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As part of the effort to evaluate TRIM (Timber Resource Inventory Model) for the next RPA National Assessment, a study was conducted using natural pine stands in North Carolina. TRIM has been used for regional timber supply studies in both the Pacific Northwest and the South (Southern Timber Supply Study). The model results are tools used for economic planning and policy making for regions in which timber is part of the economic base. TRIM uses yield tables arrayed by age class in the inventory projection calculations. The application of yield tables in TRIM can potentially alter the results of regional timber supply analysis. The objective of this study, is to investigate the TRIM growth mechanism and examine the effects of empirically derived yields on TRIM projections. In this process, different levels of data aggregation were compared and two other types of yield tables were developed and evaluated. Model projections were

based on growth and inventory estimates derived from two successive Forest Inventory and Analysis (FIA) inventories. Simulation runs took into account "approach to normality", acreage shifts, and timber removals over the range of age classes as described by field measurements. Results were evaluated based on their comparison to FIA field measurements. In most simulations, TRIM growth and inventory projections were substantially below the growth and inventory values calculated from the FIA data. The projections varied with the yield tables used, but higher yields produced the most favorable results. For a North Carolina timber supply study, these results would indicate a sharp decline in the supply of natural pine which is the opposite of what was recorded in the field. This study suggests that empirical yield curves do not represent aggregate stand growth when stands have the characteristics found in North Carolina's natural pine.

An Evaluation of an Inventory Projection System:
TRIM Model Predictions vs.
Forest Inventory Field Measurements in North Carolina

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INTRODUCTION

Background

In 1974 Congress passed the Forest and Rangeland Renewable Resources Planning Act (RPA). This act mandated the USDA Forest Service to make a periodic assessment of the long-term supply and demand of timber resources in the United States. Included in the Assessment is an analysis of a 50 year projection that is used to evaluate the effects of alternative government policies on timberland commodities. National and regional trends in forest products consumption, production, and prices, are of interest to federal and state planning agencies, members of congress, forest and related wood products industries, and individuals seeking timber supply and demand forecasts.

The current method of making projections employs two models which work together to find an equilibrium between supply and demand. This method uses the TAMM model (Adams and Haynes 1980) as a tool to provide long range timber demand projections. In the past TRAS (Larson and Goforth, 1974) has been the timber supply model which projects long range effects of demand on aggregate timber inventories. In the next Assessment TRAS will be replaced by the Timber Resource Inventory Model (TRIM) (Tedder et al. 1987). TRIM is currently being used with TAMM in the Southern Timber Supply Study coordinated by the USDA Forest Service for 12 Southern states.

Initial TRIM inventory projections in the Southeast indicate a sharp growth decline in the softwood timber types. According to Knight (1985) growth in the Southeast has reached a peak and begun to decline. But TRIM projected annual growth started 18 percent (500 million cubic feet) below the current growth rate as calculated by the Forest Inventory and Analysis (FIA) researchers. The FIA growth was based on field measurements of permanent inventory plots. The FIA and TRIM researchers checked their calculation methods, but no errors could be found.

Objectives

This study will investigate the relationships between TRIM projected and the field measured growth. The difference between projected and measured growth has two possible causes.

First, the possibility exists that the FIA measured growth is not the same thing as TRIM calculated growth. This would be a definitional problem over the meaning of the word "growth".

Second, regional projections require inventory and management information to be highly aggregated (averaged). It is possible the averaging which occurs in aggregation suppresses a growth element of stand dynamics which could be measured at the sample plot level but is not being reported by TRIM.

Objective Statement

The objective of this study is to determine, by the analysis of growth calculation methods in conjunction with TRIM simulations, if

TRIM growth and inventory predictions can match field measured values. This study will attempt to answer the following questions:

1. Is the difference in TRIM predicted growth and FIA predicted growth due to the difference in how each is calculated or possibly defined (i.e. inventory could be projected correctly even if the two growth estimates did not match)?
2. Does the level of data aggregation bias TRIM growth and inventory calculations?
3. Does the TRIM growth calculation method need to be redefined or modified (in the model)?

The TRIM Model

Previous Assessments have used TRAS/TAMM for projections. TRAS uses a diameter class projection system to model large aggregations of timberland inventory. Tedder (1983) and Brooks (1984) have criticized the TRAS model because it does not recognize individual species types and sites, and has difficulty modeling alternative management scenarios.

TRIM is a yield table projection system which uses age classes rather than diameter classes to model timber stands over time. It has been used for several regional timber supply studies. Flick (1984) used TRIM to model private softwood timber supplies in the Pacific Northwest. Data Resources, Inc. (1985) used TRIM to model the timber supply situation for 12 Southern states. The Southern Timber Supply Study for which TRIM/TAMM is being used has been in progress since late 1983 (results due in early 1987). (For more background about TRIM see the Appendix.)

The TRIM Inventory

The starting TRIM timber inventory is aggregated into modules which share the same characteristics. In regional supply studies these characteristics include species type, site class, and ownership group. Within each module, the inventory volume and its associated acres are represented by 18 age classes and three stocking classes. In other words, a module has the potential to carry acres and volume per acre in 54 different cells. Each of these cells may be the average volume per acre and total acres from several individual timber stands (for an example inventory see Figure 20 in Appendix). It should be noted that the inventory within a module can be partitioned into a total of 5 management intensity classes with 54 cells each. The model uses the same principles to simulate management in each of the 5 management categories, so for discussion, the basic functions of the category used in this study will be explained.

During a simulation TRIM applies a set of management parameters to the inventory module which advance the acres ahead in time. All of the acres in a module share the same yield, harvest, regeneration, and acreage shift parameters. TRIM could be considered an "open framework" since all of these parameters must be supplied by the user.

The Yield Table

The heart of the TRIM projection mechanism is the yield table. The yield table plays a direct role in the growth calculation of current and future timber inventories. If TRIM has a problem calculating growth, it will be the yield table or its application which will be at fault. Therefore, this part of the discussion will focus on yield table theory and the TRIM application of the yield table.

Yield tables have been used since the 18th century to predict growth and volume (Spurr 1952). Chapman (1924), Spurr (1952), and others (Brender and Clutter 1970, Buckman 1962, and Pienaar and Shiver 1986) find site, stand age, and stand density to be highly correlated with stand growth and potential yield. Like the inventory in TRIM, the yield table volume per acre is arrayed by 18 age classes for a specific species type and site. Stocking density is used to calibrate inventory volume to the associated yield table volume per acre.

Two basic types of yield tables are described by Chapman (1924) and Spurr (1952). They are called "normal" and "empirical" yield tables which are different representations of a volume measure by stand age (see example of yield table in Figure 2). The normal yield table is supposed to represent volume per acre for <u>fully stocked stands</u> of timber within a site class. The normal yield curves would be derived from the very best <u>undisturbed</u> stands in a class of timber. They would represent the highest growth attainable for the particular timber class.

In contrast, the empirical yield curve represents the <u>current</u> (or average) condition of a particular timber class. Empirical yields would be derived by measuring the volume per acre (by age) for a <u>range of stocking densities</u> within a site class, and averaging them.

Farrar et al. (1986) report that the true normal yield table has little value to the forest manager since the "normal" stands are rarely encountered in the field which makes them hard to apply to most stands, which are less densely stocked. They report on a variation of the normal yields called "well-stocked" yield tables. The well-stocked yield tables are supposed to have an advantage over the normal yield tables because lower than "normal" (but above average) stand densities are used in their development. The well-stocked condition is more often found in the field and considered a management option than is the "normal" condition.

The term "well-stocked" is used by Schumacher and Coile (1960) to describe the type of yield tables which they derived for southern pines from measurement plots in well-stocked stands. They use the term stocking as a measure of a stand's ground area utilization based on diameter class, trees per acre, and basal area per acre standards. Well-stocked stands are those considered stocked 100 percent and above. Their yield tables were developed from plot measurements taken in well-stocked stands and then aggregated by species, site, and age.

McClure and Knight (1984) follow the "well-stocked" method to develop what they call empirical yields for southern pines. They use the term "fully-stocked" (which has been associated with normal yield tables) to describe stands 100+ percent stocked. This is a variance from the definitions of both empirical and normal yields given above. For use in this paper it is assumed that the yields of McClure and Knight fit the "well-stocked" definition of Schumacher and Coile. Further use of the term "empirical yields" in this paper will refer to the "well-stocked"/"fully-stocked" method of yield table development.

The Yield Table in TRIM

Both types of yields have been used for regional TRIM simulations. The yield tables used in TRIM for the Southern Timber Supply Study were empirical under the "well-stocked" definition. In a study of the Pacific Northwest-Westside, Flick (1984) used what he called normal yield tables to model timber supplies in the Douglas-fir region. He argued that true empirical yields include stands which have been subject to previous volume reducing disturbances. Their current volume would not be an indication of the potential for undisturbed stands of the same age.

The yield tables in a TRIM simulation guide inventories by using relative volume stocking percentages to calibrate the changes in yield table volume over time to the inventory. In the beginning of the simulation, the starting inventory volume per acre is divided by the appropriate yield table volume in each age class, thus each age class in the starting inventory is "calibrated" to the yield table. In each subsequent period of simulation, stand volume is calculated by applying the stocking percentage to the yield table volume in the next age class. Chapman (1924) explains this technique as a method to create a meaningful relationship between a normal yield curve and an actual inventory.

It should be noted that the volume stocking used to calibrate the yield table to the inventory in TRIM is not the same as the Forest Survey definition of stocking as measured in the field (see McClure and Knight 1984). The Forest Survey definition and most stocking densities referred to in the literature, are based on site utilization. This is a basal area - tree density relationship which is calculated with plot level information. The definition used in describing TRIM stocking is strictly a net volume ratio (inventory volume per acre divided by yield table volume per acre). McWilliams and Birdsey (1986) report that when aggregating a large number of plots, this field measure of stocking relates directly to a volume production measure of stocking. Therefore, at the aggregate level the two types of stocking measure could be considered comparable.

Net growth in TRIM is simply the vertical change in position on a net yield curve from one age class to the next (mathematical derivative of the yield curve). Stands make this change in each simulation period based on their relative stocking percent of yield table volume. Spurr (1952) explains that net yield tables represent net growth but cautions that parameters used in developing the yield tables must be consistent and stand density must be precise. Buckman (1962) describes yield as increments of growth and Clutter (1963) used the term "compatible growth and yield" for a loblolly pine model for which yield could be derived as the mathematical integration of the growth function.

Approach to Normal

Chapman (1924) stated that when using normal yield curves for a single stand, over time the relative stand density could be expected to approach the normal stocking density. This is the concept which assumes stands will naturally tend to fully utilize available growing conditions (Brooks 1984).

Much work was done on this concept in the 1930's (Clutter 1963). Chaiken (1939) studied data from remeasured Virginia and loblolly pine plots and found that older stands were closer to normal stocking than younger stands. The younger stands approached normal stocking faster than older understocked stands, and poorly stocked stands approached normal faster than better stocked stands. Schumacher and Coile (1960) examined stocking trends from remeasured loblolly pine plots in

North Carolina and found that these stands asymptotically trended towards 100 percent stocking.

During a TRIM simulation stands can be allowed to make improvements in stocking through an approach-to-normal function. This function adjusts the relative stocking percent based on user supplied parameters. The stocking adjustment is consistent with the ideas presented above, i.e. the rate of adjustment to understocked stands is faster than that of better stocked stands, and younger stands approach normal faster than older stands (for the form of the function see the Appendix).

The stocking of <u>regenerated</u> stands begins at a stocking percentage supplied by the user. The approach-to-normal function adjusts this stocking percentage each period in the same way it does for the starting inventory. To find this regeneration stocking level, Flick (1984) calculated the average stocking ratio for just the stands in the first 3 age classes (age 1 to 30) and discounted the stocking back to the first age class with an inverse form of the approach-to-normal function. He argued that these younger stands are representative of current regeneration management techniques and that older stands would have had their volumes reduced by cutting or other disturbance. Meanwhile, in the Southern Timber Supply Study the volumes of all stands represented under the yield table were used calculate the regeneration stocking percentage.

Growth on Harvest

The final way which TRIM calculates growth is through growth-on-harvest. Barber (1985) reported that the sequencing of harvest may bias the inventory volume available to harvest when inventories are represented in age classes. TRIM takes the harvest at the beginning of the simulation period and then adds growth to the residual inventory. It is assumed that the timber stands in each age class are evenly distributed over all 5 or 10 actual ages within the age class. If the acres in the said age class were to be harvested over a 5 or 10 year period then one would assume that the oldest acres in the age class would be harvested each year.

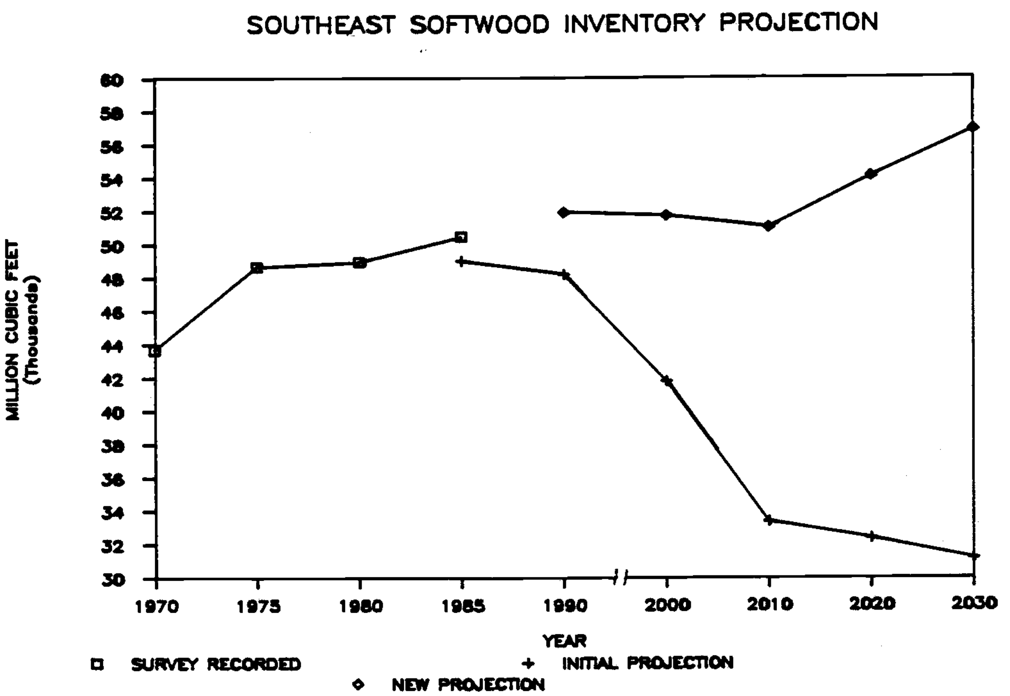
Currently the yield tables in TRIM represent midpoint values but under the above harvest scenario the acres being harvested should produce endpoint volumes. Therefore, growth-on-harvest "grows" all of the current inventory volume per acre values ahead half of a period and harvest is satisfied with the higher "endpoint" volume per acre values. The net effect is that less acres are harvested to fulfill the volume request.

