through total leaf area, as estimated by sapwood basal area, has been suggested [Zedaker 1982]. Since both water use and photosynthetic potential are directly related to a trees leaf area, this factor may be the common denominator for species comparisons in competition assessment.

On a less technical, field level approach, several attempts at indirectly evaluating the competition surrounding a crop tree have been made. Two methods [Willis 1978; Dierauf and Garner 1970, unpublished informational report] have described four Free-To-Grow levels that classify crop trees with regard to the proximity of the competing stems and the degree to which such competition may shade and overtop the crop tree. In both of these classifications, guidelines for release decisions have either been incorporated into the class description or are listed afterward. A five category Free-To-Grow classification has also been established relating height and nearness of the competition to individual crop trees [Todd 1983]. Unfortunately, with the additional category, the separation between some classifications has become vague and unclear.

Aerial Photography

Use of aerial photography in the management of natural resources has made great strides in the past several decades. From humble beginnings in forest mapping and reconnaissance work in the 1920's [Becking 1959], aerial photography, as but one aspect of remote sensing, has gained increasing acceptance as a tool for resource managers.

In order to gain a better insight into the uses of aerial photography by resource managers in the South, various surveys have been circulated. In 1970 and again in 1974, forest industries were polled as to their current and expected future uses of aerial photography [Baker and Smith 1974]. These surveys found most respondents making at least limited use of medium scale (1:15840) black and white photography in activities such as the location of ground samples, photo-sampling and inventory work. Future plans for photo use included area determination of regeneration surveys and plantation exams for survival and stocking. A more recent survey [Mead and Raspberry 1980] that targeted resource managers in government and private industry reported frequent use of aerial photographs by virtually all of the respondents. Use of the 9"X9" (23cm X 23cm) format camera was almost universal with no one reporting frequent use of either 35mm or 70mm format systems. Medium scale black and white photos were again finding wide use among forest industries while the use of color film was increasing, especially by the Forest Service. Even though a wide variety of photo uses were mentioned by the respondents, there was still a general concensus for increasing development of low cost aerial photography.

The camera format chosen has been influenced strongly by the ultimate use of the photography. Where precise measurements are needed, as in topographic mapping and other photogrammetric work, the 9"X9" format aerial camera has been the system most frequently utilized in North America [Spurr 1960]. The quality design and construction of the 9-inch aerial cameras have combined to make them the generally accepted standard for metric accuracy [Wolf 1974]. Features such as fixed and calibrated focal length lenses, built-in and calibrated fiducial marks and lens systems specifically designed for metric accuracy all contribute greatly to this cameras capabilities [Slama 1980].

As interest in low-altitude photography evolved in the 1950's, the problem of image motion or blurring with the conventional 9" aerial camera developed. Special cameras and devices intending to compensate for image motion were produced, but all were found to be quite expensive and too complicated for general forestry use. Following the production of a more light-sensitive color film in 1955, the door was then open for the development of cameras with faster shutter speeds that could take advantage of the new "fast" film [Heller _et_ _al._ 1959]. Among the cameras that combined increased shutter speed with the new film to overcome image motion problems was the 70mm aerial camera. This camera has been used successfully in large scale photo-sampling schemes and the film format (2.25" high X 2.5" wide) has made it easy to interpret adjoining film images stereoscopically without having to cut the roll [Aldrich _et_ _al._ 1959]. Lower initial purchase price, reduced developing costs and a relative ease of installation, compared with the bulky, larger format cameras [Heller *et al.* 1959], have helped to promote its use.

Despite the advancements made by the 70mm camera in providing quality photography at a lower cost than conventional aerial cameras, interest in other small format options has remained. In an article based on a masters thesis by Harold J. Hill, Willingham [1959] recognized the photogrammetric limitations of 35mm aerial photography but recommended its use in projects involving visual interpretation. The use of 35mm photography to supplement existing aerial photography by providing rapid, up-to-date photo coverage on smaller areas has also been stressed [Willingham 1959; Zsilinszky 1969]. Advantages such as cost, ease of handling and versatility have made the 35mm camera a viable alternative as a tool for resource managers [Klein 1970]. The following applications of this small format system are among those cited by Jensen and Meyer [1976] in their remote sensing handbook: timber inventory [Aldred and Hall 1975], planning timber sales [Meyer 1973], insect and disease detection [Aldrich *et al.* 1959; Heller *et al.* 1969; Douglas *et al.* 1972; Wert and Wichman 1968], monitoring logging road construction and timber tresspass documentation [Meyer 1973].

In a study comparing the three main formats for aerial photography [Clegg and Scherz 1975], some interesting results were obtained. In the test for resolution quality, targets were imaged by each system at flying heights of 1000, 3000 and 5000 feet. It was found that the 9" system's resolution was superior at all heights, but that the 35 and 70mm resolutions were about the same at each height. All three formats had satisfactory resolution at the height of 1000 feet. Testing for photographic interpretation capability, the smaller formats were found less desirable for soil mapping, but were preferred for the mapping of vegetation. Metric accuracy tests showed that the smaller formats provided point locations as accurately as the 9" system, but only within tightly controlled areas. It was felt that large errors in measure could be expected at the flying height of 5000 feet with controls located at the perimeter of the photo. Costs of camera systems in the three format options clearly favored the smaller formats and it was concluded that small format camera systems would be a good choice for a use such as environmental mapping where accuracy is in the tens of feet.

Some studies have made use of aerial photography in assessing forest plantations for purposes other than early survival/density estimation. Both color and black and white films at a scale of 1:8000 were used in assessing the stocking in 4-7 year old Monterey pine (Pinus radiata D.Don) plantations in Australia [Myers 1974]. Satisfactory estimates of stocking were obtained and it was noted that undercounts occurred as frequently as overcounts with no differences in counts made under mono- and stereoscopic magnification (8X). As part of another project, the success of a chemical plantation release was evaluated [Hagen and Meyer 1977] using 70mm color infrared photography in the Superior National Forest, Minnesota.

Evaluating the regeneration in a plantation does not have to be a counting process. A non-enumerative regeneration assessment in Minnesota [Weih *et al.* 1984] was made to determine stocking levels of aspen regeneration following harvests. 35mm photography flown at a nominal scale of 1:20,000 was used to classify regeneration as either insufficiently stocked, in a range of 0-199 trees per acre, partially stocked, at 200-999 trees per acre, or stocked, at greater than 1000 trees per acre. The combination of Ektachrome 64 Pro Film with a UV-2A and Ross Enhancing Filter was judged best to make this determination. The overall conclusion reached was that this method was a good low-cost way of obtaining aspen regeneration stocking levels. A manual for use in regeneration assessment has been developed by the Ontario Centre for Remote Sensing [Goba *et al.* 1982] for the Forest Resource Group of the Ministry of Natural Resources, Ontario, Canada. In addition to equipment selection, flight planning, in-flight procedures and film processing, the manual describes several non-enumerative assessment techniques. Topics dealt with include stocking and density assessment, estimation of regeneration success and species identification information. The techniques described are applicable to artificial as well as naturally established regeneration.

Work involving the actual counting of surviving stems in newly established plantations using large scale, small format aerial photography has been less extensive. The practicality of aerial photography for use in reforestation surveys of young pine plantations was examined in 1974 [Bernstein 1974] and the results were not overly encouraging. Color photos, taken at scales of 1:500 and 1:1000 from a helicopter, were used to count pine stems ranging in height from 6 inches to 15 feet. Photo counts, made using 2X magnification, were found in most cases to be only one-half to three-fourths of the totals obtained in the field count. Individual errors ranged from underestimates of 470 trees per acre to overestimates of 517 trees per acre. Imprecise scale determination and resulting improper adjustment of photo plot boundaries, and also misidentification of non-crop vegetation were identified as possible sources of error. In a more successful attempt, tree counts were made in a plantation 2-3 years after establishment using a 70mm camera and color film [Nelson 1976]. At scales of 1:1068 and 1:1224, photo tree counts identified 96-97 percent of the trees found on ground plots with omissions occurring mainly with trees less than 1 foot

8 inches in height in the 2nd year plots and with trees less than 3 feet 4 inches in height in the 3rd year plots. Total tree counts were found to differ by only twelve trees in the 3 year old plots. Nelson commented that although surrounding grasses and vegetation were a factor in the detection of the pines, photography during the growing season could be advantageous in evaluating the competition and prescribing early treatment needs for its reduction.

A more recent effort [Campbell and Mead 1980] involving survival estimates made use of a 35mm camera, a 205mm telephoto lens and color infrared film in an attempt to image pine seedlings on intensively prepared sites one year after planting. A range of photo scales were used, from 1:300 to 1:1040, with the larger scales predictably providing the higher percentage of imaged seedlings. At a scale of 1:300 it was found that 93-100 percent of the seedlings were imaged while at 1:890, success had dropped to 84-90 percent. Though not totally satisfied with the results, the researchers felt that the methods used could result in increased sampling intensity, helping to offset their findings. The authors suggested that using trained interpreters in the aerial photo data acquisition phase may have helped improve their results.

Up to this point there has been little research with regard to competition assessment in forest plantations using aerial photography. In 1972, an effort was made to utilize a vertical projection of Bitterlich's sample angle in the form of a cone projecting upward from a point at the base of a subject tree [Latham 1972]. When viewed stereoscopically on specially prepared parallax measuring equipment, any neighboring tree that impinges upon the interior of the cone was considered the subject tree's competitor. A determination could then be made of the competition stress on any particular tree or the density of competing trees present within the stand.

The use of large scale, small format aerial photography as part of an overall pine plantation management program has not been widely adopted. Although many attempts at non-enumerative regeneration assessment techniques have been tried, a reliable, accurate, enumerative method of estimating the density of regeneration in pine plantations has not been established. Also, research into the use of aerial photography in assessing the competition levels in pine plantations has been minimal. Thus, it appears that the potential for research in these areas is both necessary and worthwhile. Obtaining this information from a single set of photographs makes the potential for this study seem even more attractive for the improved management of loblolly pine plantations.

METHODS AND PROCEDURES

This study evaluated the feasibility of obtaining reliable plantation density estimates and competition level assessments solely from measurements and observations taken from 35mm aerial photography. A single set of exposures provided the basic photographic information to be interpreted. It was hypothesized that these procedures will allow plantation managers to plan, schedule and perform release operations more efficiently and effectively.

There were three main phases to this study. Initially, ground-based measurements were obtained from previously delineated sample plots. These measurements included crown measurements and identification of the woody competition species. In addition, total enumeration of the seedlings and a sampling of Free-To-Grow classifications were performed. Hereafter, the term "seedling" will refer to planted loblolly pine trees, the stand component of interest. Following equipment acquisition and flight planning, an aerial photo mission was flown to obtain information on the previously mentioned study plots from the air. After the film had been developed and processed, the resulting enlarged projections of the slides were analyzed for the parameters of interest and their potential for providing the desired information was examined.

Study Areas

The planting areas involved in this project are part of an ongoing competition study by researchers at VPI and SU. All three areas are located in the Piedmont Region of Virginia, including, a private ownership near Dillwyn in Buckingham County, sections of the Appomatox-Buckingham State Forest and Champion International land located near Keysville, in Halifax County. Each of these locations contained loblolly pine plantings established in 1981, 1982 and 1983 that were 3,4 and 5 years old when this project's work began. While plantations of these ages may be slightly beyond the ideal time to evaluate the need for a release treatment, due to economic and other considerations they may be closer to the time when the actual field operations take place.

At the inception of the original competition study, woody and herbaceous competition levels were artificially established in the study plots using various combinations of ground applied herbicides. The following competition control treatments were applied.

1. Total control
2. Herbaceous control only
3. Total woody control only
4. 1/3 woody only control
5. 2/3 woody control only
6. 1/3 woody + herbaceous control
7. 2/3 woody + herbaceous control
8. No control

With regard to this project, the artificially created competition levels provided a wide range of competition conditions for evaluation. While establishing these levels of competition, an effort was made to retain the original spacing and arrangement of the vegetation. When one-third of the woody vegetation was removed, for example, it was not completely removed in one section of the plot. Instead, every third woody competing stem was removed as it was encountered. In this way, spatial vagaries which might have affected interpretation were generally not created during these treatments.

Data Collection - Ground Survey

Crop tree and competition measures were made in the plots during September, 1985. In each one-fourth acre (0.1 hectare) plot, where a particular competition level had been established, five systematically located pine seedlings served as centers of circular subplots. The radii of the subplots were variable, each equaling one and one-half times the height of the subject pine (no subplot radius, however, was less than 4 feet 11 inches nor greater than 9 feet 10 inches). The distances and bearings to all competing hardwood and volunteer pine stems within the plot were recorded along with the species, height and two perpendicular crown diameters. Any hardwood or volunteer pine stem taller than its distance to the subject pine was also included as a competitor. In three additional fixed radius subplots located around randomly selected subject pines, competition measures were also taken. These results, combined with the previous five subplots, were used to obtain an estimate of the groundline basal area per acre of woody vegetation in each treatment plot using prediction equations [unpublished information] developed specifically for the original competition project.

One hundred percent tallies of seedlings in each treatment plot were made to establish ground truth for stem counts. The procedure used to obtain ground stem counts was intended to represent an actual field appraisal, however, due to the size of each plot, some non-typical methods were employed to improve counting accuracy. Sighting poles were set at plot corners to facilitate location of sidelines and thereby improve boundary identification. While enumerating trees within a plot, an attempt was made to follow established rows. When row location was not obvious, systematic sweeps were made through the plot, counting all loblolly pine trees either in a "row", or, of comparable height and crown development between "rows".

A systematic sample of approximately ten percent was made to evaluate the Free-To-Grow status of the seedlings. The following four category system, developed for the Cheasapeake Corporation [Willis 1978] was used.

Class 1 -	At least 50% of pine stem above competing hardwoods
Class 2 -	0-50% of pine above the competition with no more than two sides shaded
Class 3 -	0-50% of pine above the competition with three or more sides shaded, <u>or</u> overtopped on no more than two sides
Class 4 -	Completely overtopped with competition on three or more sides

This information provided an additional indirect measure of the level of competition on each plot, an estimate of the actual number of seedlings per acre in each of the four Free-To-Grow classes.

Shortly before the photo mission was flown, white and fluorescent orange wood and white plastic targets were placed at the corners of the ground plots. These targets made identification of the plot boundaries possible in the photo interpretation phase. Clear demarcation of the plots was necessary to enable valid comparisons of photo and ground obtained stem counts.

Data Collection - Aerial Survey

This phase of the project involved the taking of large scale 35mm aerial photographs from a fixed-wing airplane. A Cessna 182 aircraft, rented from Air Virginia in Lynchburg, Virginia, was employed for this purpose. The photographs were taken through a bellyhole in the airplane fuselage. The camera used was a manual, Canon AT1 35mm SLR, equipped with a 50mm lens, haze-cutting filter and autowinder. The film chosen for this project was color reversal (slide film) having an ASA of 100. This film/filter combination was selected to improve resolution and to reduce the graininess of the final product.

The photo mission was flown on October 26, 1985. It was planned that contrasting foliage color would help maximize the differentiation between seedlings and competition on the photography, and also facilitate the recognition of the competing hardwood species by their typical fall coloration. Two different scales of photography were taken for purposes of comparison. In order to achieve photo scales of 1:4000 and 1:6000 using a 50mm lens, flying heights of roughly 700 and 1000 feet above the average terrain were maintained. These choices of scale were based upon successful applications of similar equipment at altitudes of 500-1000 feet above the ground, as well as preliminary discussions regarding this type of work held between Dr. Jim Smith, V.P.I., and Jim Willis, of the Cheasapeake Corporation.

Data Collection - Photo Interpretation and Measurement

Interpretation and measurement work for this project was done from enlargements of the slide images viewed monoscopically. The slides were viewed using a vertically mounted rear-projection surface positioned a suitable distance from the projector to permit enlargements of approximately 25X. The two photographic scales chosen and the projection enlargement factor planned resulted in plot image dimensions of approximately five inches and seven inches square.

In order to establish a permanent record of the plots, the locations of plot corners were transferred onto a sheet of acetate and plot boundaries were drawn. Within each plot area, the outlines of the regions corresponding to interpreted pine seedling crowns, individual competition crowns and crown clumps, and areas containing sufficient amounts of visually distractive ground level herbaceous vegetation, were recorded. Only areas of ground vegetation providing a poor contrasting background for the seedlings were included in the latter category. Seedling crowns were marked with a small "x" to enable their recognition in future interpretation work, and as they were delineated, a running tally was kept for the photo obtained pine density estimate. Crowns of the competition, judged to be taller than or equal to average crop tree height were designated with the letter "T", thereby grouping competition crown areas into two distinct height classes. A total of 144 plot maps were drawn, with one map prepared for each plot at each of the two scales.

Following completion of the plot maps, a relative measure of the amount of plot area occupied by each variable of interest was determined. Using a dot grid having a systematic, 81 (9X9) dots per square inch pattern, the number of dots within the entire plot boundary, as well as in each region of interest, were counted. From these totals, a ratio of the number of dots counted in each individual region to the number of dots in the entire plot provided relative percentages of plot area occupied by each interpreted plot variable. These relative percentages became the basic interpretation variables used in later analyses.

Analysis of the Data

Traditionally, estimates of pine density and the level of woody competition present in a plantation have been determined by performing costly, labor-intensive ground surveys. The basic hypothesis motivating this research was that photo identifiable characteristics of the seedlings and the competition present in the plantation directly affect the aerial density estimation and competition level assessment processes.

Determination of the Factors Affecting Photo Interpretation

This aspect of the analysis involved the empirical investigation and identification of factors affecting the interpretation of seedlings in the aerial photography. Experimental factors including scale of the photography, location of the planting sites and age of the plantations were initially examined for their effect on seedling interpretation. The biological factors of seedling size, the amount of groundline basal area in Virginia pine (*Pinus virginiana* Mill.) and the amount of groundline basal area in all woody competition, were also examined with regard to their effects.

The reasons for investigating the experimental factors varied. The scale of the photography, for example, is under the direct control of the forest resource manager. Thus, preliminary knowledge regarding interpretation quality could lead to a more informed choice of project scale. The amount of coverage, the time required to obtain the desired coverage and the total costs incurred are all directly affected by the scale of the aerial photography. The effects plantation location and plantation age had upon crop tree interpretation were important for other reasons. Knowing whether data from different locations provided similar results could be used in determining the desirability of using a combined data set for prediction purposes. The effect plantation age had upon crop tree interpretation was investigated to help choose between the options of combining all aged data, inclusion of an age regressor variable in the ground density prediction equations or the need for separate prediction equations at each plantation age.

The biological factors examined had been obtained as part of another project and were not all intended to be specifically determined from the photography. It was felt, however, that knowledge of their effects could prove useful for photo interpretation work in areas having similar biological characteristics. As the average height of crop trees in the plots ranged from 2 feet 8 inches to 12 feet 2 inches, their values were divided into four discrete levels as indicated.

LEVEL	RANGE OF HEIGHT (in feet)
1	2.7 < Avg. height <= 5.0
2	5.0 < Avg. height <= 7.4
3	7.4 < Avg. height <= 9.8
4	Avg. height > 9.8

The relationship between the physical size of the seedling and how well it was interpreted in the photography was examined. It was hypothesized that by determining the effect of seedling size on interpretation, the optimal stage of plantation development to maximize interpretation accuracy could be established.

To examine the effects that the amount of Virginia pine groundline basal area present in the plot may have had on the interpretation process, the following four levels of this measure were established.

LEVEL	RANGE OF VA. PINE G.B.A. (ft^2 per acre)
1	0 < Va. pine G.B.A. <= 30.5
2	30.5 < Va. pine G.B.A. <= 61
3	61 < Va. pine G.B.A. <= 95.9
4	Va. pine G.B.A. > 95.9

This coniferous species presented the strong possibility of being misinterpreted for loblolly pine at these young ages. It was hypothesized that as the amount of groundline basal area in Virginia pine increased, overestimates of ground density would also increase (assuming adequate estimations otherwise).

The measured amounts of total groundline basal area in all woody competition ranged from 2.4 to 182.9 square feet per acre in the plots and the following four levels of groundline basal area were established.

LEVEL	RANGE OF WOODY COMPETITION G.B.A. (ft^2 per acre)
1	0 < all G.B.A. <= 43.6
2	43.6 < all G.B.A. <= 91.6
3	91.6 < all G.B.A. <= 135.2
4	all G.B.A. > 135.2

It was hypothesized that increasing amounts of all woody competition in the plots would visually clutter and confuse the seedling interpretation process. Plots having little or no woody competition present, it was expected, would result in improved density estimation. It was planned that relationships regarding the previous two factors could help suggest photo interpretable, competition related variables to use in a ground density prediction equation.

To assess the quality of seedling interpretation, the difference between the actual ground determined plot seedling density and the corresponding density interpreted from the photography was examined. The difference value was computed as photo count minus ground survey count, and as such, photo density estimates that underestimated were indicated by a negatively signed difference, while overestimates were positively signed. Since we were interested in how these differences were affected by certain divisions (or levels) of the previously mentioned experimental and biological factors, average measures of accuracy and precision among the divisions (or levels) were compared.

The sign (or direction) and the size of the average difference (bias) were examined to evaluate accuracy. Precision of the photo estimate was assessed by computing the standard deviation of the differences. Average absolute error (the average of the absolute values of the differences), another measure of precision, was also determined. Since values of ground obtained counts ranged from 27 to 245 trees per plot, the average relative absolute error (average of the absolute differences expressed as percentage of ground density) was also computed. Later references to the nature and quality of the photo estimated crop tree counts were intended to have the following connotations.

large underestimate - photo count less than 70 percent of ground count
moderate underestimate - photo count between 70 and 90 percent of ground count
adequate estimate - photo count between 90 and 110 percent of ground count
moderate overestimate - photo count between 110 and 130 percent of ground count
large overestimate - photo count more than 130 percent of ground count

Development of Density Prediction/Correction Equation

Although differences may be found between photo obtained and ground measured densities, a strong correlation between these values can still permit reliable prediction of the ground density from photo counts. Initially, the estimation of ground density was kept as simple as possible to reduce the potential amount of photo interpretation work required. For this reason, the adequacy of using a basic "correction" equation to predict ground density from simple photo counts was investigated. Simple linear regressions were constructed with the seedling count obtained on the ground as the dependent variable, and photo interpreted seedling count as the independent or regressor variable. Traditional quality-of-fit measures such as the correlation coefficient (r), standard error of the estimate ($S_{y.x}$) and coefficient of variation (CV) were used to compare the equations produced. In addition, an analysis of residuals [Myers 1986] was performed. Residual analysis was employed to confirm whether certain dubiously measured data points were off the trend set by the remaining data. In residual analysis, both R-student values (or standardized residuals) and HAT diagonal values (measures of standardized distance from a data point to the remainder of the data) were examined. A large R-student value (indicating an unusually large error in fit) paired with a small HAT diagonal value (giving power to outlier diagnosis) indicated a data point that was significantly off the trend set by the rest of the data. Data points found at this stage to be suspect were re-examined and the data set was corrected to reflect these changes.

Photo identifiable variables other than seedling counts that may have served to either enhance or interfere with the density assessment, were also investigated. Average seedling crown size, total seedling crown closure, crown closure of competing woody vegetation (especially that of stems deemed equal to or exceeding average crop tree height) and the percentage of plot area involved in some form of visually distractive herbaceous ground cover, were examined as potential regressor variables in a ground density prediction equation. The significance of additional variables to the regression were determined through the use of partial F-tests. Interaction between these variables and/or transformations of these variables were considered only when such variables made intuitive sense, considering the nature of the situation. A superior prediction equation was chosen by comparing coefficients of determination (R^2), standard errors of the estimate and coefficients of variation. Collinearity and influence diagnostics [Myers 1986] were also consulted.