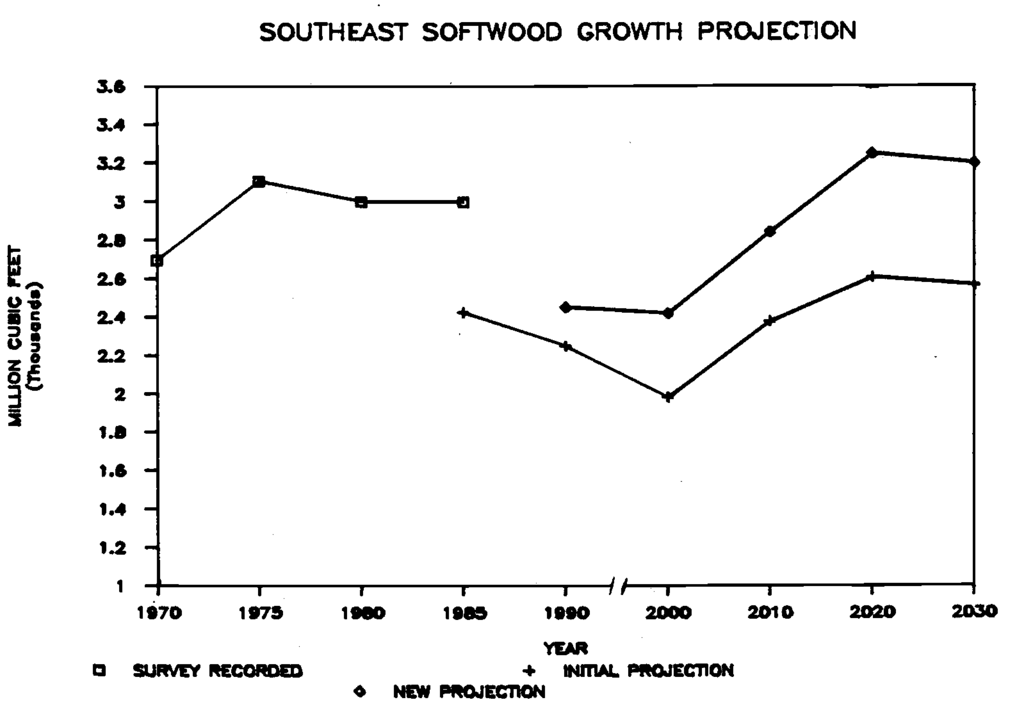
The TRIM model used in this study did not report this actual reduction in the removal as "growth". But since this is growth, it was calculated and included in the results presented later.

Problem Definition

Early results from the Southern Timber Supply Study were predicting a growth decline in the Southeast which the field measurements did not support. TRIM predicted an immediate drop-off in the inventory growth of Florida, Georgia, North and South Carolina, and Virginia. Figure 1 illustrates this growth "drop-off" as a mismatch between the historical and predicted growth values in 1984. The low level of growth calculated by TRIM contributed to a major decline in the

Figure 1. Southern Timber Supply Study TRIM projections of Southeastern inventory and growth made with empirical yield tables





projected inventory.

This decline was of concern to the FIA leaders at the Southeastern Forest Experiment Station in Asheville, North Carolina and many state and private representatives of forestry. Growth seemed off by as much as 35 percent for individual species-owner types when compared with plot growth data (Herb Knight 1985, personal communication). For the combined SE inventory 1985 growth was 29 percent below the USDA (1980) RPA Projections. This difference amounted to 1 billion cubic feet of net annual growth.

Though the difference between the historical and projected growth is quite large, the reason for it could not be found. The field data was examined and the model was checked, yet nothing could be found to suggest either data or method errors in the inventory data or in the model. The issue became polarized between those who believed the model and those who supported the FIA growth numbers. The source of the problem was not understood and methods implemented to boost growth were only partially successful.

It is important to remember that model projections are rarely right on target. Buchman and Shifley (1983) review the literature concerning the evaluation of growth and yield models. They found most authors agree that no projection system can perfectly represent the real system being modeled. One must assume a margin of error in both the inputs (field measured inventory, and harvest) and the outputs (projected growth and inventory). Little is to be gained from proving that a projection system is an inexact copy of nature, what is more important is how well the model meets the user's objectives. The question must be asked, how well should TRIM projected growth match up with field measured growth?

TRIM has not been validated, and the sensitivity of inventory to changes in growth are not known. TRIM's primary function with TAMM is to produce timber inventories, and not growth (TAMM does not use the TRIM growth reported). Reynolds (1984) presents a mathematical approach to model validation and says that before a model can be used with confidence, an effort must be made to determine how well the model can predict the characteristics of interest in a real system. Any attempt to validate TRIM must an approach which investigates the relationships between growth, inventories, and removals in both the model and in the field measurements.

Problem Statement

To satisfy the objectives, the problem was divided into three areas of investigation:

1. First is the possibility that TRIM is computing growth correctly and the FIA is also computing growth correctly but each is a different measure of growth. This would be seen as a definitional problem of the word growth. One method of prediction may estimate one particular type of growth, while another may give valid results for another aspect of growth (Spurr, 1952).

2. Second, is the level of acre aggregation required to model an entire timber producing region affecting the ability of the model to project growth which is based on individual tree measurements? Combining acres under a yield table may have an undesirable affect

on yield-table-based growth.

3. The third possibility is that TRIM is predicting an actual growth decline which is occurring in the field. Based on the latest Forest Surveys, net annual growth of softwood timber in the South has peaked after a long upward climb and is now turned downward (Knight 1985). TRIM's initial projection would indicate this trend will be much more severe than now assumed.

METHODS

As a means of accomplishing the objectives an experiment was designed to examine TRIM's predictive ability by comparing model projections to field measurements. TRIM was used to project a timber inventory over the 10-year inventory remeasurement period for the state of North Carolina (1974 to 1984). The objective in setting up the TRIM simulations was to model what was reported to have occurred in the field as closely as TRIM inputs would allow. The Survey data was assumed to represent what actually occurred in the field (within the respective sampling error).

TRIM projections were evaluated based on the difference between the model's projected 1984 inventory and the field measured 1984 inventory (target inventory). TRIM projected growth and field measured growth were examined and compared. The TRIM inventory projection figure is more important than the growth figure to the demand model in regional study. But growth is a component which cumulatively builds future inventories and its importance in TRIM will be examined.

Evaluation Criteria

1. A successful TRIM inventory projection would be one for which the projected inventory was within the sampling error bounds around the field measured inventory. This would also be the case for a successful growth projection but due to the possibility that there is a definitional problem between the two numbers, the sampling error bound was not required to be met for a successful run. It

was determined to be more important to explain any differences in growth as a means of accomplishing the objectives.

2. A marginal projection would be one in which the error region around the field inventory overlapped the error region around the TRIM projected inventory (assumed to be the same percent error as the field sample). It could be argued that a model could predict "true" growth and still be outside the target inventory error bounds provided the true starting and ending field inventories were at the opposite extremes of their error boundaries.

3. An unsuccessful projection would provide an inventory outside of any error overlap between the projected and measured values. Even if projected growth was within the error around the field value the simulation would be considered unsuccessful (this would indicate a growth definition problem).

TRIM simulations were examined with the above criteria under four different inventory aggregation schemes (shown below). The natural pine species type was used in all four schemes. Natural pine was chosen because it is better represented through age 90 than was planted pine, there were more acres of natural pine recorded than any other natural type, and there is and abundance of literature dealing with the species that make up this type (loblolly pine being the most important).

The following four basic sets of TRIM simulations were developed using the natural pine species type in North Carolina:

Aggregation Schemes

1	2	3	4
Survey Unit 3	Survey Unit 3	Statewide	Statewide
NIPF Owner	NIPF Owner	All Owners	All Owners
Natural Pine	Natural Pine	Natural Pine	Natural Pine
3 Sites	Aggregate Site	3 Sites	Aggregate Site

The survey unit and statewide schemes represent two levels of geographic aggregation. Survey Unit 3 is in the Piedmont region of North Carolina and contains about a third of the state's softwood volume (see discussion in Appendix).

Aggregating by 3-sites vs. 1-site will be examined to fulfill the objective of investigating affects of inventory aggregation. The two site class levels represent the aggregation of inventory data by productivity classes (as defined by the Forest Survey in Appendix). The 3-site vs. 1-site projection will be evaluated based on how well each meets the success levels in the criteria. If both projections meet the same criteria it will be assumed, for the said setup, that aggregation had no affect on the outcome. The criterion will only be applied within a geographic region because comparing aggregation at the state level to aggregation at the survey unit level is not a valid use of the criterion since these are two different inventories. However, the outcome between the geographic aggregations will be compared and discussed.

The period length of the TRIM simulation was set to 5 years. Therefore, all TRIM run parameters were developed on the basis of a 5-year cycle, i.e. harvest, yields, land shifts etc. Two complete cycles would be required for the model to get from 1974 to 1984. The midpoint year would be 1979.

The Data

The Southeastern Forest Experiment Station, Asheville, North Carolina provided the 1974 and 1984 North Carolina inventories. Upon receiving the inventory data it was aggregated to the levels found in the publications by Knight and McClure (1975) and Sheffield and Knight (1986) and checked for accuracy. Each inventory included net growing stock, growth, removals, mortality, and the associated acres by geographic location, owner, species, stand age, and stocking percent. The 1974 inventory was used to make up the TRIM input decks using the same methods which will be used for the 1989 Assessment. The 1984 inventory was aggregated under the above 4 schemes and used as the "target" to compare and evaluate TRIM projections.

The TRIM Inventory

For the TRIM simulation, the growing stock inventory was aggregated into the Basic Resource Unit (BRU module) which represents an aggregation of acres which share the same characteristics. The BRU's contain acres and volume per acre arrayed by 18 five-year age classes over three stocking levels. Early in this study it was determined that carrying one average stocking level produced the same results as did carrying three stocking individual classes. Therefore, the North Carolina BRU's carry the inventory by 18 five-year age classes in one stocking class.

A total of four BRU's were developed at the state level, and four were developed at the survey unit level. A BRU was developed for the inventory in each site class. Thus, inventory was represented by three BRU's under the 3-site aggregation scheme and one BRU under the 1-site scheme.

Management

Growth and yield of the inventory is controlled by the Grouped Resource Unit (GRU) input file. A GRU was developed to represent the management of each BRU. The GRU yield tables, growth on harvest parameters, and regeneration stocking levels came from the 1974 data. Harvest parameters and area change information came from the 1984 data.

In each GRU is the yield table which interacts with the BRU inventory and the approach-to-normal function. Two different types of yield tables were used in the above simulation hierarchy. These were empirical yield tables derived from fully stocked inventory volume plots, and growth yield tables derived from growing stock growth measurements. All yield tables were specific to a site class and developed from data within that site class. (The growth and empirical yields used for this analysis are shown in Figures 21 and 22 in the Appendix.)

Empirical yields were derived by plotting the average volume per acre by age class of fully stocked (100-132 percent) natural pine stands and running a freehand curve through the points. Multiple regression techniques produced r-squared values of 0.75 to 0.97 but were not well behaved at the endpoints. An example of an empirical yield table developed for North Carolina can be seen in Figure 2.

Growth yields were developed as an alternative to empirical yields. The idea behind them was to compare the growth measured on

Figure 2. Empirical yield table plotted with the fully stocked stands from which it was made

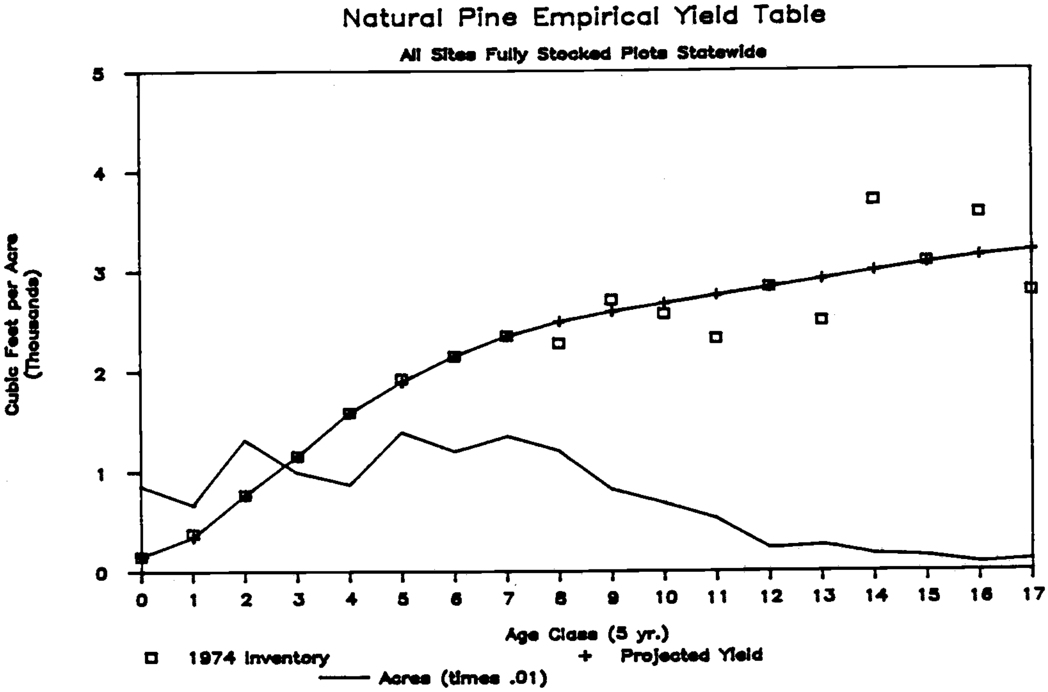
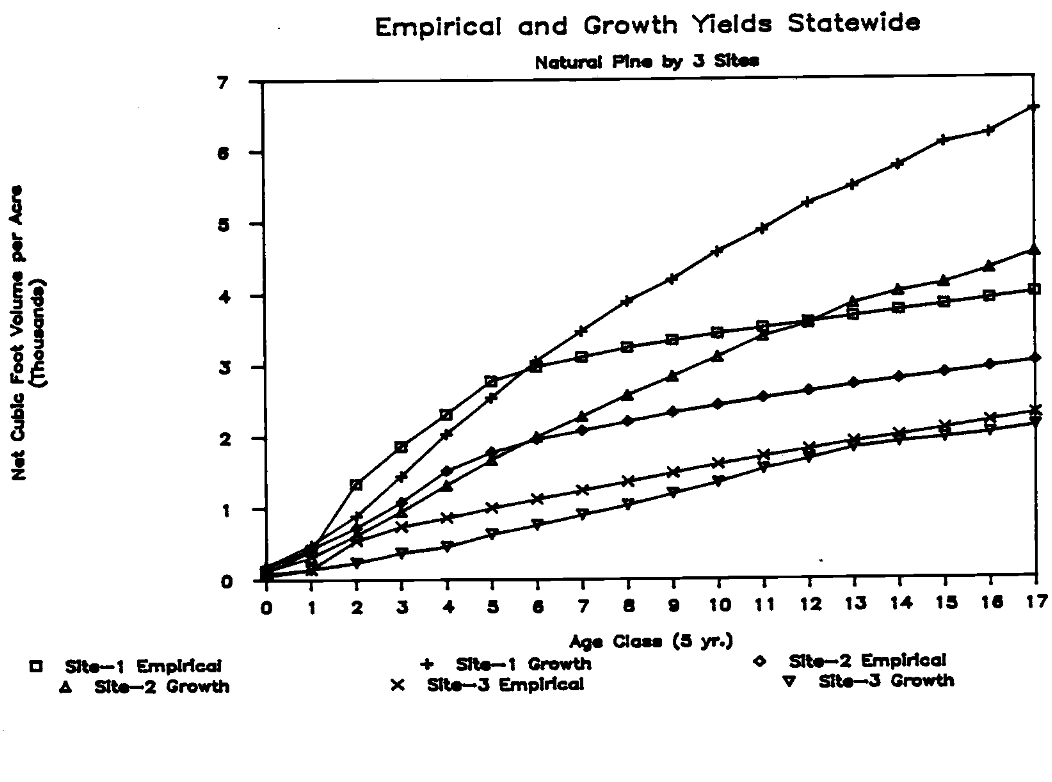


Figure 3. Comparison of natural pine empirical yield tables and growth yield tables representing the same site class



inventory in the field to the growth curve (the yield table) which TRIM uses to add volume to the inventory. Since growth and yield in TRIM are strictly compatible, this was an attempt to make an analysis of the field measured growth and its relation to the existing volume per acre and empirical yield "growth".

The growth values from the 1984 remeasured permanent plots were used since they were hypothesized to represent the growth that occurred on the inventory between 1974 and 1984. Growth data was aggregated age within site class, and <u>all</u> growth and associated acres in the site class were summed. For each age class a 5 year growth per acre figure was calculated. This growth per acre was then accumulated starting with the first age class and adding the 5 year growth in each successive age class. The final result was a yield table for which the volume per acre value in any one age class was really the net growth per acre which was measured on that age class and all younger age classes. It can be seen in Figure 3 that the growth and empirical yield tables look quite different.

As previously mentioned, all of the acres were aggregated into one average stocking class. The regeneration stocking level midpoint in each GRU was found by dividing the inventory volumes which were in the associated BRU by the GRU yield table. This was done for both the empirical yield and growth yield TRIM runs. All age classes were used except age class 0 (0 thru 7 years) which had evidence of plots with residual volumes that could inflate the stocking average.

The approach-to-normal function was used for all simulation runs. Thus, stocking was allowed to improve with time. The asymptote for all runs was 100 percent volume stocking of the yield table (the form of the equation is in Appendix). Thus individual cells above 100 percent stocking would decrease in stocking and understocked stands would improve in stocking. For stand ages 0 to 39 the function worked at "full approach", while from age 40 to 59 the function adjusted stocking at "half approach". In the empirical yield GRU's, no approach would take place past the 11th age class and stands would maintain the initial stocking or the stocking which they had when passing through age class 10. For the growth yield GRU's, the assumption was made that stocking would improve over all the age classes and therefore the "half approach" was left on from age 40 onward.

Growth-on-harvest inputs were calculated from both types of yield tables for each GRU. This parameter is a multiplier which increases the volume per acre in each age class before a harvest is taken. They were developed by calculating the percent increase required to reach the midpoint volume per acre between each age class on the yield table (endpoint value in reference to a single age class).

Acre Shifts

The Survey data indicated a substantial decline in natural pine acreage between the two inventories. Statewide, the natural pine acres used in this study dropped by 18.8 percent (1.07 million). At the survey unit level NIPF natural pine acreage drop was 21.8 percent (0.4 million). The largest factors contributing to these losses were type changes caused by timber harvesting and land clearing followed by lack of regeneration or regeneration to planted pine (Sheffield 1986).

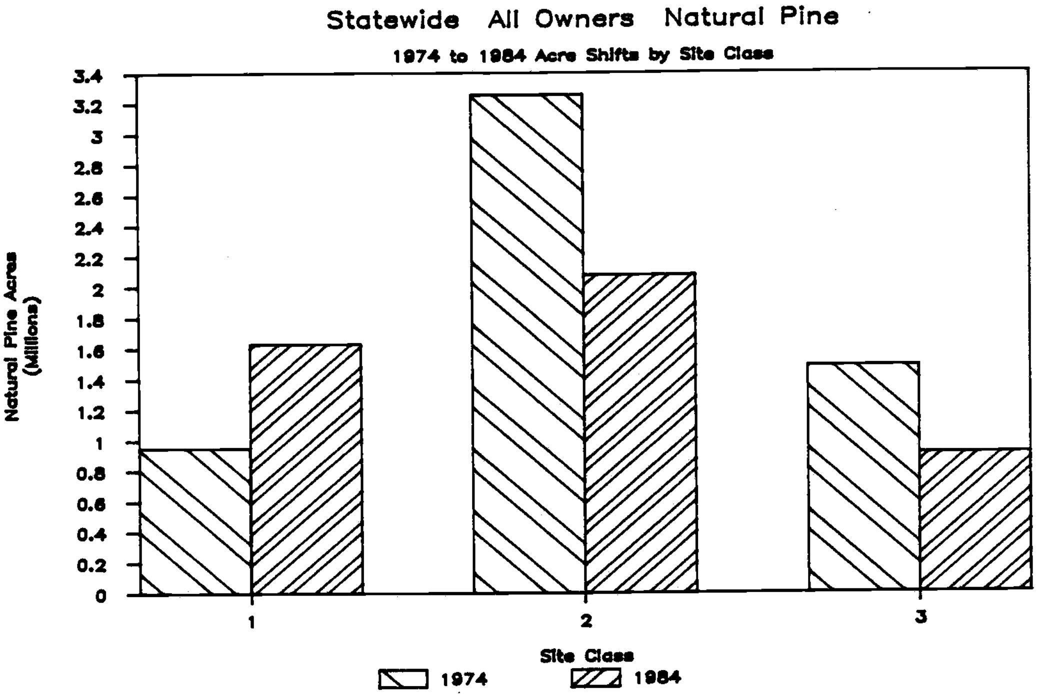
Acres also shifted <u>among</u> the three sites. A sizable acreage shift took place to site class 1 at the expense of site class 2 (see

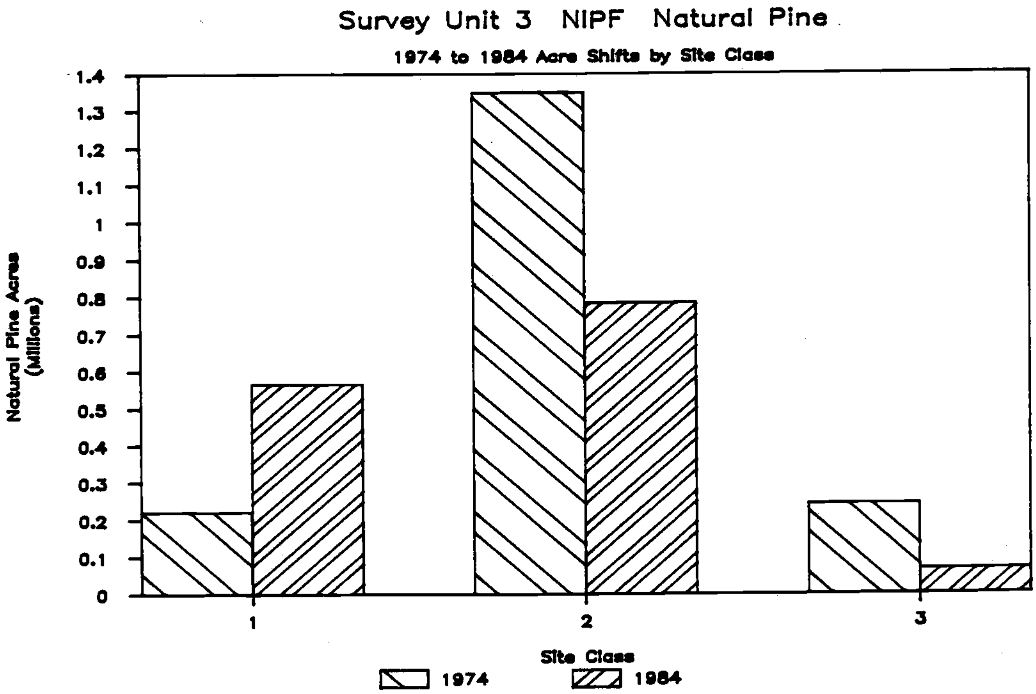
Figure 4). At the state level the site 1 net acreage gain was 71 percent. At the survey unit level this gain was 155 percent. A major reason for this shift was the reclassification of Virginia pine to a higher site. For the most part, this was probably due to a difference in training of the 1984 survey crew over the 1974 crew rather than an improvement in site. (Herb Knight 1986, personal communication).

The TRIM runs were set up to make acre shifts which would come as close as possible to match what occurred in the field. To accomplish this, two methods were used (donor and unstocked), and results compared. TRIM donor acre categories were used for 3-site simulations while both the donor method and unstocked method were used in the aggregate site GRU. The donor acres were set up like inventory reserves <u>from</u> which site class 1 acres came into the inventory, and <u>to</u> which, the site class 2 and 3 acres moved out of the inventory (under the 1-site scheme acres simply moved out). Total volume would change based on the volume per acres of the age classes losing and gaining acres. The unstocked method was used to move a proportion of the <u>harvested</u> acres out of the land base, these acres carried no inventory with them.

Half of the total acre change occurred in each of the two 5-year periods. Moving acres out of the inventory posed more problems than did bringing acres in. Acres move out of the GRU based on the total requested, but within <u>each</u> age class the number that leave will be proportional to the number of acres held in the age class compared to the rest of the GRU-BRU inventory, i.e. all age classes give up acres and the proportion of total acres in each age class does not change

Figure 4. Natural pine acreage changes in North Carolina among three site classes at two geographic levels between 1974 and 1984





after the donor shift. Inventory volume declines, based on the volume per acre associated with the acres leaving each age class.

Meanwhile, incoming acre shifts to site class 1 were specific. The model allows incoming acres to be specified by age class in a card of the BRU file. Incoming acres contribute to the inventory volume based on the corresponding yield table age class volume and stocking level assigned to the incoming donor acres (one of three stocking percent levels). It was assumed that the volume on acres entering site class 1 was probably borderline between site class 1 and 2. Therefore the stocking level assigned to entering acres was an average inventory stocking percent between site class 1 and 2 calculated with the site class 1 yield table.

The aggregate 1-site runs only lost acres from the inventory. Again, when the donor method was used, this loss was across all age classes and could not be "target specific". Meanwhile, the shift of harvested acres to the unstocked category was a much better representation of what was occurring in the field. Unfortunately this method would not work with the 3-site runs because not enough acres were harvested in site class 2 and 3 to make up the total losses (or shifts) recorded in the field.

Removals

The net removal volumes were derived from the 1984 inventory plots. Removals are measured on the field survey plots with the same basic sampling methods which are used to measure inventory volume, growth, and mortality. The removals used as TRIM inputs were from plots for which the "old forest type" was natural pine. This plot designation was used in order to capture the removals from plots which were in natural pine in 1974 but had changed type by 1984 (i.e. by cutting and planting or reverting to hardwoods). It was observed that over half of the state-level harvest volume came from acres which were no longer classified as natural pine in 1984.

The removal volumes were used to assign harvest proportions to the age classes in the GRU file. Removal volumes were aggregated at the same level as was the inventory represented by the GRU. "Old plot age" was used because the current age of the plot in 1984 would not represent the age class from which the removals came. No cutting was allowed in the first two TRIM age classes (age 0 thru 12). The harvest proportions calculated were based on the proportion of total volume which came from each age class.

It should be noted that all the removals in these TRIM simulations were done as land clearing and not thinning. Thus, all the acres which are cut to satisfy the removal, return to the first age class for regeneration (or possibly move into the unstocked pool). From Sheffield and Knight (1986) it was determined that 28 percent of the acres disturbed for volume removal experienced a partial cut. From the Survey data it was determined only 8 percent of the removal volume came from both commercial thinning and selective cutting (high grading). It was decided that this would not have enough impact to justify creating a thinning GRU for the simulations.

There was an Allowable Cut Unit (ACU) file developed for each aggregation scheme. The total removal of volume which occurred between 1974 and 1984 was divided into two equal 5-year figures. The 5-

year removals were placed in the (ACU) file for application to the GRU inventories. In the 3-site projections the single 5-year harvest gets proportioned to the three GRU's based on the proportion of total available volume in the GRU. TRIM uses both the growth on harvest and age class harvest proportions when calculating the total volume available in a GRU.

A calibration of the ACU removal volume had to be made when using donor shifts because these shifts take growing stock volume with them. This was an iterative process which required making several simulations and calculating the actual volume removed from the inventory. The removal figures were adjusted until the lost donor volume plus the removal requested equaled the target harvest volume (newer versions of TRIM allow donor removals to satisfy harvest but the version used was not yet updated).

Projections

Projections were made using PC-TRIM on a microcomputer. The simulation length was extended past 1984 to 2024 to observe the trend in inventory and growth when acres and removals were held constant at the 1984 levels. The initial base projections were set up in the following format for both the survey unit and statewide schemes:

3-Site Aggregation Scheme:
(Donor Shifts)
1. Empirical Yield
2 Growth Yield

1-Site Aggregation Scheme:

(Donor Shifts)	(Unstocked Shifts)
1. Empirical Yield	1. Empirical Yield
2. Growth Yield	2. Growth Yield

Initial projection results were an indication that other schemes should be tried to test the sensitivity of the model. Two things became apparent. First there was sampling error surrounding the removal level which might affect the results. Second, the growth-drain identity calculated at the state level with Survey values underestimated the target inventory by almost 9 percent. TRIM works with a strict growth-drain principle (i.e. current inventory minus removals, plus growth, equals next periods inventory). Therefore, TRIM's growth and inventory projections are not really comparable to field data unless the growth-drain elements in the field data are compatible with the ending inventory. Since harvest is a TRIM input and growth is an output, removals were adjusted so the growth-drain function would produce the 1984 inventory using 1974 inventory and 1974-1984 growth.

The second set of projections were made using the same format as above with the following adjustments made to the removal level:

Survey Unit 3: The the Survey removal was reduced by the sampling error to the lower bound.

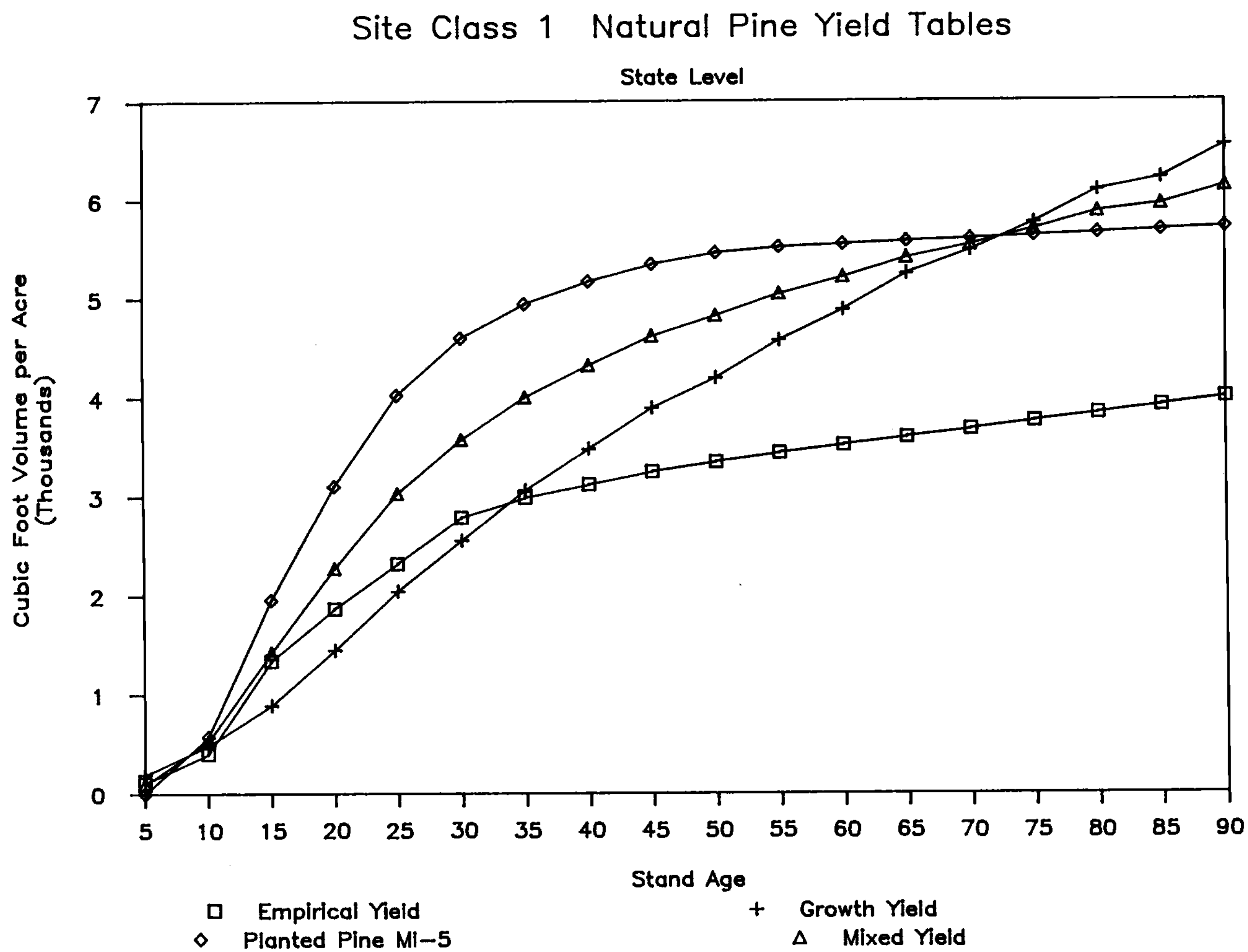
Statewide: The growth-drain identity removal was calculated (as described above) and this was further reduced by the sampling error to generate a "worst case" error lower bound.

Again the ACU harvest request was calibrated when donor shifting was used. Comparisons to the target inventory can be found in the results.