The usefulness of a ground density prediction equation is determined by its accuracy, precision and applicability. To examine the degree of applicability, the need for separate location- or age-based prediction equations was investigated. For simple linear forms of the prediction equation, similarity of individual regression expressions was tested using a method outlined by Snedecor and Cochran [1980]. In this procedure, once residual variances are determined to be the same, the slopes, then the intercepts of the separate equations are tested for equality. If no significant differences are detected, one can conclude that a combined data set can be used. As the test for equality of residual variances is extremely sensitive to irregularities (such as non-normality) in the data, it was assumed, in all cases, that the residual variances were the same. When prediction equations contained more than one regressor variable in the final form, a single F-test, comparing the sums of squares for error of the reduced model to the full model's error sums of squares, was performed. The full model was constructed under the assumption that all the location (or age) variables needed to be represented in the model. Where differences in the regression lines were detected through testing, actual comparisons between predicted values from the individual location- or age-based equations and the pooled prediction equation was made for a typical range of the independent variable. Depending on the disparity of the values noted by this comparison, recommendations regarding the practical need for separate prediction equations were suggested.

Development of Competition Level Prediction Equations

This portion of the analysis dealt with predicting the level of woody competition present in the plots. It was hypothesized that the level of competition the loblolly pine were experiencing could be reliably predicted using variables interpreted from the same set of photographs used for the density estimation.

Various field procedures have been considered, or are actually being used to evaluate competition in pine plantations. For this reason, this aspect of the project employed both a direct and an indirect competition prediction approach. The direct approach was intended to predict the groundline basal area (in square feet per acre) of competing woody vegetation present in the plot, from variables interpretable on aerial photographs of the plantations. The groundline basal area values used were obtained from regression equations [unpublished information] developed to predict groundline basal area from crown measurements. Variables interpretable on the photography that were considered as potential regressors included the crown closure of the tall woody competition, the crown closure of the shorter woody competition and/or the crown closure of all woody competition. The previously mentioned statistical criteria were again used to help select a superior prediction equation.

Indirect evaluation of the competition was performed through estimating the number of seedlings per acre in particular Free-To-Grow categories. According to guidelines established for the Cheasapeake Corporation [Willis 1978], spraying for release is not necessary if either,

(a) the total number of crop trees per acre in Classes 1,2 and 3 is less than 300 (Class 4 is included in the total if the stand is 3 years old or less), or,

(b) the total number of crop trees in Classes 1 and 2 (the more favorable classes) is 400 trees per acre or more.

Instead of spraying for release, areas determined to fall within the guidelines of case (a) would be considered for re-site preparation and replanting. Areas best described by case (b) would be left as-is for further development.

Continuing with our attempts to predict plantation information from interpretation of aerial photography, we proceeded to construct equations that would predict estimates relating to the cutoff values for the cases described above. Seedlings that had been designated in the more favorable Free-To-Grow classes (1 and 2) were presumed to be physically distinct from their nearby competitors. It was assumed that a strong association would be found to exist between the number of trees in these classes and the number of crop trees interpreted in the photography. Initially, this relationship was investigated for its predictive value. Improvement of this prediction equation by inclusion of other photo interpretable variables was also examined. A second equation, intended to predict the number of seedlings in the first three Free-To-Grow categories (Category 4 trees were included only if the planting was three years old or less), was also developed. Since the total Free-To-Grow categorization encompasses characteristics of both the seedlings and their competitors, virtually all photo interpretable variables were considered as potential regressors in these prediction equations.

Referring back to the guidelines of the Cheasapeake decision-making system, predicted values from each of our equations enabled each plot to be assigned one of the following courses of action.

1. Re-site prepare and replant
2. Spray to control the competition
3. Leave the stand as-is

Actual values for these decision-making criteria were also obtainable from ground survey data. The results of decisions made from ground sampling and photo interpretation were compared through construction of error matrices.

One error matrix was prepared for each of the two scales of data used in the interpretation. Each error matrix was a 3 X 3 array that expressed the number of plots categorized as needing a particular management course of action relative to their true category (based on ground observed results). Using a computed coefficient of agreement [Cohen 1960], the degree of agreement between the two methods of decision-making was tested for each scale as well as the significance of the difference between the matrices prepared for the two scales. Two accuracy measures, producer's accuracy and user's accuracy [Story and Congalton 1986], were also computed for comparison. Producer's accuracy is a measure of the percentage of samples categorized on the ground that have been classified correctly on the image. User's accuracy is indicative of the probability that a sample from a classified image represents that category on the ground.

Evaluation of the Level of Hard-To-Control Competition

In attempting to determine the amount of hard-to-control woody competition a plot contained, a more qualitative approach was used. Before interpreting the level of hard-to-control woody competition in the plots, some preliminary work was required. The total measured groundline basal area of all competing species in the sampled portion of each plot was combined with crop tree groundline basal area in the same areas to obtain a value for the total groundline basal area. Competing tree species including red maple (*Acer rubrum* L.), various hickories (*Carya* spp.) and ashes (*Fraxinus* spp.), blackgum (*Nyssa sylvatica* Marsh.) and sourwood (*Oxydendron arboreum* (L.) DC.), were deemed hard-to-control based on experience from local release treatment applications. The groundline basal area of just these species was then separately totalled, and a ratio of these two values was used to determine a percentage of the total measured groundline basal area composed of species that were hard-to-control.

No criteria regarding intolerable levels of hard-to-control competition have as yet been established. For this reason, cutoff levels of ten, twenty and thirty percent of total groundline basal area in hard-to-control species were chosen to represent a range of potential levels to which this technique could be applied. Two to three plots containing each of these cutoff amounts were chosen as training sets. Following a period of familiarization with the general density, texture, tone and color of the images in each set, the remaining plots were categorized by visual comparisons. With reference to each particular cutoff value, the plots were designated as being either "over" or "under" the specific criterion. In order to determine how well the photo interpreted level of hard-to-control competition compared to actual ground measurements, error matrices were again constructed. The coefficients of agreement were computed for the matrices and the degree of agreement within each was tested. Also, the significance of the differences between the two scales of data at a cutoff level and between the different cutoff levels at a particular scale, was determined.

RESULTS AND DISCUSSION

The purpose of this section is to report on and discuss accomplishments related to the research objectives of this study. Quality of seedling interpretation was investigated through direct comparisons of the photo and ground obtained plot densities. These results were examined with regard to the possible effects underlying experimental and biological factors may have had. Equations for predicting ground density were constructed and their usefulness was examined. Competition was evaluated directly, by developing equations that predicted groundline basal area in all woody competition, and indirectly, by equations that predicted the number of seedlings per acre in various Free-To-Grow classes. Treatment decisions made by both ground and aerial observation and measurement, were compared and tested for agreement. Finally, results of classifications regarding the level of hard-to-control competition the plots actually contained, were compared to photo interpreted plot classifications.

Factors Affecting Photo Interpretation

The location and identification of pine seedlings on aerial photography was not always straightforward. Characteristics of the plantations under observation and the imagery itself contributed to less than ideal interpretation conditions. In this section, several experimental and biological factors were investigated in an attempt to determine the effect each may have had upon the interpretation of seedlings.

Photographic Scale

The effect of scale on seedling interpretation was the first factor to be considered since it is a fundamental property of aerial photography known to affect both interpretation accuracy and cost. In this section, only the effect of scale was examined. In later sections, the effects of the other factors were examined in light of the underlying scale of the imagery.

Neither scale was found to demonstrate a clear superiority in the number of photo estimates that closely matched the actual field determinations. Approximately half of the plots, at either scale, had photo density estimates that were within ten percent of ground densities. At the 1:6000 scale, overestimates or underestimates were just as likely to occur. Poorer estimates at the larger scale, however, were found to be much more likely to overestimate ground density. The majority of all overestimates of ground density occurred at the 1:4000 scale, but, strangely, the most serious overestimate occurred in the 1:6000 scale data. By far, the majority of underestimates occurred in the

1:6000 scale data. The tendency to err on the side of overestimation at the 1:4000 scale may have been caused by the ability to see too much. Perhaps as more extraneous vegetation became visible in this imagery, more incorrect interpretations of seedling crowns were made. The smaller scale imagery may have kept such misinterpretation to a minimum.

Results were re-examined for each plot as the scale of the imagery changed from 1:6000 to 1:4000. In a majority of all plots (71 percent), the nature of the photo estimation (i.e., underestimation, adequate estimation or overestimation) did not change with the corresponding change of scale. For the plots that changed their nature as the scale of the imagery changed, it was found that plots having adequate estimates at the 1:6000 scale tended to overestimate ground density as the scale increased. Underestimates at the 1:6000 scale tended to agree with ground density as the scale increased. Also, some plots that were underestimated at the 1:6000 scale, overestimated ground density when the larger scale imagery was used. In general, the change in scale from 1:6000 to 1:4000 was found to cause photo density estimates to increase. This finding may have resulted from two factors. At the 1:6000 scale, perhaps less obvious clumps or individual stems of competing vegetation were ignored, as were smaller seedlings. Using the 1:4000 scale imagery, however, might have resulted in the ability to see not only the smaller seedlings, but to misidentify other non-crop vegetation as well.

The accuracy and precision measures of these photo estimates are shown in Table 1. The average differences between photo and ground densities were quite small. The signs of these average differences indicated that estimates made at the 1:6000 scale tended to underestimate ground density while the opposite occurred at the larger scale. The wide range of differences apparent at both scales contributed to the relatively large standard deviation values. Similar precision results were found in a study by Smith [1983] dealing with estimating regeneration success using 1/50th acre sample plots. It must be remembered, however, that sampling error played no part in this research. These measures indicated that the large scale estimates were more precise, although only slightly so. Average absolute error, another measure of the precision of the estimates, and average relative absolute error showed no great difference between the two scales examined.

Plantation Location

1:6000 Scale. Virtually all overestimates of ground density occurred in Location 1, the Keysville plots, and Location 2, the plots on the private ownership near Dillwyn. The only average difference, however, that indicated a consistent tendency to overestimate was the data from Location 2 (Table

Table 1. Summary Statistics of the Differences Between Photo Estimated and Ground Obtained Tree Counts (per acre) at Two Photographic Scales

	AVG.	LARGEST			AVG.	AVG.REL.
SCALE	DIFF.[a]	OVER.[b]	UNDER.[c]	STD.DEV.	ABS.ERR.[d]	ABS.ERR.(%)[e]
1:6000	-17.6	212	-504	108	73	17
1:4000	+10.3	264	-332	96	68	16

a/ DIFFERENCE = photo count - ground count

b/ overestimate

c/ underestimate

d/ the average of the absolute values of the differences

e/ the average of the absolute value of the differences expressed as percentage of ground count

2). The smallest bias indicator, and therefore the most accurate estimations, occurred at the Location 3 plots, located in the Appomatox-Buckingham State Forest. Precision, as measured by both the standard deviation and the average absolute size of the differences, also was best at Location 3. Two-thirds of all moderate underestimates, and all large underestimates occurred at Location 1, and contributed to the large negative average difference found there (Appendix A). Precision was found to be poorest in Location 1 data also. Several obvious characteristics of the plantations at these locations may have contributed to the results found thus far. Plantings at Location 1 had generally smaller, poorly developed seedlings (at Age 3 and 4), scattered survival patterns and considerable development of tall grasses. All of these conditions could have reduced the quality of seedling interpretation, at least at this scale. Plantings at Location 3 generally had taller, more well-developed seedlings surviving in mainly well-defined rows. These characteristics may have served to enhance the interpretation process.