Mixed Yields

A final state-level strategy was tried in which a new composite yield table was developed for the 3-site and aggregate 1-site projections. The composite, or mixed yield table, is simply the arithmetic average between the highest planted pine yield table used in the Southern Timber Supply Study (developed by Herb Knight) and the growth yields developed for this study. Figure 5 shows the components of the site class 1 mixed yield table. A stand following either the planted pine yield and the natural pine growth yield would have almost the same total growth by the last age class. But under the planted pine curve most of the growth occurs in the younger age classes while the growth-yield slope is more constant. The mixed-yield curve represents about the same total growth as the two other curves, but it allows for more growth in the younger stands than does the growth yield curve. The methods used to set up the mixed-yield GRU's are the same as those followed for the growth yield table GRU's.

Figure 5. Illustration of the natural pine site class 1 empirical yield table, growth yield table, planted pine yield table, and the mixed yield table



RESULTS

Survey Unit 3

Both the Forest Survey data and the TRIM projection results using the base removal level are summarized in Table 1 below. The projection results are graphed in Figures 6 and 7 below.

The Forest Survey data is a summary of the inventory, growth, and removal volumes which were derived from the field plot summary data. The sampling error was interpolated from tables in Knight and McClure (1975) and Sheffield and Knight (1986). The growth-drain identity represents 1974 inventory, plus measured growth, less measured removals. The identity predicted a 1984 inventory which was within 1 percent of the 1984 Survey measured inventory.

The TRIM projection results are from simulations using both the empirical yield tables and the growth yield tables. The values in brackets are the percents by which TRIM growth and inventory projections differed form the Survey reported values.

Empirical Yield - Base Removals

When using empirical yields and Survey reported removals, the results in Table 1 and Figure 6 show that all the projected inventories fall below the Survey reported inventory. The growth was an average of 28 percent low, and the projected 1984 inventory is an average of 10 percent below Survey. Assuming the 1984 TRIM projected inventory to have a 3.7 percent error, the error region around the TRIM projection did not overlap the error region around the 1984

Survey reported inventory. Thus, all three of these projections meet criterion # 3 (they are unsuccessful).

It can be seen that the 3-site projection produced the most growth, and hence, the largest inventory value over the entire 50-year projection. The the donor shift and unstocked shift projections were almost identical but the donor shift method had poorer growth during the first two periods when acres were shifting. Based on the criteria for judging between projections, the 3-site and 1-site-unstocked shift were equivalent to 1984 as were the 1-site-unstocked and 1-site-donor shift projected inventories.

Growth Yield - Base Removals

When the growth yields and Survey (base) removals are used, an increase in growth and inventory for the projection occurs (Figure 7). All three projections are within the sampling error surrounding the 1984 Survey inventory and therefore meet criteria # 1. Growth was low by an average of 8 percent while inventory was low by about 2 percent. The highest inventory projection was made with the 1-site-unstocked shift scheme. This run produced the highest growth until about halfway through the projection when the 3-site growth leveled off while the others continued to decline. Based on the criteria all three schemes are equivalent at 1984, thus aggregation had no affect on the results.

Table 1. Forest Survey data and TRIM projections for the natural pine type in Survey Unit 3 on nonindustrial private lands

FOREST SURVEY
(net cubic feet - millions)

		Sampling Error	
1974 Inventory	2,520	± 91	(3.6%)
74-84 Growth	1,003	± 36	(3.6%)
74-84 Removals	964	± 95	(9.9%)
1984 Inventory	2,534	± 94	(3.7%)

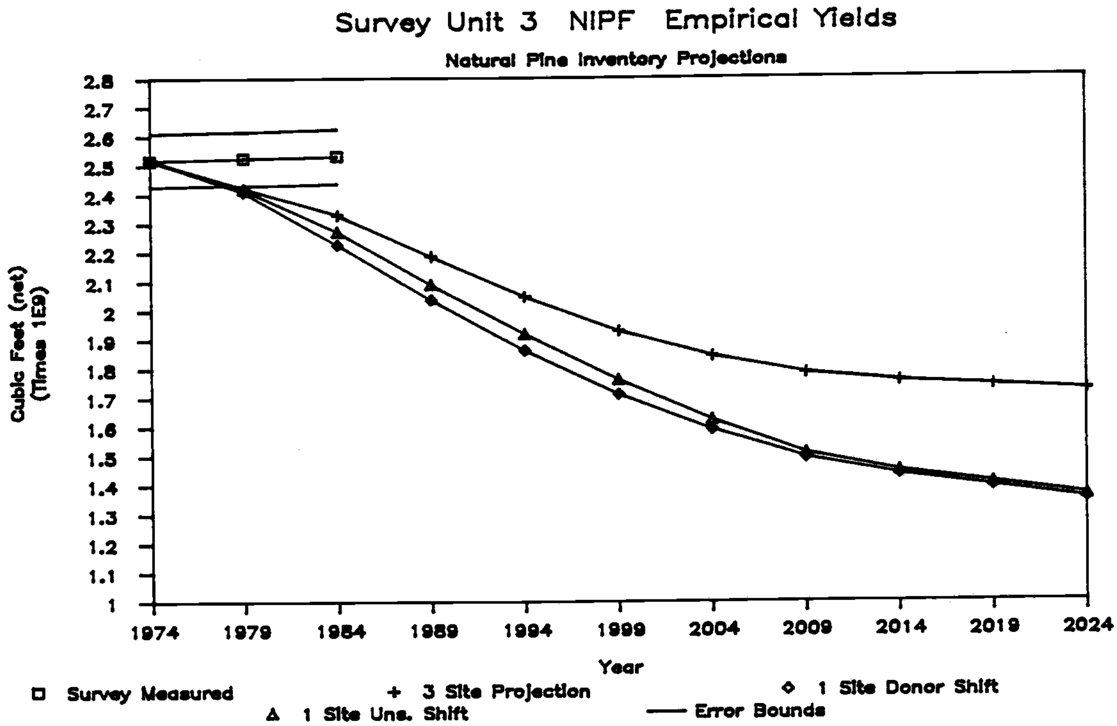
Identity = I + G - R = 2,559
Difference = + 25 (1%)

Acres (thousands):	1974	1,827
	1984	1,426
Loss =		401

TRIM BASE-REMOVAL PROJECTIONS
(net cubic feet - millions)

	Starting Inventory	Input Removals	TRIM Growth	Ending Inventory	Inventory Difference
Empirical Yields					
3 Sites Donor Shifts	2,520	964	774 (-22.8%)	2,335	-199 (- 7.9%)
1 Site Donor Shift	"	"	664 (-33.8%)	2,228	-306 (-12.1%)
1 Site Unst. Shift	"	"	716 (-28.6%)	2,273	-261 (-10.3%)
Growth Yields					
3 Sites Donor Shifts	2,520	964	896 (-10.7%)	2,452	- 82 (- 3.2%)
1 Site Donor Shift	"	"	916 (- 8.7%)	2,477	- 57 (- 2.3%)
1 Site Unst. Shift	"	"	962 (- 4.1%)	2,520	- 14 (- 0.6%)

Figure 6. Three TRIM projections of inventory and growth for Survey Unit 3 using empirical yield tables and base removals



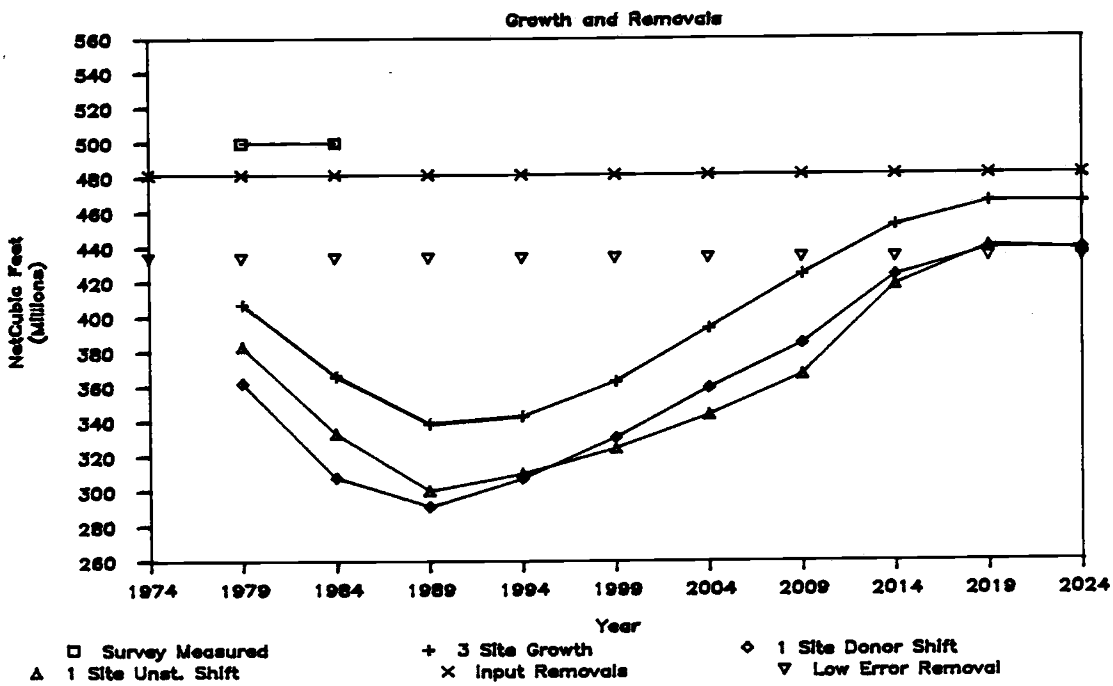
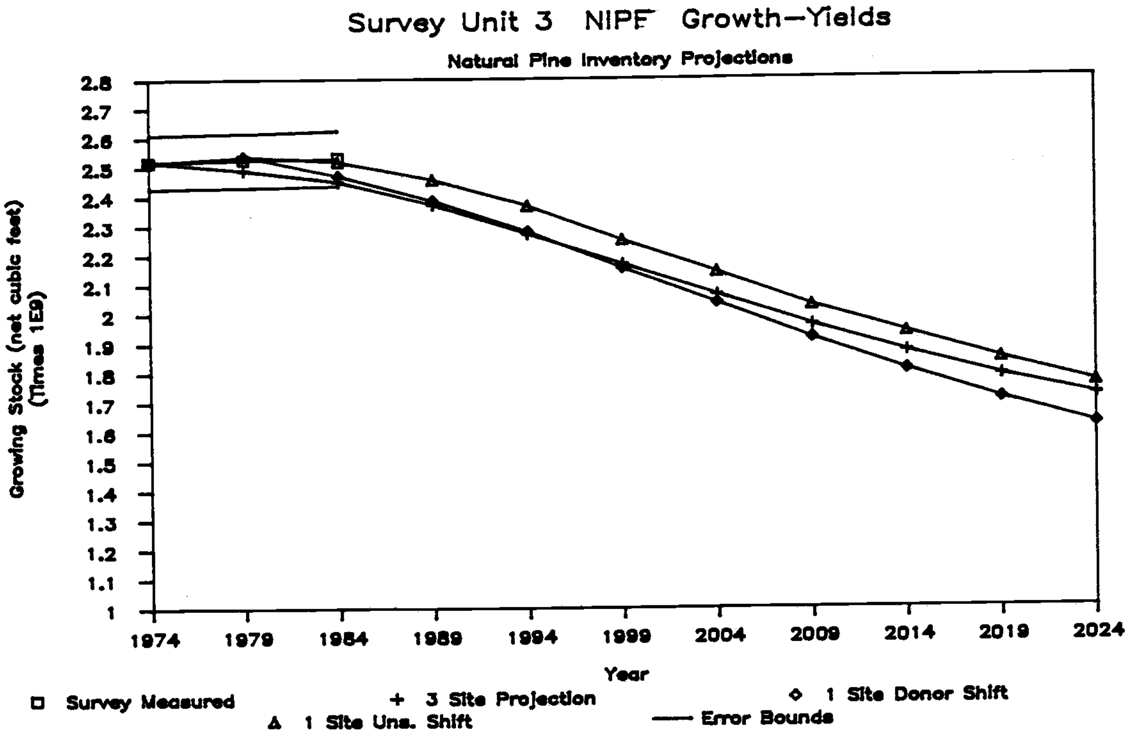
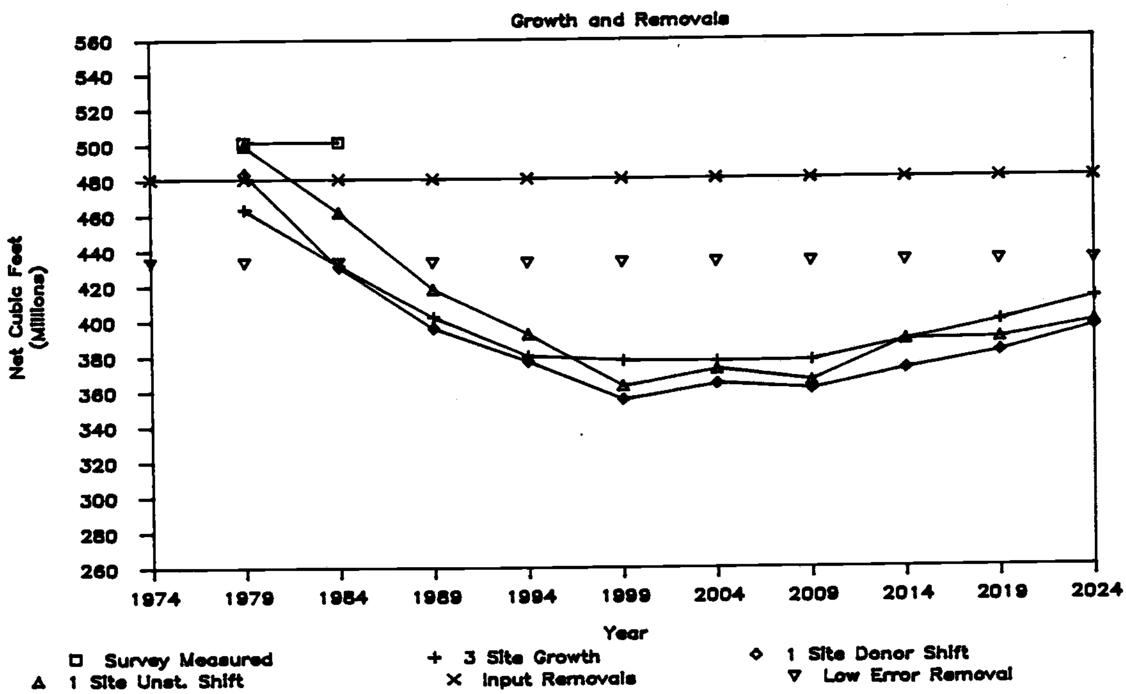


Figure 7. Three TRIM projections of inventory and growth for Survey Unit 3 using growth yield tables and base removals





Empirical Yield - Reduced Removals

Another set of projections were made in which the removal figure was reduced by the total sampling error (9.9%) to 434 million cubic feet (MMCF) per period (see Table 2 and Figures 8 and 9 below). This was done to test a "worst case" situation to observe the effects for which removals would have been overestimated in the field. Under the empirical yield scenario, growth did not change, while inventory improved across all three projections to 6.6 percent below the Survey level. In fact, growth declined slightly over the 50-year projection with these lower removals. In this case, changes in removal levels (within the error bounds) have very little affect on TRIM calculated growth.

The three simulations performed identically between each other in this reduced harvest run as in the base harvest run. This time the 3-site scheme and the 1-site-unstocked scheme would fall under criterion # 2 while the 1-site-donor scheme would still be under criteria # 3.