<u>1:4000 Scale.</u> Location 1 data was involved in all moderate underestimates and three-fourths of the severe underestimates of ground density, facts reflected in the negatively signed bias indicator (Table 2). The poorest precision was also found in the Location 1 data, but

Table 2. Summary Statistics of the Differences Between Photo Estimated and Ground Obtained Tree Counts (per acre) Using Data From Different Locations

		AVG.	LARGEST		STD.	AVG.[e]	AVG.REL.[f]
SCALE	LOC.[a]	DIFF.[b]	OVER.[c]	UNDER.[d]	DEV.	ABS.ERR.	ABS.ERR.(%)
	1	-86.8	116	-504	139	122	32
1:6000	2	+36.8	212	-148	71	56	13
	3	- 2.8	108	-112	54	43	7
	1	-23.8	96	-332	126	94	26
1:4000	2	+48.8	264	-172	91	76	17
	3	+ 6.0	80	- 72	42	34	6

a/ location

b/ DIFFERENCE = photo count - ground count

c/ overestimate

d/ underestimate

e/ the average of the absolute value of the differences

f/ the average of the absolute value of the differences expressed as percentage of ground count accuracy in the estimation of ground density was lowest in the data from Location 2. Location 3 photo density estimates were again judged to be the most accurate and precise, compared with data from the other two locations. The physical properties of the plantings at Location 3 again seemed to be enhancing the seedling interpretation. The results found for Location 2 may have been due in part to overestimates that occurred in the Age 4 plots. These plots were characterized by confusing row patterns, undulating topography, large areas of tall competing vegetation obscuring visibility on the ground, and considerable non-crop vegetation similar in size to the seedlings. It is possible that these physical properties contributed to the low ground counts and the correspondingly high photo counts found in these areas.

Plantation Age

1:6000 Scale. Although the bias values for all plantation ages indicated average underestimates of ground density, the negative bias of the Age 5 data was negligible (Table 3). The precision of the estimates was also found to be best in data from the Age 5 plots. Problems in both accuracy and precision were indicated in the Age 4 plots where the largest single over- and underestimates occurred, the average difference was greatest (by a small margin), and the measures of precision were the poorest. Age 4 plots at

Location 1 seemed to have been the major contributor to these results. Trees in these plots were much smaller, on the average, than the other Age 4 locations and a ground cover of dense grass may have combined with the tree size to hinder their interpretation. The ability to locate and count the seedlings on the ground may have been far superior to photo interpreted counts in these plots (at either scale).

<u>1:4000 Scale.</u> The change in scale resulted in all three average differences tending towards overestimation with only the Age 4 plots maintaining an average, although smaller, tendency to underestimate (Table 3). Although the average accuracy of the estimates in the Age 4 plots was best, the precision measures indicated that their error could exceed 100 trees per acre. Large overestimates in the Age 4 plantings at Location 2 (already discussed in the Location section) may have helped balance out Location 1 underestimates at this scale. It is interesting to note the similarity found between the relative errors of all three ages. Higher average ground counts in the Age 4 plots tempered the actual differences found between the counts.

Crop Tree Size

<u>1:6000 Scale.</u> Poorest accuracy was found in the plots that averaged the shortest seedlings (Table 4), but no trend with increasing height was apparent. Results indicated that

Table 3. Summary Statistics of the Differences Between Photo Estimated and Ground Obtained Tree Counts (per acre) Using Data of Different Ages

		AVG.	LARGEST		STD.	AVG.	AVG.REL.
SCALE	AGE	DIFF.[a]	OVER.[b]	UNDER.[c]	DEV.	ABS.ERR.[d]	ABS.ERR.(%)[e]
	3	-23.7	68	-248	76	55	16
1:6000	4	-28.7	212	-504	162	121	19
	5	- 0.5	116	-148	58	44	16
	3	+28.0	92	- 40	38	39	12
1:4000	4	- 9.8	264	-332	150	113	19
	5	+12.8	96	-172	63	52	18

a/ DIFFERENCE = photo count - ground count

b/ overestimate

c/ underestimate

d/ average of the absolute value of the differences

e/ average of the absolute value of the differences expressed as percentage of ground count plots with the tallest seedlings had the most precise estimates. Relative error was also far superior in results from plots having the tallest seedlings. It is important to recall that superior estimation precision was found to occur in plots from Location 3 and of Age 5, both sets of plots having the greatest average seedling height. Also, poorest accuracy in the estimation of ground density occurred in Location 1 plots, that location found to have had the shortest seedlings.

1:4000 Scale. No clear trends were evident in the measures computed (Table 4). While relatively small underestimates were the rule, the largest bias found was positive, in data from plots having the next-to-largest average seedling height. The least precise estimates of ground density occurred in plots that averaged the next-to-smallest seedlings. Regarding overall performance, plots having the tallest average seedling height produced ground density estimates of good accuracy and superior precision.

Groundline Basal Area in All Woody Competition

1:6000 Scale. The only average underestimate was found to occur in the plots having the lowest level of total woody competition (Table 5). Results did show that plots having the least amount of total woody competition had the poorest accuracy and precision. A possible explanation for this finding could be that at this scale, the competition may be

Table 4. Summary Statistics of the Differences Between Photo Estimated and Ground Obtained Tree Counts (per acre) Using Data From Plots With Different Average Seedling Heights

SCALE	HEIGHT LEVEL[a]	N[b]	AVG. DIFF.[c]	LARGEST OVER.[d]	LARGEST UNDER.[e]	STD. DEV.	AVG.REL. ABS.ERR.(%)[f]
	1(short)	24	-60.8	68	-252	103	21
1:6000	2	15	-22.1	108	-504	147	11
	3	25	+33.4	212	-148	80	20
	4(tall)	8	-39.0	8	- 80	32	7
	1(short)	24	- 6.5	92	-180	82	16
1:4000	2	15	- 1.9	144	-332	138	15
	3	25	+42.1	264	-172	87	21
	4(tall)	8	-15.5	68	- 72	45	6

a/ Level 1: heights from 2'8" to 5'0"
Level 2: heights from 5'0" to 7'5"
Level 3: heights from 7'5" to 9'10"
Level 4: heights greater than 9'10"

b/ N = the number of plots at each level

c/ DIFFERENCE = photo count - ground count

d/ overestimate

e/ underestimate

f/ average of the absolute value of the differences expressed as percentage of ground count acting as a good contrasting background for the seedling interpretation. The number of plots containing the two highest levels of total groundline basal area, however, was only 4 (of 72). Comparisons with their accuracy and precision measures could have been misleading and therefore they were not included in this discussion.

1:4000 Scale. In an expected result, plots that had the lowest level of total groundline basal area had density estimates with the greatest accuracy and precision (Table 5). In this case, competition appears to be more of a hinderance than a help to interpretation. Location 3, found to contain the smallest average amount of total groundline basal area, was previously noted as having good estimation accuracy. As the amount of total groundline basal area increased to the next highest level, both accuracy and precision were found to decrease. Again, due to the extremely small sample of plots containing the highest levels of total groundline basal area, their results will not be discussed.

Groundline Basal Area in Virginia Pine

1:6000 Scale. The largest bias indicator was found to occur in the plots having, surprisingly, the smallest amount of Virginia pine (Table 6). Although all remaining levels indicated positive biases, the amount of the overestimate dropped as the amount of Virginia pine increased, also an

Table 5. Summary Statistics of the Differences Between Photo Estimated and Ground Obtained Tree Counts (per acre) Across the Levels of Woody Competition

SCALE	TOTAL COMP. LEVEL[a]	N[b]	AVG. DIFF[c]	LARGEST		STD. DEV.	AVG.REL. ABS.ERR.(%)[f]
				OVER.[d]	UNDER.[e]		
1:6000	1(low)	49	-36.2	108	-504	111	16
	2	19	+22.5	212	-164	95	20
	3	3	+24.0	68	- 4	60	22
	4(high)	1	+ 4.0	4	4	-	1
1:4000	1(low)	49	- 1.1	92	-332	81	12
	2	19	+35.6	264	-316	131	26
	3	3	+54.7	84	28	28	22
	4(high)	1	-44.0	- 44	- 44	-	8

a/ Level 1: gndline. basal area from 0 to 30.5 ft^2/Ac.
Level 2: gndline. basal area from 30.5 to 61 ft^2/Ac.
Level 3: gndline. basal area from 61 to 95.9 ft^2/Ac.
Level 4: gndline. basal area more than 95.9 ft^2/Ac.

b/ N = number of plots at each level

c/ DIFFERENCE = photo count - ground count

d/ overestimate

e/ underestimate

f/ average of the absolute value of the differences expressed as percentage of ground count

Table 6. Summary Statistics of the Differences Between Photo Estimated and Ground Obtained Tree Counts (per acre) Across the Levels of Virginia Pine Competition

SCALE	VA.PINE COMP. LEVEL[a]	N[b]	AVG. DIFF.[c]	LARGEST OVER.[d]	LARGEST UNDER.[e]	STD. DEV.	AVG.REL. ABS.ERR.(%)[f]
1:6000	1(low)	53	-31.0	108	-504	109	16
	2	16	+22.0	212	-164	104	20
	3	2	+12.0	68	- 44	79	20
	4(high)	1	+ 4.0	4	4	-	1
1:4000	1(low)	53	+ 3.5	96	-332	80	13
	2	16	+30.8	264	-316	142	26
	3	2	+56.0	84	28	40	19
	4(high)	1	-44.0	-44	- 44	-	8

[a] Level 1: gndline. b.a. from 0 to 43.6 ft^2/Ac.
Level 2: gndline. b.a. area from 43.6 to 91.6 ft^2/Ac.
Level 3: gndline. b.a. area from 91.6 to 135.2 ft^2/Ac.
Level 4: gndline. b.a. area more than 135.2 ft^2/Ac.

[b] N = number of plots at each level

[c] DIFFERENCE = photo count - ground count

[d] overestimate

[e] underestimate

[f] average of the absolute values of the differences expressed as percentage of ground count

unexpected result. The small sample that accounted for the highest levels of Virginia pine, however, may have affected these results. For this reason, measures computed and results obtained for the two highest levels were not included in any further discussions. Precision of the ground density estimations for the different levels did not differ greatly.

<u>1:4000 Scale.</u> The greatest accuracy and precision occurred in the plots having the lowest amounts of Virginia pine. Recall that plots of Age 3 and from Location 3, where the amount of Virginia pine was least, were found to have the best precision and accuracy for estimates of ground density. As the amount of Virginia pine in the plots increased one step from its lowest level, the average difference reflected a tendency to overestimate, at both scales. Possible misinterpretation of this species as crop trees was the likely cause of this result.

Summary

In considering only the scale of the photography, neither the 1:6000 scale nor the 1:4000 scale showed greatly superior photo interpretation potential. While accuracy and precision measures indicated ground density estimates to be slightly better at the larger scale, a definite trend to overestimate at the larger scale was noticed. Accuracy and precision in the estimation of ground density was found to be best in the plots of Location 3, at both scales. The near-total consistency in the results that placed Location 1 and Location 3 at either end of the accuracy/precision spectrum, indicated an influence of site and other factors on photo interpretation. The poorest precision in ground density estimation was found in the Age 4 plots at both scales. Plots containing the oldest trees were found to provide the most accurate and precise ground density estimations at the 1:6000 scale. Plots that had the largest average seedling height were also found to have the most precise density estimates. Shorter seedlings were generally associated with poorer precision. Average seedling height did not seem to have a clearly defined influence on accuracy. At the 1:6000 scale, poorest accuracy and precision were found in plots that contained the lowest amount of total competition. On the other hand, superior accuracy and precision resulted from density estimates made on plots with the least total competition at the 1:4000 scale. The best accuracy and precision were found for plots having the least amount of Virginia pine at the 1:4000 scale. The poorest accuracy occurred in plots having the lowest amount of Virginia pine at the 1:6000 scale.

Prediction of Stand Density

Seedling counts interpreted from aerial photography were not identical to the results obtained from ground surveys. Although these density values were not the same, strong relationships between them were apparent upon inspection. Using photo interpretable variables, attempts were made to develop equations for predicting ground density from aerial photography.

Simple Linear Relationships

Initially, simple linear regressions were constructed to determine their adequacy for predicting ground density knowing only the photo interpreted count. Following the preparation of ground density prediction equations for both 1:6000 and 1:4000 scale data, residual analysis was employed to determine whether any existing data points could be confirmed as suspect. Several data points, at both scales, were noted in this analysis and both field and photo density measures were re-examined. In addition, field checks revealed the need for some plot boundaries to be adjusted on the imagery also resulting in "new" field counts. Following this one-time correction of data point values, the simple linear regressions were fitted again, and two regression equations were produced (Table 7), one for each scale. All summary measures seemed to favor the 1:4000 scale regression, but only by a small margin.

In order to investigate the advisability of using a combined data set for prediction, simple linear regressions

Table 7. Ground Density Prediction Equations Based on Scale of the Photography

1:6000 Scale	$GD^{a} = 71.47 + 0.882*PD^{b}$ $r^2=0.68 \quad S_{y.x}=103.6 \quad CV=22.3$
1:4000 Scale	$GD =-16.35 + 1.017*PD$ $r^2=0.75 \quad S_{y.x}=92.3 \quad CV=19.8$

a/ GD = seedling count per acre made in a field survey

b/ PD = seedling count per acre made through photo interpretation were computed again with the data sorted by location of origin (Table 8). This was done to empirically compare the summary measures from these regressions and then test if any statistical difference in the regressions could be found. It was apparent, through traditional fit statistics, that the simple linear model fit the data from Location 3 best, and the data from Location 2 poorest, at both scales. Good general development of the seedlings, more well-defined planted rows and less competition present could have contributed to the better fit and highest linear correlation found in the Location 3 equation. Although the coefficients of determination did not differ greatly between Location 1 and 3, the quality-of-fit measures indicated the data were considerably more scattered about the Location 1 regression line. The small average seedling size and high grass found in many of this location's plots may have resulted in more inconsistent estimates upon which the equation was based. The switch to a larger scale of imagery was found to produce the most obvious improvement in model fit for the data from Location 1. The ability to obtain a slightly "closer look" at the 1:4000 scale apparently helped to identify the crop trees while reducing the effect of the surrounding grass. Due to the desirability of using a combined data set to produce a single, location independent prediction equation, the similarity of the regression equations was tested. Having assumed that the residual variances were the same,

Table 8. Location-Based Ground Density Prediction Equations

	<u>1:6000 Scale</u>			
Location 1:	GD[a] = -62.67 + 1.515*PD[b]	$r^2=0.71$	$S_{y.x}=125.5$	CV=33.3
Location 2	GD = +98.85 + 0.700*PD	$r^2=0.59$	$S_{y.x}=55.1$	CV=13.5
Location 3:	GD = +154.58 + 0.751*PD	$r^2=0.76$	$S_{y.x}=47.6$	CV=7.8
	<u>1:4000 Scale</u>			
Location 1:	GD = -159.38 + 1.518*PD	$r^2=0.79$	$S_{y.x}=106.7$	CV=28.3
Location 2:	GD = +156.60 + 0.557*PD	$r^2=0.38$	$S_{y.x}=67.9$	CV=16.7
Location 3:	GD = +78.76 + 0.863*PD	$r^2=0.83$	$S_{y.x}=40.3$	CV=6.6

[a] GD = seedling count per acre made in a field survey

[b] PD = seedling count per acre made through photo interpretation

the equations were tested for equality of slope. At both scales, the F-tests performed indicated significantly different slopes for the individual regression lines. Although this finding would normally indicate the inadvisability of combining the data sets, a separate equation for data from each location of origin was highly undesirable. In order to investigate the actual differences between ground density values predicted by a pooled expression rather than by individual expressions, a table of these values was prepared (Table 9). At the 1:6000 scale, the pooled regression equation provided predictions of ground density that generally tended to agree with the results from Locations 2 and 3. The most serious discrepancies occurred between the pooled and the Location 1 results at the three highest levels of photo obtained density. Similar trends were noted in the predictions resulting from the use of 1:4000 scale data. This may have occurred due to the higher ranges of ground density values being poorly represented in these particular plots. Predictions in this range using the Location 1 equation may have been greatly extrapolated. Using a larger, more well-distributed sample should allow a pooled prediction equation to suffice at all locations.

Simple linear regressions were also computed separately for each plantation age to empirically compare their summary measures and to test the resulting equations statistically

Table 9. Ground Density Predictions of Stems Per Acre From Pooled and Location-Based Equations

		PREDICTED GROUND COUNT[a]			
SCALE	PHOTO COUNT	SITE 1	SITE 2	SITE 3	POOLED
	200	240	239	305	248
	400	543	379	455	424
1:6000	600	846	519	605	601
	800	1149	659	755	777
	1000	1452	799	905	954
	200	144	268	251	187
	400	448	379	424	390
1:4000	600	752	491	596	594
	800	1055	602	769	797
	1000	1359	714	942	1001

a/ each column represents a set of predicted values made using the particular equation specified for similarity (Table 10). While the model fit was essentially the same for the Age 3 and Age 5 data at the 1:4000 scale, the fit to the data from the oldest plantings was obviously better at the smaller scale. Clearly the most serious inadequacy in the fit of the model to the data was found at Age 4. Also, the quality-of-fit statistics indicated the data to be more scattered about the Age 4 regression line, at both scales. Only the Age 3 regression seemed to clearly benefit by the use of the 1:4000 scale rather than the smaller scale data. A "closer" view seemed to benefit the interpretation of the younger trees.

The problem demonstrated by the poor fit to the data of Age 4 needs some additional comment. Good results found using data of Age 3 and Age 5 suggests that something unusual was occurring at this stage of plantation development. This period may occur between the time competition developing from large existing root systems flourishes, and the time rapid pine growth finally allows the seedlings to dominate the stand. Age 4 may prove to be a transition age in seedling interpretation and subsequent density prediction. This "in-between" time could have resulted in inconsistent estimations and resulting poor fit to the linear model.

To make the prediction of ground density from aerial photography as generally applicable as possible, age-specific prediction equations were not preferred. The

Table 10. Age-Based Ground Density Prediction Equations

1:6000 Scale

Age 3 Equation: $GD^{a} = 135.04 + 0.707*PD^{b}$
$r^2=0.75$ $S_{y.x}=63.3$ $CV=15.7$

Age 4 Equation: $GD = 249.38 + 0.608*PD$
$r^2=0.29$ $S_{y.x}=146.8$ $CV=25.2$

Age 5 Equation: $GD = -46.49 + 1.110*PD$
$r^2=0.92$ $S_{y.x}=55.7$ $CV=13.6$

1:4000 Scale

Age 3 Equation: $GD = -56.44 + 1.066* PD$
$r^2=0.91$ $S_{y.x}=37.7$ $CV=9.3$

Age 4 Equation: $GD = 176.16 + 0.720*PD$
$r^2=0.39$ $S_{y.x}=135.7$ $CV=23.3$

Age 5 Equation: $GD = -60.60 + 1.106*PD$
$r^2=0.90$ $S_{y.x}=62.1$ $CV=15.1$

[a] GD = seedling count per acre made in a field survey

[b] PD = seedling count per acre made through photo interpretation

individual regression expressions were tested to determine whether they were similar enough to allow combining the data sets. Again, proceeding on the assumption of homogeneous variance, the slopes of the individual regression equations were compared. Results of the F-tests indicated that the individual age-based regressions did not have the same slope. Based on the previous findings, a separate regression for each particular age plantation under consideration was indicated. In order to examine the practical differences that could be expected in the density predictions between individual expressions versus a pooled prediction equation, a table of these values was prepared (Table 11). At both scales, predictions of ground density by the age-based regressions tended to agree with each other and the pooled regression predictions at all but the extremes of photo seedling count. Based on these comparisons it seemed that the pooled regression equation could be expected to provide adequate density predictions for all aged plantations.

Inclusion of Other Variables in the Model

The potential for additional photo interpretable variables to improve the ground density prediction equation was examined. Earlier findings that indicated data from different locations or ages could produce variable prediction results were not disregarded. Initially,

Table 11. Ground Density Predictions of Stems Per Acre From Pooled and Age-Based Equations

SCALE	PHOTO COUNT	PREDICTED GROUND COUNT[a] AGE 3	AGE 4	AGE 5	POOLED
1:6000	200	276	371	175	248
	400	418	492	397	424
	600	559	614	619	601
	800	700	735	841	777
	1000	842	857	1063	954
1:4000	200	157	320	161	187
	400	370	464	382	390
	600	583	608	603	594
	800	796	752	825	797
	1000	1010	897	1046	1001

a/ each column represents a set of predicted values made using the particular equation specified however, investigation of the inclusion of additional regressors into the predictive model was begun using the entire data set at each scale.

<u>1:6000 Scale.</u> Of the photo interpretable variables that were investigated, only the percentage of plot area in visually distractive ground vegetation was found to significantly improve the ground density regression. The following form of the prediction equation was developed.

$$GD = 29.15 + 0.941*PD + 4.488*PGV$$

$$R^2=0.76 \quad S_{y.x}=90.9 \quad CV=19.5$$

Where,
GD = seedling count obtained by field survey, on a per acre basis
PD = seedling count obtained through photo interpretation, on a per acre basis
PGV = percentage of the photo plot area in visually distractive ground cover

The addition of the second regressor variable to the original simple linear model resulted in an overall improvement in fit. The standard error of the estimate dropped, R-squared increased, and the CV statistic fell, amounting to changes of ten percent or more over their previous values. After consulting the appropriate diagnostics, collinearity was not found to be a problem between the two regressors selected. Due to the fact that none of the plots at Location 3 or of Age 4 contained any percentage of visually distractive ground vegetation, the model under consideration was not of full rank. Because of this, procedures intended to test the need for separate age-or location-based regressions were not performed.

1:4000 Scale. No other photo interpretable variables were found to be significant in the presence of the photo obtained seedling count variable. Thus, no changes to the simple linear form of the prediction equation were necessary.

Summary

Inclusion of photo interpretable, competition related variables provided virtually no help in the density prediction process. Using 1:4000 scale data, no photo interpretable variables were found to improve upon the equation that simply adjusted the photo obtained seedling count. Statistical testing indicated the advisability of constructing separate regressions based on the location of origin of the data and the age of the plantation. Actual computed predictions of ground density, however, did not differ greatly when results from from these equations were compared. The addition of the variable involving visually distractive ground level vegetation was found to provide a statistically significant improvement over the simple linear model when 1:6000 scale data was used. Since the need for separate age- or location-based prediction equations for this multiple linear model could not be adequately tested, a single expression was constructed using the entire data set. The ultimate choice of a superior prediction equation should be based on results from a validation data set.

Evaluation of Woody Competition Level and Type

Continuing with efforts to obtain useful information concerning young loblolly pine plantations from the air, the ability to utilize aerial photography in assessing woody competition was the topic covered in this phase of the analysis.

Prediction of Groundline Basal Area

The amount of groundline basal area in all woody competition has recently been considered as a measure of the overall competition in a young pine stand. In this section an attempt was made to predict groundline basal area, in square feet per acre units, from variables interpretable on aerial photography. The photo interpretable variables that made intuitive sense as potential regressors included the percentage of plot area containing crowns of short competition, the percentage of plot area containing crowns judged to be equal to or greater than the average seedling height on the plot, and the percentage of plot area containing all woody competition crowns, regardless of their height.

At both scales, two separate regressions, one involving both short and tall competition components, and the other, a single total competition regressor, were considered. In the equation that allowed the two height-based competition components to enter separately, their partial plots were examined. The plots prepared for each of these variables seemed to indicate non-linear trends. To improve the fit of the model to the data, various transformations on the separate regressors, as suggested by their slightly non-linear partial plots, were attempted. None of the transformations examined succeeded in improving the fit of the regression. Based on these results, equations based on the simpler, single total competition variable were selected (Table 12). The summary measures for these regressions indicated no profound differences, with the 1:6000 scale data providing only a slightly better overall model fit.

As both location and age have been shown to have had an effect on ground density prediction, it was felt that their effect on predicting total woody groundline basal area should also be investigated. After sorting the data by location of origin, and again assuming homogeneity of residual variances, the equality of the slopes for the different regression lines was tested. Although the slopes for the different lines were found to be significantly different using the 1:6000 scale data, the test procedure did not find them to differ significantly at the larger scale. Since the testing of 1:4000 scale data indicated regression lines that shared a common slope, only the test for a common intercept remained. This F-statistic was found to be insignificant and it was concluded that in the case of

Table 12. Competition Groundline Basal Area Prediction Equations

1:6000 Scale: GBA[a] $= +8.425 + 2.351*\mathrm{PTOTC}$[b]
$r^2=0.42 \quad S_{y.x}=24.1 \quad CV=67.9$

1:4000 Scale: GBA $= +9.245 + 2.121*\mathrm{PTOTC}$
$r^2=0.38 \quad S_{y.x}=24.8 \quad CV=69.8$

[a] GBA = groundline basal area in all woody competition, expressed in square feet per acre

[b] PTOTC = percentage of plot area containing crowns of all woody competition

1:4000 scale data, one regression equation was sufficient for all locations involved. Results from the 1:6000 scale data indicated that separate location-based prediction equations were necessary (Table 13).