Growth Yield - Reduced Removals

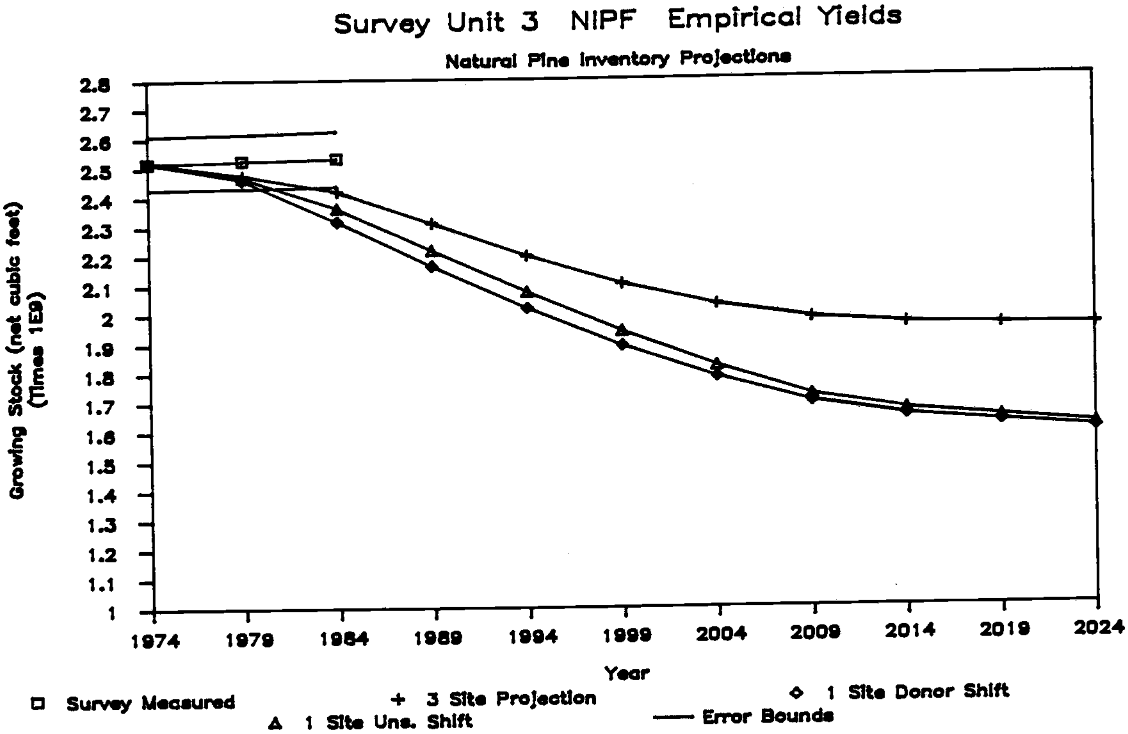
When growth-yields were used and removals reduced, the average inventory level of the three simulations was + 1.8 percent of the target (see Table 2 and Figure 9). Again, as observed with the empirical yields, total growth hardly changed with reduced harvest levels (less than a 0.5 percent increase). The inventory and growth relationships between the aggregation runs also remained the same. All three projection schemes meet criterion # 1 and aggregation makes no difference on the outcome at 1984.

Table 2. Survey Unit 3 projection results when removals are reduced by the sampling error

TRIM REDUCED-REMOVAL PROJECTIONS
(net cubic feet - millions)

	Starting Inventory	Input Removals	TRIM Growth	Ending Inventory	Inventory Difference
Empirical Yields					
3 Sites Donor Shifts	2,520	868	768 (-23.2%)	2,421	-113 (- 4.5%)
1 Site Donor Shift	"	"	666 (-33.4%)	2,319	-215 (- 8.5%)
1 Site Unst. Shift	"	"	712 (-28.8%)	2,364	-170 (- 6.7%)
Growth Yields					
3 Sites Donor Shifts	2,520	868	898 (-10.2%)	2,546	+ 12 (+ 0.5%)
1 Site Donor Shift	"	"	920 (- 8.0%)	2,575	+ 41 (+ 1.6%)
1 Site Unst. Shift	"	"	964 (- 4.1%)	2,617	+ 83 (+ 3.3%)

Figure 8. Three TRIM projections of inventory and growth for Survey Unit 3 using empirical yield tables and reduced removals



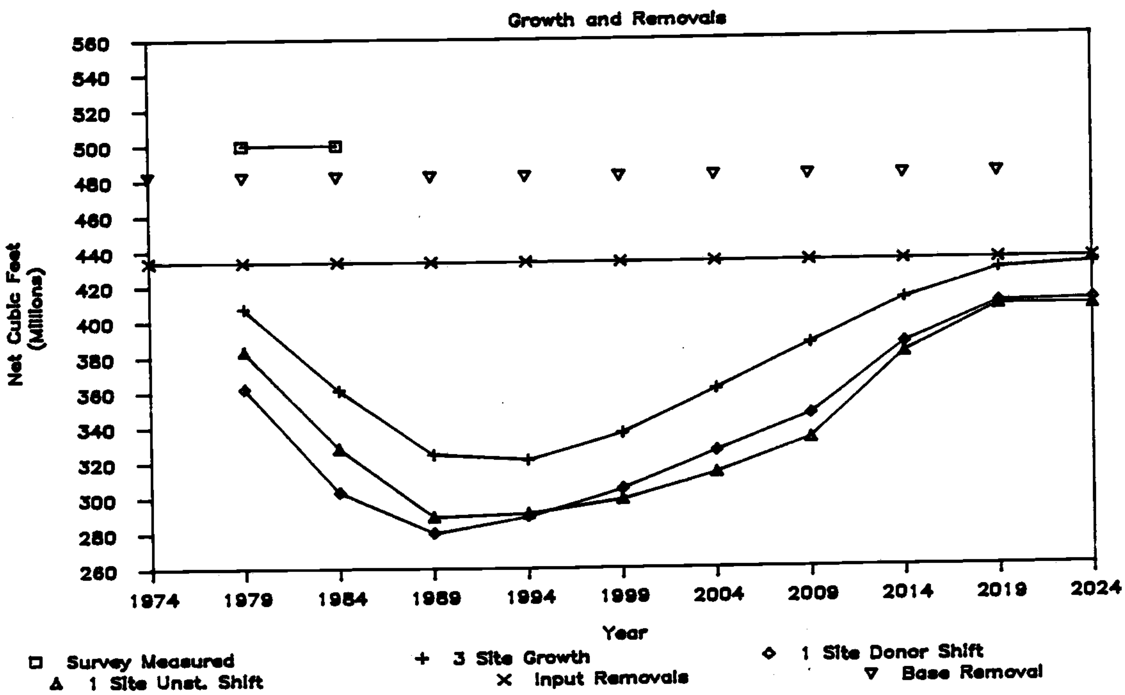
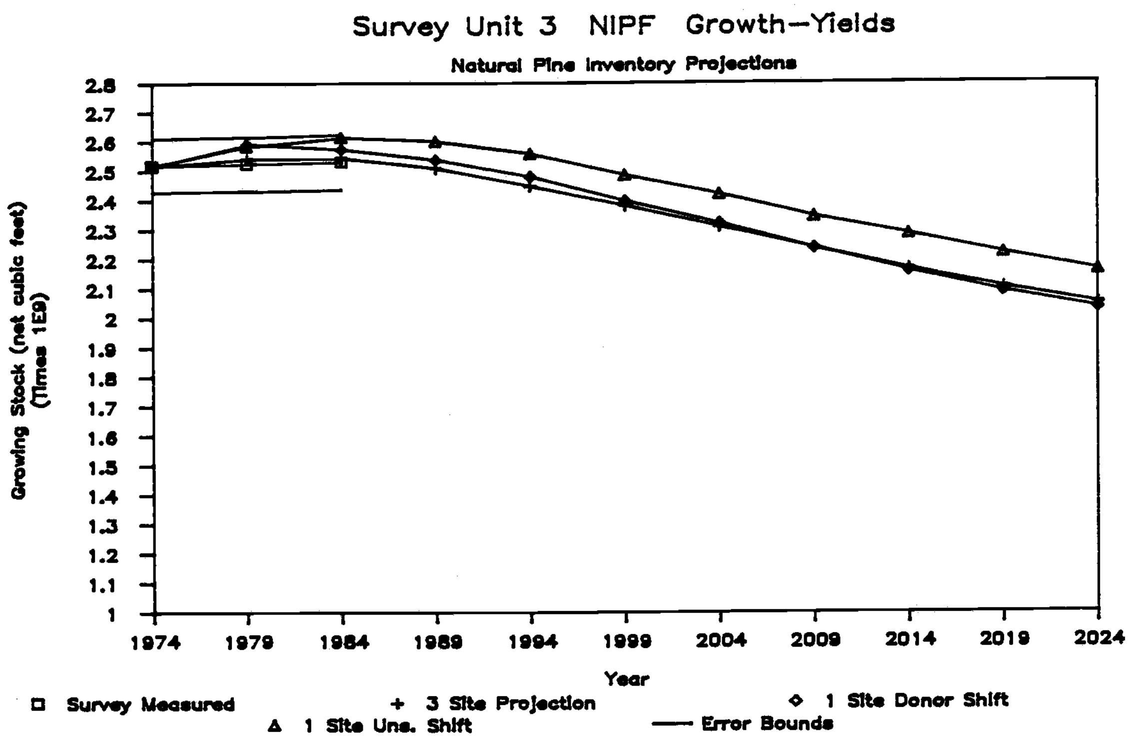
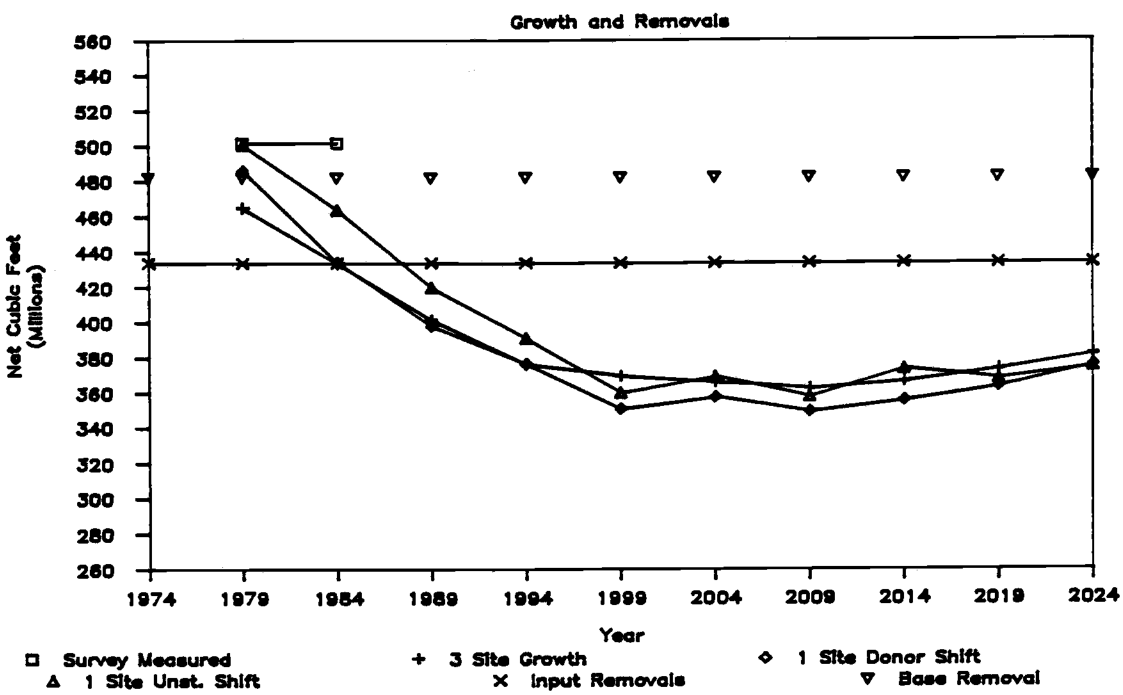


Figure 9. Three TRIM projections of inventory and growth for Survey Unit 3 using growth yield tables and reduced removals





Statewide Results

The state level analysis includes all of the natural pine acres in North Carolina. The base-removal projection results at the state level were were much further from the 1984 target than they were for Survey Unit 3. As can be seen in Table 3 and Figure 10, using empirical yields with Survey removals produced projections of inventories which were below the 1984 target by 22 percent. Projected growth was 35 percent below the reported level. The growth-yield method could just get within 14 percent of the target inventory (see Figure 11).

As previously mentioned, a problem can be seen in the growth-drain identity in Table 3. When using Survey data the ending growth-drain inventory is below the 1984 Survey inventory by 8.6 percent (682 MMCF). Meanwhile, the FIA makes a growth-drain calculation which is much closer to the 1984 measured inventory. The growth and removal figures presented here were derived a little differently than those reported by the FIA. The FIA reports slightly higher growth and slightly lower removal values. A higher growth level would make the identity shown here closer to the 1984 target. It is very probable that the growth figure derived from the 1984 plot data does not include growth on removals or other growth from acres that left the natural pine type between 1974 and 1984.

Since TRIM functions on a strict growth-drain principle within which removals are inputs and growth is an output, it was decided to adjust removals to the level which puts the growth-drain identity on target. Increasing the growth target for the sake of the growth-drain function would have only made the projected growth figure further below target (by 48 percent). To test a "worst case" scenario at the state level it was hypothesized that removals from the plot data were overestimated. For the TRIM projections, the removal levels were reduced to meet the growth-drain identity and from there they were <u>further</u> reduced by the sampling error which made the total reduction reduction of 25.3 percent (or 861 MMCF over 10 years).

The projections presented in Table 4 and Figures 12 and 13 show the results of the reduced removal. These results differ from the 1984 target by percentages much like those from Survey Unit 3 under the base removals. It can be seen that at the state level there was less variability between the 3 projection methods than there was at the survey unit level.

Table 3. Forest Survey data and TRIM projections for the natural pine type statewide on all ownerships

FOREST SURVEY
(net cubic feet - millions)

		Sampling Error	
1974 Inventory	7,545	± 151	(2.0%)
74-84 Growth	3,125	± 63	(2.0%)
74-84 Removals	3,401	± 180	(5.3%)
1984 Inventory	7,951	± 167	(2.1%)

Identity = I + G - R = 7,269
Difference = - 682 (- 8.6%)

Acres (thousands):	1974	5,891
	1984	4,731
	Loss =	1,160

TRIM BASE-REMOVAL PROJECTIONS
(net cubic feet - millions)

	Starting Inventory	Input Removals	TRIM Growth	Ending Inventory	Inventory Difference
Empirical Yields					
3 Sites Donor Shifts	7,545	3,402	2,002 (-35.8%)	6,147	-1,804 (-22.7%)
1 Site Donor Shift	"	"	1,994 (-36.2%)	6,142	-1,809 (-22.8%)
1 Site Unst. Shift	"	"	2,036 (-34.9%)	6,179	-1,772 (-22.3%)
Growth Yields					
3 Sites Donor Shifts	7,545	3,402	2,676 (-14.4%)	6,819	-1,132 (-14.2%)
1 Site Donor Shift	"	"	2,700 (-13.6%)	6,831	-1,120 (-14.1%)
1 Site Unst. Shift	"	"	2,734 (-12.5%)	6,877	-1,074 (-13.5%)

Figure 10. Three statewide TRIM projections of inventory and growth using empirical yield tables and base removals

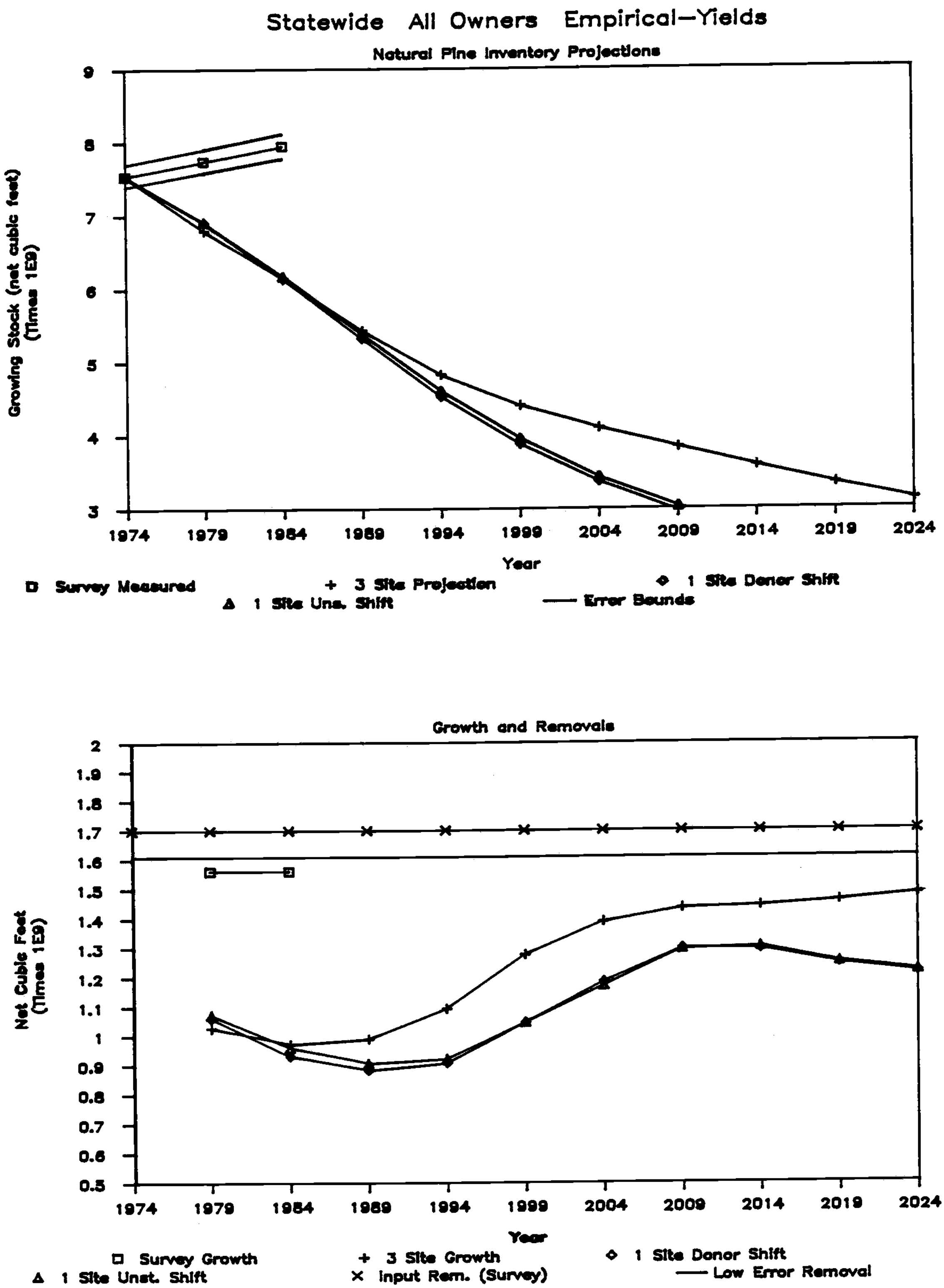
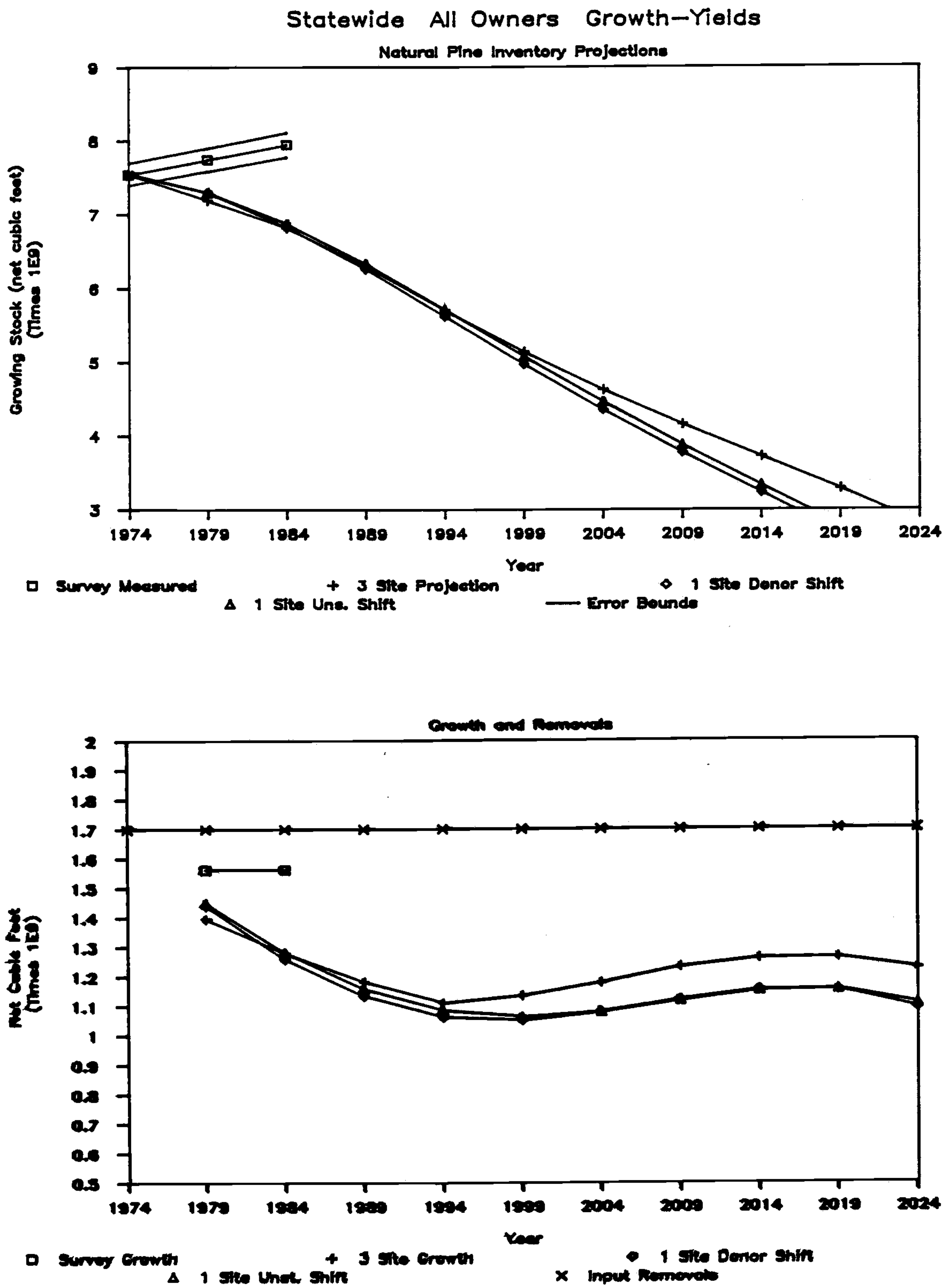


Figure 11. Three Statewide TRIM projections of inventory and growth using growth yield tables and base removals



Empirical Yield - Reduced Removals

When using the empirical yields, inventories were below the 1984 target by about 12 percent. Growth was an average of 36 percent below the Survey figure. Thus, reducing the removal figure by 25 percent actually caused a very slight decrease in growth (5 MMCF). These projections behaved very much like they did under the base removals. All three schemes meet criteria # 3, and there is no difference between them due to aggregation. Growth is always below the removal level so inventory declines over the 50 years. Growth is again higher for the 3-site run and this inventory begins to level off first. It can be seen in Figure 12 that growth almost increases to the removal level by 2024 and inventories level off.

Another run was made using the straight growth-drain removal of 2,720 MMCF with the 1-site unstocked shift scheme (not shown). Projected inventory was below target by 13.8 percent and growth was low by 35 percent. This 7.1 percent increase in removals caused a 0.0 percent change in growth and a 2.5 percent reduction in the 1984 inventory (which was the 180 MMCF difference in removals). The projection meets criterion # 3.

Growth Yields - Reduced Removals

When the removals were reduced, the growth-yield inventory projections were much closer to the 1984 target (see Table 4 and Figure 13). Both of the 1-site aggregate projections satisfied criteria # 1 while the 3-site projection was just slightly lower and met criteria # 2.

It can be seen that growth changed very little when the removal figure was lowered 862 MMCF. There was a very slight increase in growth (about 72 MMCF) by 1984 but halfway through the projection the reduced-removal growth dropped below the base-removal growth.

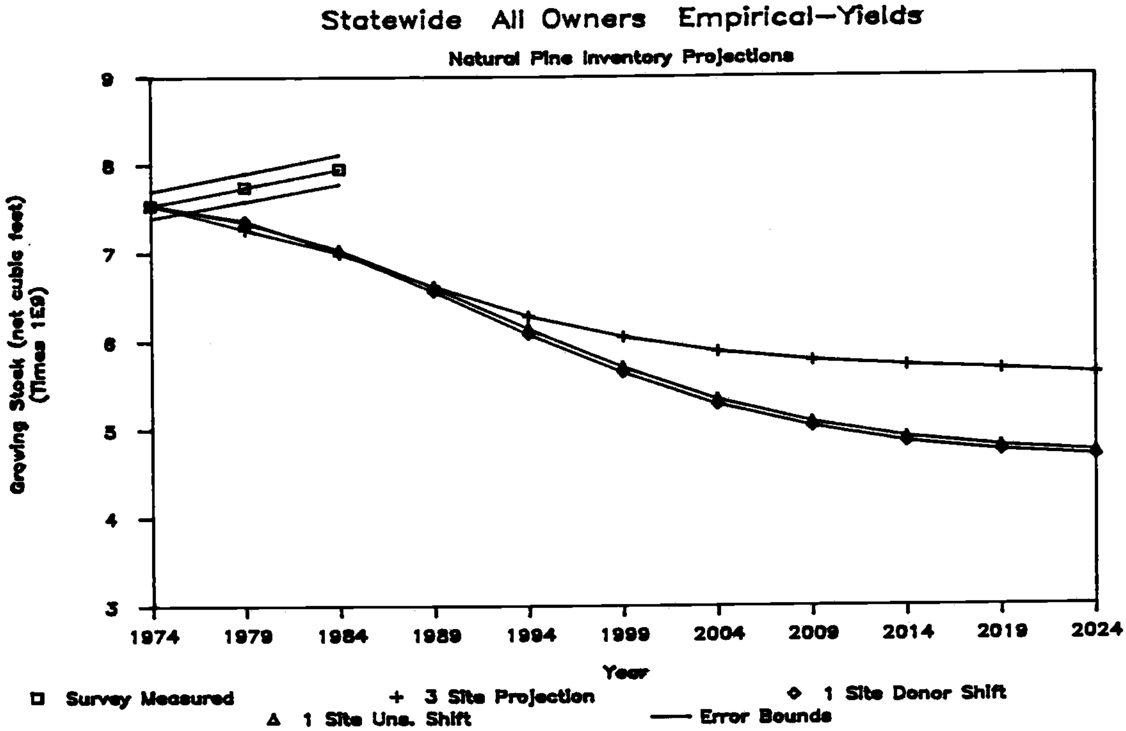
As was done under the empirical yields, a 1-site unstocked simulation was made using the identity removal (not shown). Inventory was 4.2 percent below target and growth was low by 10.6 percent (0.5 percent decrease). Here it was seen that the increase in removals decreased inventories by a slightly higher amount because of the decrease of growing stock growth. This projection meets criterion #3.

Table 4. Statewide TRIM projection results when growth-drain identity removals are reduced by a 6.6 percent sampling error

TRIM REDUCED-REMOVAL PROJECTIONS
(net cubic feet - millions)

	Starting Inventory	Input Removals	TRIM Growth	Ending Inventory	Inventory Difference
Empirical Yields					
3 Sites Donor Shifts	7,545	2,540	1,984 (-36.5%)	6,994	- 957 (-12.0%)
1 Site Donor Shift	"	"	1,990 (-36.2%)	7,008	- 943 (-11.9%)
1 Site Unst. Shift	"	"	2,032 (-35.0%)	7,036	- 915 (-11.5%)
Growth Yields					
3 Sites Donor Shifts	7,545	2,540	2,736 (-12.5%)	7,738	- 213 (- 2.7%)
1 Site Donor Shift	"	"	2,782 (-11.0%)	7,786	- 165 (- 2.1%)
1 Site Unst. Shift	"	"	2,808 (-10.1%)	7,814	- 137 (- 1.7%)

Figure 12. Three statewide TRIM projections of inventory and growth using empirical yield tables and reduced removals



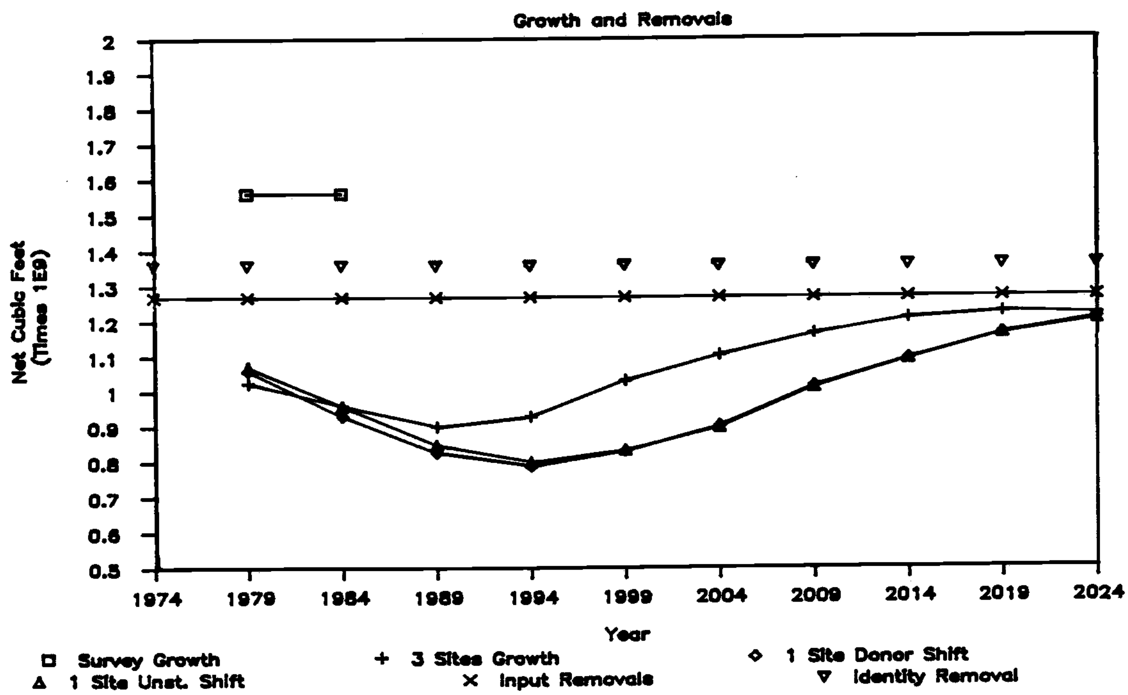
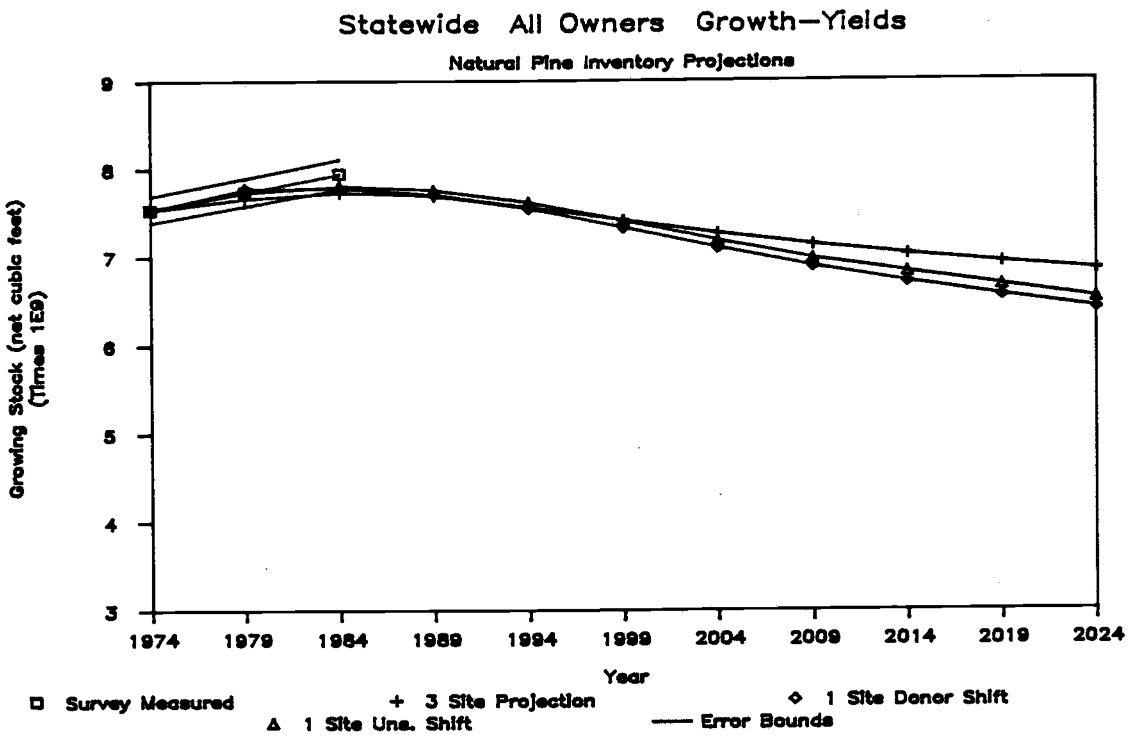
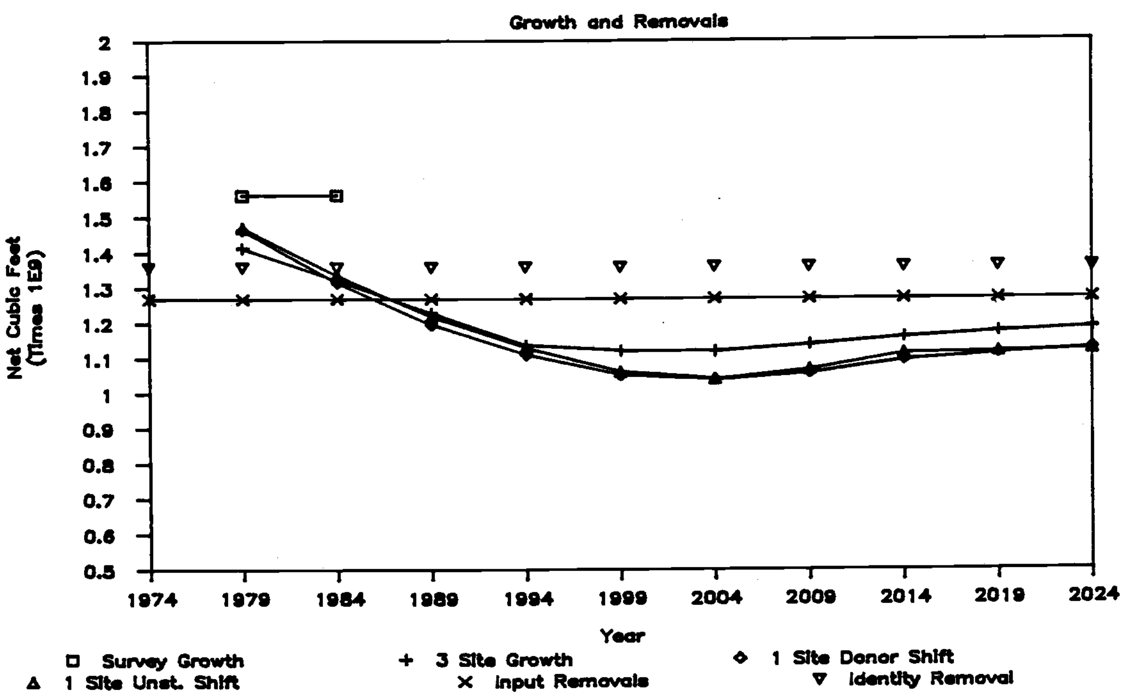