Actual predicted total woody groundline basal area values did not differ greatly between the pooled equation and the individual Location 1 and Location 2 equations (Table 14). Predictions from the pooled equation, however, were consistently larger than the results from the Location 3 equation. One reason for this could be the failure of the Location 3 data to support prediction at the higher levels of total competition percentage. If this form of prediction equation were used, a larger data set, more representative of the entire area, could perhaps improve the ultimate precision of the estimates. It was felt that a pooled equation could perform adequately regardless of the location of origin of the data.

The need for separate regression lines based on the plantation age was also examined. Again, the residual variances were assumed to be the same. While the slopes were found to differ significantly between regression lines at the 1:6000 scale, the larger scale data regressions were again shown to share a common slope. The follow-up test for a common intercept was performed and the lines were found to have different intercept values when the 1:4000 scale data was used. Based on the results of our examinations to this

Table 13. 1:6000 Scale Location-Based Groundline Basal Area Prediction Equations

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Location 1: GBA[a] = $-3.24 + 3.284$*PTOTC[b]
$r^2=0.82$ $S_{y.x}=14.2$ CV=41.2

Location 2: GBA = $18.35 + 1.935$*PTOTC
$r^2=0.20$ $S_{y.x}=35.3$ CV=76.9

Location 3: GBA = $16.51 + 1.096$*PTOTC
$r^2=0.24$ $S_{y.x}=14.2$ CV=54.4

---

a/ GBA = groundline basal area in all woody competition, expressed in square feet per acre

b/ PTOTC = percentage of plot area containing crowns of all woody competition

Table 14. Predictions of Competition Groundline Basal Area (in square feet per acre) From Pooled and Location-Based Equations Using 1:6000 Scale Photography

PLOT AREA IN ALL COMP. (%)	PREDICTED TOTAL WOODY COMPETITION[a] LOC.1	LOC.2	LOC.3	POOLED
10	30	38	27	32
20	62	57	38	55
30	95	76	49	79
40	128	96	60	102

[a] each column represents a set of predicted values made using the equation specified

point, data from 1:6000 scale photography should technically require a different prediction equation for each age of data examined (3,4 or 5 years). Use of the 1:4000 scale imagery was found to require the construction of equations with different intercepts, but sharing a common slope (Table 15). The extremely large coefficients of variation (CV) should be noted. One possible explanation for statistics of this magnitude could have been the tremendous variation in the measured values of groundline basal area itself. Coefficient of variation, found for the dependent variable, ranged from 64 percent for the oldest plantings to over 85 percent for the youngest. Such variation, it seems, cannot help but contribute to the poor fits found in the regressions.

Even though statistical testing found a difference between the separate age-based regressions, actual predictions of total groundline basal area from both the individual prediction equations and from a single pooled prediction equation were compared (Table 16). At both scales, predictions made from the Age 3 equation were consistently smaller than results from the pooled equation. A possible explanation for the poor agreement between the Age 3 regression equation and all the others may lie in the fact that the Age 3 data did not support the prediction equation throughout the range of total competition percentages. Using a pooled form of the equation for all plantation ages beyond the age of three is recommended. A

Table 15. Age-Based Competition Groundline Basal Area Prediction Equations

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1:6000 Scale

Age 3: GBA[a] = 8.758 + 8.667*PTOTC[b]
$r^2=0.27$ $S_{y.x}=12.7$ CV=74.5

Age 4: GBA = 6.387 + 2.777*PTOTC
$r^2=0.45$ $S_{y.x}=15.5$ CV=51.2

Age 5: GBA = 18.299 + 2.496*PTOTC
$r^2=0.39$ $S_{y.x}=30.0$ CV=50.6

1:4000 Scale

Age 3: GBA = -1.35446 + 1.718*PTOTC

Age 4: GBA = 13.20783 + 1.718*PTOTC

Age 5: GBA = 30.86626 + 1.718*PTOTC

---

a/ GBA = groundline basal area of all woody competition, expressed in square feet per acre

b/ PTOTC = percent of plot area containing all woody competition crowns

Table 16. Predictions of Groundline Basal Area (in square feet per acre) Using Pooled and Age-Based Equations

	PLOT AREA IN	PREDICTED TOTAL WOODY COMPETITION[a]			
SCALE	ALL COMP.(%)	AGE 3	AGE 4	AGE 5	POOLED
1:6000	10	17	34	43	32
	20	26	62	68	55
	30	35	90	93	79
	40	43	117	118	102
1:4000	10	16	30	48	30
	20	33	48	65	52
	30	50	65	82	73
	40	67	82	96	94

[a] each column represents a set of predicted values made using the particular equation specified

separate Age 3 prediction equation should be used.

Prediction of the Number of Seedlings Per Acre in Various Free-To-Grow Classes

Making release decisions in young pine stands using Free-To-Grow classifications is a procedure that is currently in use by practicing forest resource managers. Results of a sampling of Free-To-Grow classifications are used in a two-phased approach to determine the need for a chemical spray application.

Free-To-Grow Classes 1 and 2. It was planned to keep the prediction process as simple as possible, and still do an adequate job in ascertaining the number of seedlings in these particular Free-To-Grow classes. For this reason, the simple relationship between Class 1 and Class 2 seedlings and the number of seedlings interpreted from the photography was initially examined. The seedlings interpreted in the photography were probably trees under less competitive influence from their neighbors, and hence, more likely to have been in the more favorable Free-To-Grow classes. Simple linear regressions, with the number of seedlings per acre in Free-To-Grow Classes 1 and 2 as the dependent variable and photo interpreted seedling density as the independent variable, were constructed at both scales (Table 17). A slightly better model fit was noted with the 1:4000 scale data. The large sample correlation coefficients (r) shown

Table 17. Equations Developed to Predict the Number of Seedlings Per Acre in Free-To-Grow Classes 1 and 2 From Photo Estimated Seedling Counts

---

1:6000 Scale: FTGPA[a] = $-33.952 + 0.889 * \text{TPA}$[b]
$r^2=0.58$ $S_{y.x}=130.2$ CV=35.9

1:4000 Scale: FTGPA = $-128.09 + 1.037 * \text{TPA}$
$r^2=0.65$ $S_{y.x}=118.8$ CV=32.7

---

a/ FTGPA = the number of trees per acre in Free-To-Grow classes 1 and 2

b/ TPA = seedling count per acre as determined by photo interpretation by both regressions support the strong association intuitively felt to relate these two variables.

Although these prediction equations were not unsatisfactory, it was felt that the addition of one or more regressor variables might significantly improve the prediction properties of the equation. The percentage of seedlings in the plot, classified in either Free-To-Grow Classes 1 or 2, was plotted against potential regressors as an early approach to examining variable relationships. Several important trends were noted in the plots prepared. As average seedling crown size and percentage of seedling crowns increased to their highest levels, the percentage of favorable seedlings maintained a high level. Also, as values of the percentage of both tall and shorter woody competition crowns increased, the percentage of favorable seedlings dropped to its lowest point. Effects of the four variables mentioned at other than their highest levels were not easy to discern. The only clear trend throughout its range, was the plot of the percentage of favorable seedlings versus the percentage of the plot area containing all woody competition crowns. The plots clearly demonstrated a general linear trend, with the plotted points dropping from left to right. The negative slope in this relationship indicated smaller percentages of seedlings were classed as having favorable Free-To-Grow status when the amount of total competition in the plot increased. A computer program designed to isolate optimal subsets of regressor variables by comparing coefficient of determination (R^2) statistics was also employed to select from the list of potential regressors. In this investigation, the variables that repeatedly occurred in optimal subsets included photo interpreted seedling density, percentage of seedling crowns and percentage of plot area containing all competition crowns, reinforcing some of the results obtained in the previously discussed plots.

Considering all preliminary results, three variables were determined to be the most important in the prediction of the number of trees per acre in favorable Free-To-Grow classes, and the equations were then constructed (Table 18). The signs of the variables representing percentage of plot area in all woody competition crowns and percentage of plot area in seedling crowns, at both scales, were interesting to note. The negatively signed total competition variable indicated that increasing amounts of competition served to decrease the predicted number of seedlings that were free-to-grow. The positively signed seedling crown area variable indicated that as greater amounts of plot area are devoted to seedling crowns, the number of seedlings per acre judged to be free-to-grow will increase. Both of these findings agreed with an intuitive understanding of the situation. The 1:6000 scale data can be seen to have provided a slightly better model fit. This final form of

Table 18. Equations Developed to Predict The Number of Seedlings Per Acre in Free-To-Grow Classes 1 and 2

<u>1:6000 Scale</u>

$$\text{FTGPA}^{\underline{a}} = 162.083 + 0.542*\text{TPA}^{\underline{b}} - 9.489*\text{PTOTC}^{\underline{c}} + 5.820*\text{PCW}^{\underline{d}}$$

$$R^2=0.81 \quad S_{y.x}=89.4 \quad CV=24.6$$

<u>1:4000 Scale</u>

$$\text{FTGPA} = 70.618 + 0.670*\text{TPA} - 7.035*\text{PTOTC} + 5.686*\text{PCW}$$

$$R^2=0.79 \quad S_{y.x}=92.8 \quad CV=25.6$$

---

[a] FTGPA = the number of trees per acre in Free-To-Grow Classes 1 and 2

[b] TPA = the number of seedlings per acre interpreted from the photography

[c] PTOTC = percent of plot area in crowns of all woody competition

[d] PCW = percent of plot area in seedling crowns

the equation was tested to see whether data from either different locations or of different ages would produce significantly different regression lines. Tests revealed that separate location-based equations would be required for both scales. Separate age-based equations were not found to be needed.

Free-To-Grow Classes 1,2 & 3 (and 4). Recalling the Cheasapeake Corporation's guidelines, the decision to re-site prepare and replant hinges on the number of trees that have survived per acre, whether they are in superior Free-To-Grow classifications or not. Predicting the number of seedlings per acre in the first three Free-To-Grow classes (as well as category 4 if the stand is three years old or less) was required to make the release decision from aerial photography. The same list of potential regressor variables previously consulted was selected from, and similar methods were used to construct the best prediction equation. A two variable model was felt to provide the best fit to the data, at both scales (Table 19). While the photo interpreted seedling count was again useful in explaining some of the variability of the dependent variable, the percentage of taller woody competition was also found to be significant to the regressions. Again, the signs of the regression coefficients made intuitive sense. Although appearing quite different with regard to the size of their

Table 19. Equations Developed to Predict the Number of Seedlings Per Acre in Free-To-Grow Classes 1,2 & 3 (and 4)

1:6000 Scale

$$\text{TREESPA}^{a} = 117.373 + 0.820*\text{TPA}^{b} - 10.393*\text{PTC}^{c}$$

$$R^2=0.72 \quad S_{y.x}=101.8 \quad CV=22.9$$

1:4000 Scale

$$\text{TREESPA} = -12.734 + 1.001*\text{TPA} - 4.363*\text{PTC}$$

$$R^2=0.76 \quad S_{y.x}=93.8 \quad CV=21.1$$

---

a/ TREESPA = the number of seedlings per acre in Free-To-Grow classes 1,2 & 3 (and 4)

b/ TPA = seedlings per acre interpreted from the photography

c/ PTC = percent of plot area in crowns of tall woody competition parameter estimates, the summary measures indicated only a slightly superior model fit to the 1:4000 scale data. The need for separate location- or age-based equations was then tested. Separate equations were found to be needed using the 1:6000 scale imagery. Use of the 1:4000 scale imagery, however, was found to require only individual location-based prediction equations.