Figure 13. Three Statewide TRIM projections of inventory and growth using growth yield tables and reduced removals





Mixed Yields

The final TRIM projections testing a third type of yield table are presented in Table 5 and Figures 14 and 15 (below). The 1-site unstocked shift scheme tested the mixed yield table under all three removal levels (base, identity, and reduced). The 3-site donor shift scheme was used with mixed yield tables with only the reduced-removal input (Figure 15).

As shown in Figure 14, under the 1-site scheme, decreasing removals increased both growth and 1984 inventory. With the base removal input this aggregation scheme met criteria # 3 with the inventory projection but produced more growth than was recorded in 1984. This represents the result of the growth-drain identity mismatch. When the removal was decreased to meet the growth-drain identity, TRIM growth increased and 1984 inventory then was on the high side of criterion # 2 (on the border with criterion # 1). As can be seen in Figure 14 the 50-year projection of the identity-run is very stable which means that projected growth can keep up to the removal level.

The reduced-removal projection allowed the 1-site run to get more growth out of the inventory which pushed up into criterion # 3. Growth does drop below removals in 1994 and the projected inventory levels off and drops slightly. The 3-site run with this removal level meets criterion # 1 with the lowest growth of the 4 simulations, but growth increases and the the year 2024 inventory is the highest of the group.

Table 5. Statewide TRIM projection results using mixed yield tables

TRIM PROJECTIONS
(net cubic feet - millions)

	Starting Inventory	Input Removals	TRIM Growth	Ending Inventory	Inventory Difference
Mixed Yields					
Base Removals					
1 Site					
Unst. Shift	7,545	3,402	3,214 (+ 2.8%)	7,357	- 594 (- 7.5%)
Identity Removals					
1 Site					
Unst. Shift	"	2,720	3,294 (+ 5.4%)	8,118	+ 167 (+ 2.1%)
Reduced Removals					
3 Sites					
Donor Shifts	"	2,540	2,830 (- 9.5%)	7,822	- 129 (- 1.6%)
1 Site					
Unst. Shift	"	"	3,350 (+ 6.0%)	8,319	+ 368 (+ 4.6%)

Figure 14. Statewide TRIM projections using a 1-site mixed yield table under three different removal levels

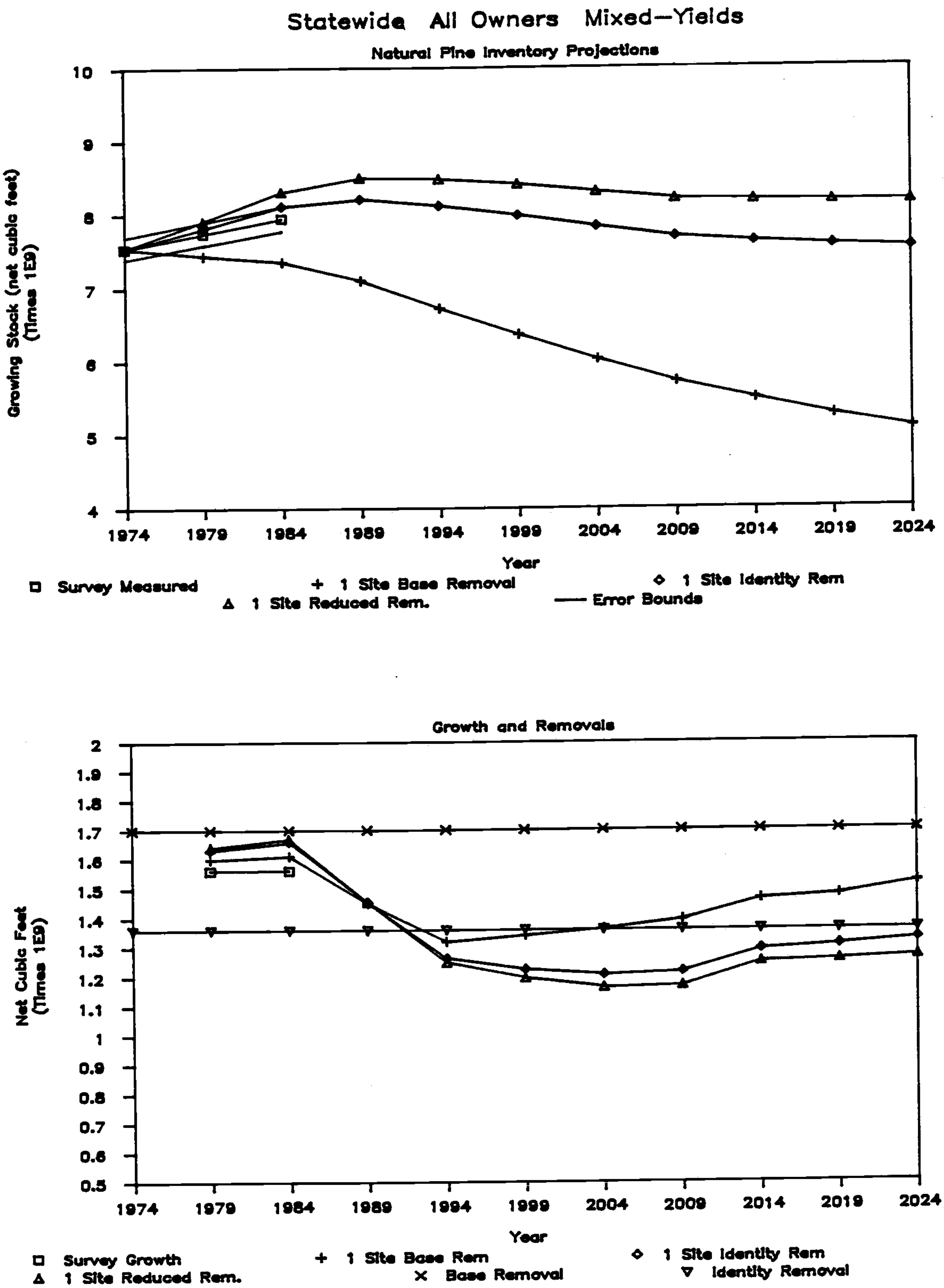
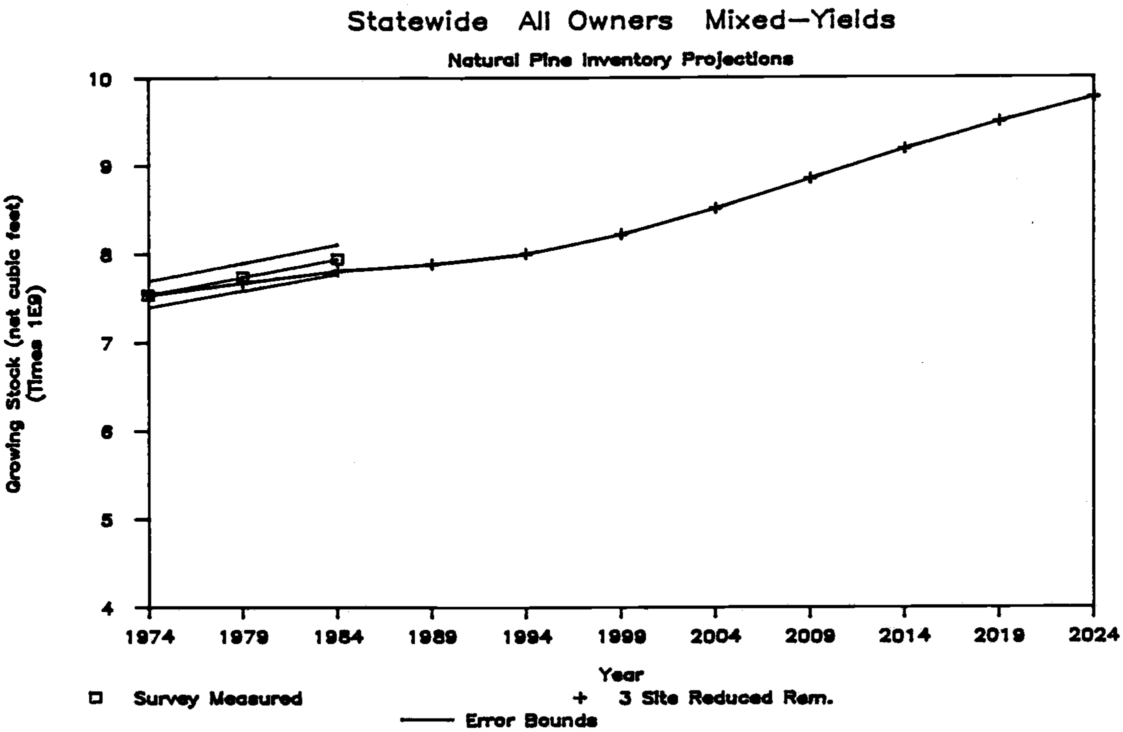
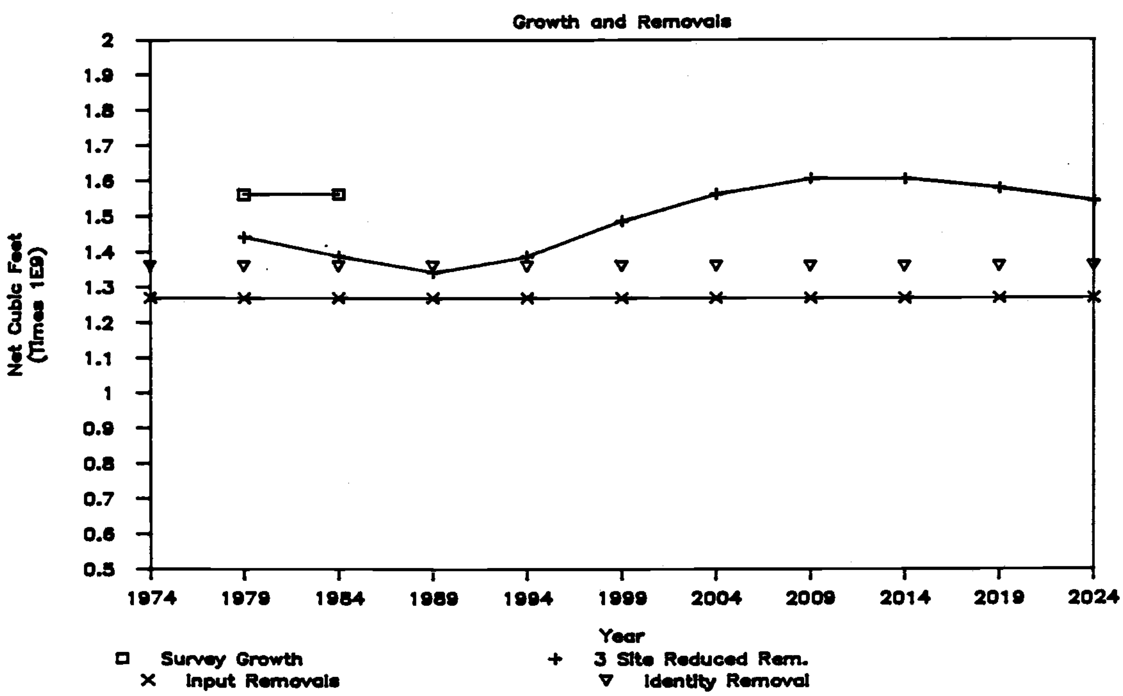


Figure 15. Statewide TRIM projections using 3-site mixed yield tables under the reduced removal level





DISCUSSION

Empirical Yields

From the results it is quite clear that the empirical yields were not successful in projecting inventory at either the state or survey unit level. All projections failed to meet criterion # 1 over the range of input removal levels. Though the yield tables for state and survey unit projections were almost identical, when using base removals the state level projections were much further off target than the survey level projections.

Acreage losses were a greater proportion of the survey unit starting acreage than they were statewide. But survey unit site class 1 gained twice as many acres (on a relative scale) as were gained by site class 1 over the whole state. The 10-year base removal volume, as a percent of starting inventory volume, is 38 percent of the survey unit inventory and it is 45 percent of the statewide starting inventory. The higher removal rate statewide may be one reason the statewide projections fall lower than survey unit projections. When statewide removals are reduced to 34 percent of starting inventory volume (reduced-removal input), then the statewide and survey unit pro-jections are very similar. (It is also possible that the survey unit removal level is too low because it excludes harvest volumes from acres which may have changed from NIPF to forest industry or other ownership just before or after harvest.)

As TRIM removals were adjusted, the total amount of growth produced did not make any significant change. The yield curves were able to produce a level of growth which was unaffected by the changes in removals. A reason for this is that harvested acres get recycled back to the younger, steeper part of the yield curve where the growth rate is the highest. In the plotted graphs representing total TRIM projected growth, the same basic patterns emerge. For two or three periods total growth declines followed by an increase. The decline is due to the acres shifting taking place in the first two periods. The loss of acres reduced total growth by reducing the number of acres that could be regenerated. Growth recovered when all of the acres harvested from the inventory were regenerated.