With the guidelines used in Chesapeake's system in mind, construction of the previous two prediction equations now permitted comparison of management decisions made on the ground and through aerial photo interpretation. At each scale, the appropriate prediction equations were used to estimate the levels of the decision factors involved. Each plot was assigned one of the following courses of action: (1) re-site prepare and replant, (2) spray for competition control, (3) leave the stand as-is for further development. A course of action was also determined based on ground measurements allowing error matrices relating these two sets of decisions to be constructed (Table 20). The coefficient of agreement, kappa (k) [Cohen 1960], was computed to test whether the agreement between ground and photo based decision-making exceeded what could have been expected by chance (Table 21). At both scales, tests on the computed kappa statistics indicated that agreement was significantly more than chance. In testing whether the differences between the coefficients of agreement for the two scales

Table 20. Error Matrices Used to Compare Ground and Photo Based Decisions Made at Different Photographic Scales

1:6000 SCALE ERROR MATRIX[a]
(Overall Accuracy = 56/72 = 78%)

		GROUND				
		1	2	3	Totals	Users Acc.(%)
	1	11	4	0	15	73
PHOTO	2	5	18	5	28	64
	3	0	2	27	29	93
Totals		16	24	32	72	
Prod.Acc.(%)		69	75	91		

1:4000 SCALE ERROR MATRIX
(Overall accuracy = 54/72 = 75%)

		1	2	3	Totals	Users Acc.(%)
	1	12	4	0	16	75
PHOTO	2	4	16	6	26	62
	3	0	4	26	30	87
Totals		16	24	32	72	
Prod.Acc.(%)		75	67	81		

[a] numbers on margins refer to management options
Option 1: Re-site prepare and replant
Option 2: Spray for competition control
Option 3: Leave as-is

Table 21. Summary Table Comparing the Degree of Agreement Between Decision-Making at Two Different Photographic Scales

SCALE	k	Z	Comparison	Z
1. 1:6000	0.656	8.75**	1.& 2.	0.396
2. 1:4000	0.612	7.57**		

** significant at the alpha=.01 level

were significantly different, the Z value was found to be insignificant indicating that the error matrices were not statistically different. Neither scale of imagery, therefore, was found to produce better overall agreement with the decisions made from ground measurements. At both scales, the extreme decisions (i.e., whether to replant the areas, or leave the stand as-is) were predicted quite well. Correct decisions made in this regard could serve to eliminate a majority of the sample plots from any further investigation and require that only a small amount of follow-up ground sampling be necessary to establish the true status of the remaining areas.

Evaluation of Hard-To-Control Woody Competition

Following work on previous quantitative competition evaluation techniques, this qualitative approach to evaluating the level of hard-to-control woody competition in young loblolly pine plantations was examined. The basis of this technique was to compare a set of photo plots having a known percentage of total groundline basal area in hard to control species, to plots having unknown percentages. Six error matrices were prepared (Tables 22 and 23), one for each of two scales, at each of three cutoff levels (10, 20 and 30 percent).

It should be noted that overall accuracy figures (providing a simple ratio of the number of plots correctly

Table 22. Error Matrices Used to Compare Ground and Photo Based Classifications of Competition Type Using 1:6000 Scale Photography

10 Percent Cutoff (Overall accuracy=58%)

		GROUND			Users
		Over	Under	Total	Acc.(%)
PHOTO	Over	21	15	36	58
	Under	14	19	33	58
	Total	35	34	69	
	Prod.Acc.(%)	60	56		

20 Percent Cutoff (Overall accuracy=67%)

		GROUND			Users
		Over	Under	Total	Acc.(%)
PHOTO	Over	6	16	22	27
	Under	7	40	47	47
	Total	13	56	69	
	Prod.Acc.(%)	46	71		

30 Percent Cutoff (Overall accuracy=79%)

		GROUND			Users
		Over	Under	Total	Acc.(%)
PHOTO	Over	3	14	17	18
	Under	1	52	53	98
	Total	4	66	70	
	Prod.Acc.(%)	75	79		

Table 23. Error Matrices Used to Compare Ground and Photo-Based Classifications of Competition Type Using 1:4000 Scale Photography

<u>10 Percent Cutoff</u> (Overall accuracy=58%)

		GROUND			Users
		Over	Under	Total	Acc.(%)
PHOTO	Over	22	16	38	58
	Under	13	18	31	58
	Total	35	34	69	
	Prod.Acc.(%)	63	53		

<u>20 Percent Cutoff</u> (Overall accuracy=68%)

		GROUND			Users
		Over	Under	Total	Acc.(%)
PHOTO	Over	7	16	23	30
	Under	6	40	46	87
	Total	13	56	69	
	Prod.Acc.(%)	54	71		

<u>30 Percent Cutoff</u> (Overall accuracy=80%)

		GROUND			Users
		Over	Under	Total	Acc.(%)
PHOTO	Over	3	13	16	19
	Under	1	53	54	98
	Total	4	66	70	
	Prod.Acc.(%)	75	80		

interpreted, to the total number of plots) indicated that accuracy improved at both scales as the cutoff level increased to 30 percent. Apparently the higher cutoff level made it easier to discriminate between plots that clearly contained more, or less, hard-to-control competition. No real preference for a particular scale of imagery could be decided upon. Computed values for Cohen's coefficient of agreement indicated that even though overall accuracy was quite high, no error matrix indicated agreement between ground and photo determinations greater than would have occurred by chance (Tables 24 and 25). Also, comparing the degree of agreement between different cutoff levels at a given scale, and different scales at a particular cutoff level indicated no significant differences.

Summary

The percentage of plot area containing crowns of all woody competition was the best predictor of woody competition groundline basal area. Variability in the measurement of groundline basal area in the field may have contributed to its relatively poor prediction. The amount of hardwood crown area that was not imaged, due to partial leaf fall, undoubtedly also affected the results. Determining management courses of action from sampling Free-To-Grow status was successfully accomplished through photo interpretation. Four different photo interpretable

Table 24. Comparisons Between Degree of Agreement Using Three Levels of Cutoff at Two Photographic Scales

SCALE	CUTOFF LEVEL	k	Z^{a}	COMPARISON	Z^{a}
1:6000	1. 10 Percent	0.159	1.33	1 & 2	0.109
	2. 20 Percent	0.139	1.00	1 & 3	-0.254
	3. 30 Percent	0.213	1.21	2 & 3	-0.334
1:4000	1. 10 Percent	0.158	1.32	1 & 2	-0.202
	2. 20 Percent	0.195	1.41	1 & 3	-0.336
	3. 30 Percent	0.230	1.31	2 & 3	-0.154

a/ none of the test statistics were significant at the alpha=.05 level

Table 25. Comparisons Between Degree of Agreement Using Two Scales of Photography at Three Cutoff Levels

CUTOFF LEVEL	SCALE	k	z^{a}	COMPARISON z^{a}
10 Percent	1:6000	0.159	1.33	0.004
	1:4000	0.158	1.32	
20 Percent	1:6000	0.139	1.00	-0.286
	1:4000	0.195	1.41	
30 Percent	1:6000	0.213	1.21	-0.067
	1:4000	0.230	1.31	

a/ none of the test statistics were significant at the alpha=.05 level variables regarding the stand need to be ascertained for best prediction of Free-To-Grow categorization. Neither scale of imagery provided noticably superior results. Photo interpreting the level of hard-to-control woody competition did not improve on results that could be expected by chance.

SUMMARY AND CONCLUSIONS

This research was conducted to investigate the potential for obtaining accurate and reliable estimates of seedling density and levels of woody competition in young pine plantations, solely from large scale 35mm color aerial photography. The study plots were located in three, four and five year old loblolly pine plantations containing a wide range of woody competition amounts. The photographic equipment and the methods used to obtain the imagery were kept simple to encourage potential application of the procedures.

The investigation of factors affecting the photo interpretation process produced few unexpected results. It was found that generally taller seedlings were interpreted better and that larger amounts of all competition tended to hinder the interpretation of seedlings, at least at the 1:4000 scale. Larger amounts of competition (of any type) tended to have the effect of enhancing seedling interpretation when 1:6000 scale data was used. Scale itself as a factor was found to vary in its effects. More findings that favored the larger scale imagery were noted in the results, although most differences were slight.

The results indicated that it was possible to obtain sufficiently accurate and reliable estimates of ground obtained seedling counts from interpretation of aerial photography. Uncorrected photo interpreted seedling counts were within ten percent of ground counts in almost half of all plots examined. Predictions of ground counts from 1:6000 scale photography improved with the interpretation of the percentage of plot area containing visually distractive ground cover. Use of 1:4000 scale imagery should produce similar estimates without the necessity of interpreting this additional variable.

The use of aerial photography for reliable evaluation of woody competition was investigated. Groundline basal area in all woody competition was one measurement oriented approach examined although specific guidelines with regard to its application have not yet been established. The degree of accuracy that this variable can be predicted from photography appears to be within a range of values, perhaps in 5 or 10 square feet per acre classes. When more is determined about this variable's intended application it may be easier to evaluate the usefulness of these results.

Applicability of the Free-To-Grow classification system to indirectly evaluate competition in young plantaions is already recognized. The ability to adequately predict the number of trees per acre in various Free-To-Grow classes from aerial photography was found to be possible. It was apparent that the majority of all plots would be evaluated similarly using either the ground or the aerial technique.

Some degree of ground checking would probably be necessary in the plots designated as needing release if additional confidence in accuracy was required.

Assessing the level of hard-to-control competition in the plots achieved limited success. As implemented, the process was inexact and could not improve on results expected by mere chance. When this determination was made with regard to a relatively high cutoff level, results for this technique improved.

Findings of this study suggest several areas for future research. Both density estimation and prediction of Free-To-Grow classifications depended heavily on seedling interpretation. Although both the location and age factors were found to provide different results in seedling interpretation, reasons for these effects were not clearly established. Research into this topic could provide valuable information regarding potential application of these techniques. Investigation into other variables including, perhaps, the percentage of seedlings in well-defined rows, could provide additional strength to predictions of seedling density. The use of stereoscopic viewing of the imagery could perhaps enhance interpretation and measurement of both density and competition components and should be explored. Finally, as more decisive guidelines on the use of competition evaluation techniques, such as groundline basal area, are established, these photo interpretation techniques should be re-examined.

The need for reliable decision-making with the minimum allocation of field personnel and expense has encouraged the interest in alternative information gathering techniques. Large scale, small format aerial photography was found to provide useful information for pine plantation management. Using these techniques to estimate density and evaluate competition can provide results comparable to ground based methods, with the added advantages of increased coverage and sampling intensity. Although not intended as a total replacement for field techniques, use of aerial photography to at least supplement the information needed in the decision-making process has been shown to be effective. As refinements to these procedures are made, use of large scale, small format aerial photography in forest management should continue to increase.

LITERATURE CITED

Aaltonen, V.T. 1926. On the space arrangement of trees and root competition. Jour of For 24(6): 627-644.

Aldred, A.H. and J.K. Hall. 1975. Application of large scale photography to a forest inventory. For Chron 51(1): 1-7.

Aldrich, R.C., W.T. Bailey and R.C. Heller. 1959. Large scale 70mm color photography, technology and equipment and their application to a forest sampling problem. Photo Eng 25(5): 747-754.

Amateis, R.L., H.E. Burkhart and S.M. Zedaker. 1983. The loblolly pine spacing studies - a progress report. School of Forestry and Wildlife Resources, Virginia Polytechnic and State Univ. Cooperative Report No.23. 6p.

Bacon, C.G. and S.M. Zedaker. 1984. First year growth response of young loblolly pine to competition control on the Virginia piedmont. In: Proceedings of the 3rd Biennial Southern Silvicultural Research Conference, Atlanta, Georgia. p 309-314.

Baker, R.D. and D.V. Smith. 1974. Aerial photograph use in industrial forest management in the south, 1970 and 1974. Texas Forestry Paper No.24, School of Forestry, Stephen F. Austin Univ., Nacogdoches, Texas. 6p.

Becking, R.W. 1959. Forestry applications of aerial color photography. Photo Eng 25(9): 559-565.

Bella, I.E. 1969. Competitive influence-zone overlap: a competition model for individual trees. Bi-monthly Research Notes, Ottawa. 25(3): 24-25.

Bella, I.E. 1971. A new competition model for individual trees. Forest Sci 17(3): 364-372.

Bernstein, D.A. 1974. Are reforestation surveys with aerial photos practical? Photo Eng and Rem Sens 40(1): 69-73.

Campbell, C.D. 1981. The potential of using 35mm aerial photography to estimate seedling survival of pine plantations in the Southeastern coastal plain. Masters Thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 92p.

Campbell, C.D. and R.A. Mead. 1980. Seedling survival estimates using 35mm aerial photography: a new approach. 1st Biennial Southern Silvicultural Research Conference, Atlanta, Georgia. 4p.

Clegg, R.H. and J.P. Scherz. 1975. A comparison of 9-inch, 70mm and 35mm cameras. Photo Eng and Rem Sens 41(12): 1487-1500.

Cohen, J. 1960. A coefficient of agreement for nominal scales. Educational and Psychological Measurement. 2(1): 37-40.

Dierauf, T.A. and J.W. Garner. Virginia Division of Forestry, Charlottesville, Va.,Unpublished Informational Report. 2p.

Douglas, R.W., M.P. Meyer and D.W. French. 1972. Remote sensing applications to forest vegetation classification and conifer vigor loss due to dwarf mistletoe. Final report for Earth Resources Survey Program - NASA. School of Forestry, Univ. of Minnesota, St.Paul, Minn. 93p.

Gerrard, D.J. 1969. Competition-quotient: a new measure of the competition affecting individual forest trees. Research Bulletin No.20, Michigan State Univ., Lansing, Mich. 32p.

Goba, N., S. Pala and J. Narraway. 1982. An instruction manual on the assessment of regeneration success by aerial survey. For: Forest Research Group, Ministry of Natural Resources. Ontario Centre for Remote Sensing, Ministry of Natural Resources, Ottawa, Canada. 49p.

Hagen R.T. and M.P. Meyer. 1977. Remote sensing as related to black bear habitat, spruce budworm damage and plantation release appraisals on the Superior National Forest. IAFHE RSL Research Report 77-4. University of Minnesota, St.Paul, Minn. 24p.

Haig, I.T. 1931. The stocked quadrat method of sampling reproduction stands. Jour of For 29: 747-749.

Heller, R.C., R.C. Aldrich and W.F. Bailey. 1959. Evaluation of several camera systems for sampling forest insect damage at low altitude. Photo Eng 25(1): 137-144.

Heller, R.C., R.C. Aldrich, W.F. McCambridge and F.P. Weber. 1969. The use of multispectral sensing techniques to detect ponderosa pine trees under stress from insect and disease. Progress Report for the Earth Resources Survey Program - NASA. USDA Forest Service Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif. 59p.

Isaev, V.I. 1975. Dimensions of sampling plots for determining survival in plantations. Les Khoz 2: 38-39.

Jensen, M.S. and M.P. Meyer. 1976. A remote sensing applications program and operational handbook for the Minnesota DNR and other state agencies. IAFHE RSL Research Report No. 76-2. Univ. of Minnesota, St.Paul, Minn. 96p.

Klein, W.H. 1970. Mini-aerial photography. Jour of For 68(8): 475-478.

Latham, R.P. 1972. Competition estimator for forest trees. Photo Eng 38(1): 48-50.

Loetsch, F., F.Zohrer and K.E. Haller. 1973. Forest Inventory. Vol. 2. 469p.

Lowdermilk, W.C. 1921. A unit of area as a unit of restocking. USDA Forest Service, District 1. Applied Forestry Notes 17. 3p.

MacLeod, D.A. and M.A. Chaudhry. 1979. A field comparison of distance and plot methods for regeneration surveys. For Chron 55(2): 57-61.

Mead, R.A. and D.A. Raspberry. 1980. Current use of remote sensing by foresters in the south. So Jour of Appl For 4(3) 143-147.

Meyer, M.P. 1973. Operating manual - Montana 35mm aerial photography system (1st revision). Univ. of Minnesota, College of Forestry. IARSL Research Report 73-3. 50p.

Myers, B.J. 1974. Stocking assessment in young pine plantations using 70mm aerial photographs. Aus For Res 6(3): 35-42.

Myers, R.H. 1986. Classical and Modern Regression With Applications. Duxbury Press, Boston, Mass. 359p.

Nelson, H.A. 1976. Assessment of Forest plantations from low altitude aerial photography. 11th International Symposium on Remote Sensing of the Environment, Ann Arbor, Michigan. p1515-1522.

Opie, J.E. 1968. Predictability of individual tree growth using various definitions of competing basal area. Forest Sci 14(3): 314-323.

Slama, C.C. 1980. Manual of Photogrammetry. American Society of Photogrammetry, Falls Church, Virginia. 4th Edition. 1056p.

Smith, D.M. 1962. The Practice of Silviculture. 7th edition. John Wiley and Sons, Inc., New York. 578p.

Smith, W.D. 1983. Evaluating regeneration success in plantations using distance sampling. In: Proceedings of 2nd Biennial Southern Silvicultural Research Conference, Atlanta, Georgia. p312-314.

Snedecor, G.W. and W.G. Cochran. 1980. Statistical Methods (7th ed.). The Iowa University Press. 507p.

Spurr, S.H. 1960. Photogrammetry and Photo-interpretation. The Ronald Press Co., New York. 472p.

Stein, W.I. 1973. What do we mean by stocking? In: Proceedings of the 1973 Annual Meeting of the Western Reforestation Coordination Committee, Portland, Oregon. Western Forestry and Conservation Association. p105-109.

Stenaker, G.A. and J.M. Jarvis. 1963. A preliminary study to assess competition in a white spruce - trembling aspen stand. For Chron 39(3): 334-336.

Story, M. and R.G. Congalton. Accuracy assessment:a user's prospective. Photo Eng and Rem Sens 52(3):397-399.

Swinford, K.R. 1965. Plantation measurements. In: A guide to loblolly and slash pine management in Southeastern USA. Georgia Forest Research Council, Macon, Georgia. Report No.14. p169-184.

Todd, S.D. 1983. Champion International free-to-grow classification. Champion Research Note SE-84-01.

Weih, R.C., G.D. Nord and M.P. Meyer. 1984. Application of 35mm aerial photography to evaluate post-harvest aspen regeneration. IAFHE RSL Research Report 84-2. 26p.

Wert, S.C. and B.E. Wichman. 1968. White fir stands killed by tussock moth - 70mm color photography aids detection. USDA Forest Service, Pacific S.W. Forest and Range Experiment Station. Research Note DSW-168.

Willingham, J.W. 1959. Obtaining vertical aerial photographic coverage with a 35mm camera. Jour of For 57(2): 108-110.

Willis, J.R. 1978. Cheasapeake Corporation of America pine seedling classification. Cheasapeake Inventory Manual.

Wolf, P.R. 1974. Elements of Photogrammetry. McGraw Hill Inc., New York. 562p.

Zedaker, S.M. 1982. The competition-release enigma: adding apples and oranges and coming up with lemons. In: Proceedings of 2nd Biennial Southern Silvicultural Research Conference, Atlanta, Georgia. p357-364.

Zedaker, S.M., R.C. Freyman, C.G. Bacon and P.L. Burch. 1985. The Dow Chemical project report. Virginia Polytechnic and State Univ., Department of Forestry. 41p.

Zsilinszky, V.G. 1969. Supplementary aerial photography with miniature cameras. Photogrammetria 25(1): 27-38.

APPENDIX A. GROUND OBTAINED AND PHOTO ESTIMATED DENSITY DATA

LOC.[a]	AGE	GROUND DENSITY	1:6000 DENSITY	DIFF.[b]	DIFF. (%)[c]	1:4000 DENSITY	DIFF.	DIFF. (%)
1	3	54	41	-13	-0.24	59	5	0.09
	3	80	57	-23	-0.29	98	18	0.23
	3	69	42	-27	-0.39	78	9	0.13
	3	90	45	-45	-0.50	113	23	0.26
	3	46	54	8	0.17	65	19	0.41
	3	112	50	-62	-0.55	126	14	0.13
	3	88	72	-16	-0.18	90	2	0.02
	3	84	63	-21	-0.25	98	14	0.17
1	4	117	127	10	0.09	106	-11	-0.09
	4	164	123	-41	-0.25	85	-79	-0.48
	4	167	104	-63	-0.38	138	-29	-0.17
	4	245	119	-126	-0.51	162	-83	-0.34
	4	176	126	-50	-0.28	146	-30	-0.17
	4	148	96	-52	-0.35	113	-35	-0.24
	4	156	127	-29	-0.19	111	-45	-0.29
	4	130	88	-42	-0.32	88	-42	-0.32
1	5	31	60	29	0.94	52	21	0.68
	5	46	58	12	0.26	59	13	0.28
	5	27	42	15	0.56	34	7	0.26
	5	52	65	13	0.25	71	19	0.37
	5	44	58	14	0.32	68	24	0.55
	5	54	43	-11	-0.20	61	7	0.13
	5	48	44	-4	-0.08	57	9	0.19
	5	36	39	3	0.08	43	7	0.19
2	3	103	113	10	0.10	124	21	0.20
	3	81	89	8	0.10	88	7	0.09
	3	65	75	10	0.15	84	19	0.29
	3	78	72	-6	-0.08	74	-4	-0.05
	3	61	69	8	0.13	67	6	0.10
	3	106	123	17	0.16	111	5	0.05
	3	112	116	4	0.04	122	10	0.09
	3	110	116	6	0.05	101	-9	-0.08
2	4	100	150	50	0.50	162	62	0.62
	4	118	171	53	0.45	184	66	0.56
	4	110	112	2	0.02	118	8	0.07
	4	126	150	24	0.19	152	26	0.21
	4	168	183	15	0.09	187	19	0.11
	4	140	157	17	0.12	176	36	0.26
	4	137	149	12	0.09	160	23	0.17
	4	143	130	-13	-0.09	140	-3	-0.02

LOC.	AGE	GROUND DENSITY	1:6000 DENSITY	DIFF.	DIFF. (%)	1:4000 DENSITY	DIFF.	DIFF. (%)
2	5	89	102	13	0.15	104	15	0.17
	5	84	101	17	0.20	105	21	0.25
	5	87	89	2	0.02	95	8	0.09
	5	101	102	1	0.01	122	21	0.21
	5	140	143	3	0.02	130	-10	-0.07
	5	101	105	4	0.04	101	0	0.00
	5	138	139	1	0.01	127	-11	-0.08
	5	136	99	-37	-0.27	93	-43	-0.32
3	3	150	144	-6	-0.04	144	-6	-0.04
	3	126	134	8	0.06	131	5	0.04
	3	114	116	2	0.02	125	11	0.10
	3	146	148	2	0.01	152	6	0.04
	3	144	137	-7	-0.05	134	-10	-0.07
	3	138	150	12	0.09	141	3	0.02
	3	126	117	-9	-0.07	121	-5	-0.04
	3	136	134	-2	-0.01	141	5	0.04
3	4	174	197	23	0.13	194	20	0.11
	4	171	178	7	0.04	173	2	0.01
	4	228	224	-4	-0.02	223	-5	-0.02
	4	169	187	18	0.11	187	18	0.11
	4	180	152	-28	-0.16	175	-5	-0.03
	4	140	150	10	0.07	147	7	0.05
	4	162	170	8	0.05	165	3	0.02
	4	168	195	27	0.16	186	18	0.11
3	5	157	138	-19	-0.12	159	2	0.01
	5	141	141	0	0.00	158	17	0.12
	5	172	163	-9	-0.05	154	-18	-0.10
	5	126	118	-8	-0.06	128	2	0.02
	5	155	140	-15	-0.10	153	-2	-0.01
	5	146	126	-20	-0.14	132	-14	-0.10
	5	147	149	2	0.01	142	-5	-0.03
	5	155	146	-9	-0.06	142	-13	-0.08

a/ location

b/ DIFFERENCE = photo count - ground count

c/ difference expressed as percentage of ground count