There were some unreported test projections for which no acre shifts took place. Under the empirical yield tables, projected growth increases from an initial starting point and then leveled off under removals (but again growth met criterion # 3 for these runs).

At both the state and survey unit level, the 3-site aggregation scheme produced higher levels of growth than did the 1-site scheme when using empirical yields The reason for this difference is how each handled acre shifts. Under the 3-site run, the number of acres in the two lower site classes declined while the number of acres in the site class 1 increased. This represented a shift in stocking because the acres under the site class 1 yield table increased. Meanwhile under the 1-site aggregation scheme, stocking was not changed because acres left the timber base and average volume per acre did not change. It was this shift of acres to higher stocking vs. no change in stocking which caused the the two aggregation schemes to produce different results.

Therefore, it is concluded that the level of inventory aggregation had no effect on the projections (other than those just mentioned). The three empirical-yield projections at the survey unit level were more variable than those for the state. This may be an effect of the survey unit losing a greater proportion of acres than the state but gaining a greater proportion in site class 1. Projection accuracy then becomes an issue of properly modeling stocking shifts. If the measured acreage shift in site class really represented a gain in stocking due to an increase in site productivity, then carrying three sites might allow for a more realistic representation of what occurred. However, under the 1-site scheme, a stocking improvement can be modeled by adjusting the regeneration stocking level or the approach-to-normal function in order to get the same effect.

It can also be seen that the 1-site unstocked shift projection produced slightly higher levels of growth and inventory than did the 1-site donor shift projections. The unstocked-method shifts a percent of the harvested acres out of the inventory base and this is intuitively much more realistic than the donor method of taking acres from all the age classes. Thus, for the 1-site aggregate projection, unstocked shifting is preferred over donor shifting.

Growth Yields

The growth yields were much more successful in projecting inventories to 1984 than were the empirical yields. The higher growth-yields produced much higher initial amounts of growth which acted to better maintain the inventories. At the survey unit level, all base and reduced-removal inventory projections met criteria # 1. At the state level, the projections are improved over the empirical yield simulations but they only meet criterion # 1 in two cases under reduced removals.

Again, as under empirical yields, the amount of total growth production changed very little when removals were adjusted. Growth declines as acres depart, and as the stand structure shifts to younger age classes, growth begins to increase. But there are two differences between empirical growth and growth-yield growth.

First, the growth-yield growth takes at least 3, and more often 4 periods to stop declining and begin increasing, the empirical-yield growth takes about 2 periods to change direction. Second, for the last half of the 50-year projection at the state and survey unit level, total empirical growth is higher than total growth-yield growth. And higher removals seem to increase this difference.

The reason for both of these differences is due to the shape of the respective yield curves. Between the 1st and 6th age class, the growth yield curve drops below the empirical yield curve (site class 1 and 2, and aggregate site yield curves). Thus for young regenerated stands, the empirical yields produce more growth than do the growth yields. So initial regeneration under growth yield tables acts to lower growth relative to regeneration under empirical yields. As stands grow older the growth yields add much more to growth, but what occurs over the projection is a shift in stand structure to the younger age classes and this is why the empirical yields produce more growth in the long run. (The main reason for this shift to a younger age class structure is because under the current removal scheme TRIM is practicing a form of evenage management. Removing volume recycles the affected acres to the first age class. Since growth volume is less than removal volume, eventually all the older age classes get "cut out" and there is a build up of acres in the young age classes.)

Growth yields produced projections with less variation among the aggregation schemes than did empirical yields. And in contrast to the empirical projections, the 1-site unstocked aggregation scheme produced the highest levels of growth and inventory by 1984. In the empirical yield discussion it was decided that the unstocked acre shift method was the most desirable based on knowledge of acre shift behavior.

The reason this method produced results higher than the 3-site scheme is probably due to the stocking relationship of the aggregate (1-site) growth-yield table to the starting inventory. Unlike the 1-site empirical yield table, the growth yield table does not level off but adds over twice the "growth" between ages 35 and 90+ as does the empirical table. The approach-to-normal function being used with growth yields is adjusting stocking for all age classes (rather than the first 12). The stocking adjustment is larger for stand volumes which are further from yield table volumes. So when average stand volumes are aggregated under one yield table the total effect of the stocking adjustment is possibly more than the total effect which occurs when the inventory is stratified under three yield tables. Under three yield tables the average inventories are closer to the asymptote. But based on the criterion, it is concluded that aggregation did not significantly affect the projection results.

The results show that growth yields projected the measured changes in inventory better than the empirical yields. Yet, they could not project the measured growth. Statewide the measured growth in natural pine acres declined by 21 percent between the 1974 and 1984 survey. Thus, making a set of growth yields as the average between 1974 data and 1984 data would have produced higher growth yield curves. It is very possible that these higher growth yields would have projected the measured 10-year growth. But here also lies the danger of using growth yields to project stands into the future. They represent a "snap-shot" of growth for a specific time interval. And growth is not constant at even the regional level. It is influenced by such things as weather and disease patterns, and changes in management practices (Knight 1985). Therefore, calibrating TRIM with 5 or 10 years of growth data could easily bias a 50-year projection.

Mixed Yields

The mixed yield (or composite yield) scheme was used at the state level as an effort to improve projection results. Mixed yields were developed under the objective to produce a yield table which would be closer to the classical definition of "normal". The empirical yields have the problem of becoming too "flat" to represent measured growth past stand age 40. The growth yields produce more growth after age 40 but they are flatter than the empirical yields in the young age classes. Therefore, a new yield table was sought which would represent both fast growth in the young age classes and continued growth at older ages.

As seen in Figure 5, the mixed yield table meets these standards.

By use of a straight mathematical average it represents the high <u>initial</u> growth on intensively managed planted pine stands, and <u>continued</u> growth on older stands from the growth yield table.

The mixed yields were the only set of yield tables to exceed the statewide growth targets (three projections were too high to meet criteria # 1 and one was too low). Total projected growth was able to maintain or build inventory in all but the simulation using the higher base removal figure. The biggest difference in projected growth between schemes was not due to a change in the removals but a change in the the aggregation format. The 3-site scheme produced the lowest initial growth but when the acre shifting stopped, growth immediately recovered and surpassed the 1-site projections. The higher growth in the 3-site projection builds inventory to the highest projected level by the year 2024.

The large difference in growth between the 1-site and 3-site reduced-removal projections is probably not due only to acre aggregation but also to the method used in developing the 1-site mixed yield table. Rather than using an aggregation averaging scheme, the 1-site yield table was calculated as the average between the site class 2 planted pine yield and the 1-site aggregate growth yield table. It may have been higher than a yield table developed with <u>average site</u> planted pine.

Growth and Yield

The inability to project growth was a common element to all but the mixed yield tables. The field measured values could not be matched. Changes to the harvest level had relatively no affect on growth produced under a projection scheme. The harvest level affected the projection inventories by reducing total stand volume. Acre shifts substantially affected both growth and inventory volume by reducing the growth potential through acreage reductions. It is the yield tables and their application which is most influential on growth. The remainder of the discussion will focus on the yield table.

It was concluded that the empirical yield tables failed under all schemes. Davis and Johnson (1987) discuss the use of yield tables in timber projection systems and present a problem encountered on the Boise National Forest. In this case, empirical yield tables were derived for ponderosa pine from plot data representing all levels of stocking (this is the classic use of the term "empirical", which represents average stocking rather than fully stocked conditions). In the older age classes the yield curve flattened out and indicated no net growth should be occurring. Yet, field measurements on the older stands produced more net growth than what the yield tables would predict.

In addressing this problem, the authors suggest that stand mortality may be underestimated. This could mean the field crew underestimated the volume of wood which had "died" between field surveys and this would cause net growth to be overestimated.

They argue it is possible stand mortality plays another role over time by periodically reducing volume through the effects of insects and fire. Past epidemics of mortality (even if measured) affect the <u>current condition</u> of a timber stand. Thus, the flattening of a yield curve could be related to volume reducing setbacks rather than a reduction of growth rate. They say:

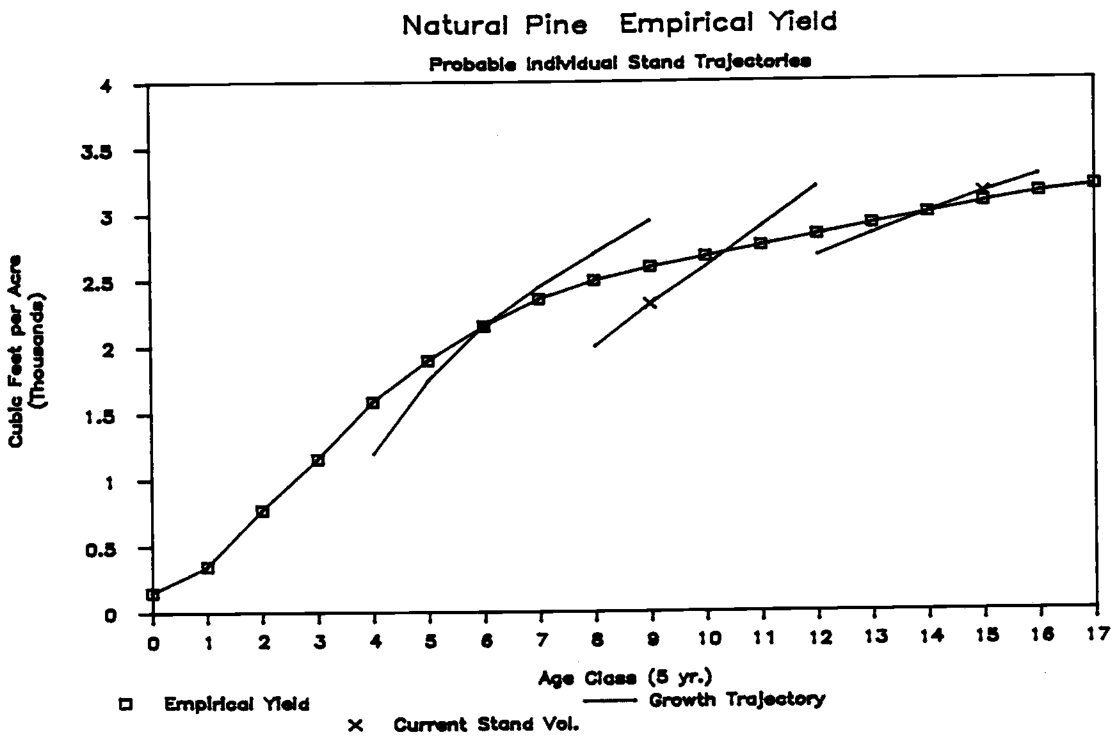
> Part of the problem surely lies in the methodology of using cross-sectional data to estimate growth over time. The stands sampled for empirical yield show how _different_ stands grew over time, not show the _same_ stand grew.

As illustrated in Figure 16, a yield curve can be projected through a group of timber stands with the expectation they follow each other over time. But instead, the stands could be independent in their own trajectories which can be affected by previous volume reducing incidents. In this case the yield table will underestimate current growth, and hence, future inventory volume.

Natural pine stands in North Carolina are subject to insect infestations, wildfire, disease, and weather, such as wind and ice storms (Knight and McClure 1975). They are also subject to partial cutting such as commercial thinning, high grading, and selective cutting. Between 1974 and 1984, about 2.3 percent of the natural pine acres were _annually_ disturbed by partial cutting or natural phenomena. Assuming that this disturbance occurred on different acres each year then potentially 23 percent of the natural pine acres received a possible volume reduction from cutting or significant damage from disturbance over 10 years.

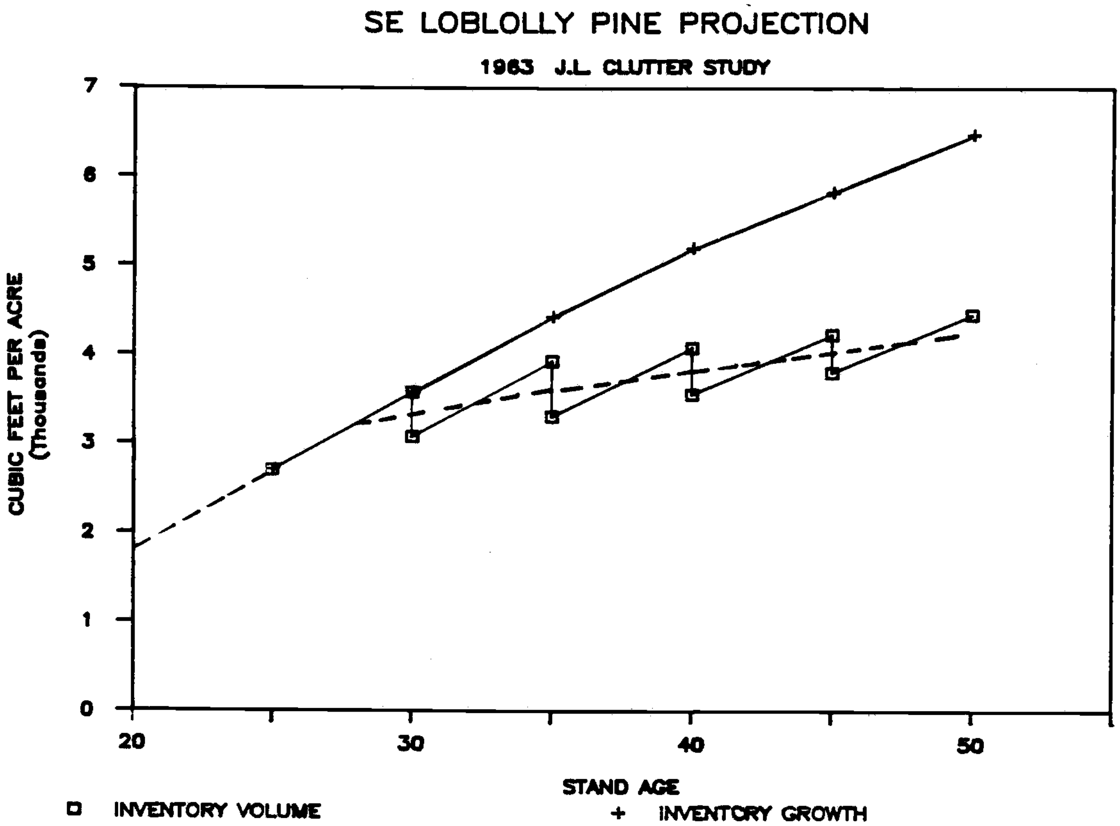
The measurable growth rate may be temporarily slowed by a volume reducing disturbance, but while the measurable volume in the stand may have declined, net growth may be measured as positive. An example of steady net growth occurring from a stand which is subject to the volume reducing effects of thinning can be seen in Figure 17. Over

Figure 16. Illustration of possible growth trajectories taken by the timber stands which were used to develop an empirical yield table



Adapted from Davis and Johnson (1987)

Figure 17. Growth and stand volume projections of loblolly pine illustrating the effects of thinning on total growth and inventory volume per acre



Adapted from Clutter (1963)

time thinning reduces the average stand volume. For a group of stands subject to thinning, their yield volume would appear as the dotted line which is the average volume per acre. But as in the example from Davis and Johnson, the individual stand trajectories would look quite different and cumulative growth would be much higher than inventory volume per acre data would suggest.

From the data set it was calculated that 8 percent of the inventory acres had evidence of partial cutting (this agreed with the 23 percent total disturbance figure). Though partial cutting did not affect a sizable proportion of the acres over 10 years, over the 50-year life of a timber stand the chances increase (80 percent of the acres support stands 50 years in age, or less). Including natural disturbance, the chances are good that all stands reaching age 50 have been subject disturbance. It can be concluded that very few of the stands in the older age classes have been undisturbed throughout their lifetime.

The yield empirical table procedure used in this study selected only full stocked stands but they are not immune from the effects of disturbance. The fully stocked stands which went into the yields statewide represented 45 percent of all natural pine acres in 1974, at the survey unit level they were 61 percent of the total. This is far too many acres which one could expect to have avoided disturbances over their lifetimes. Therefore, it must be concluded that the effects of disturbance are averaged onto these yield tables and it results in reducing their growth projection potential.

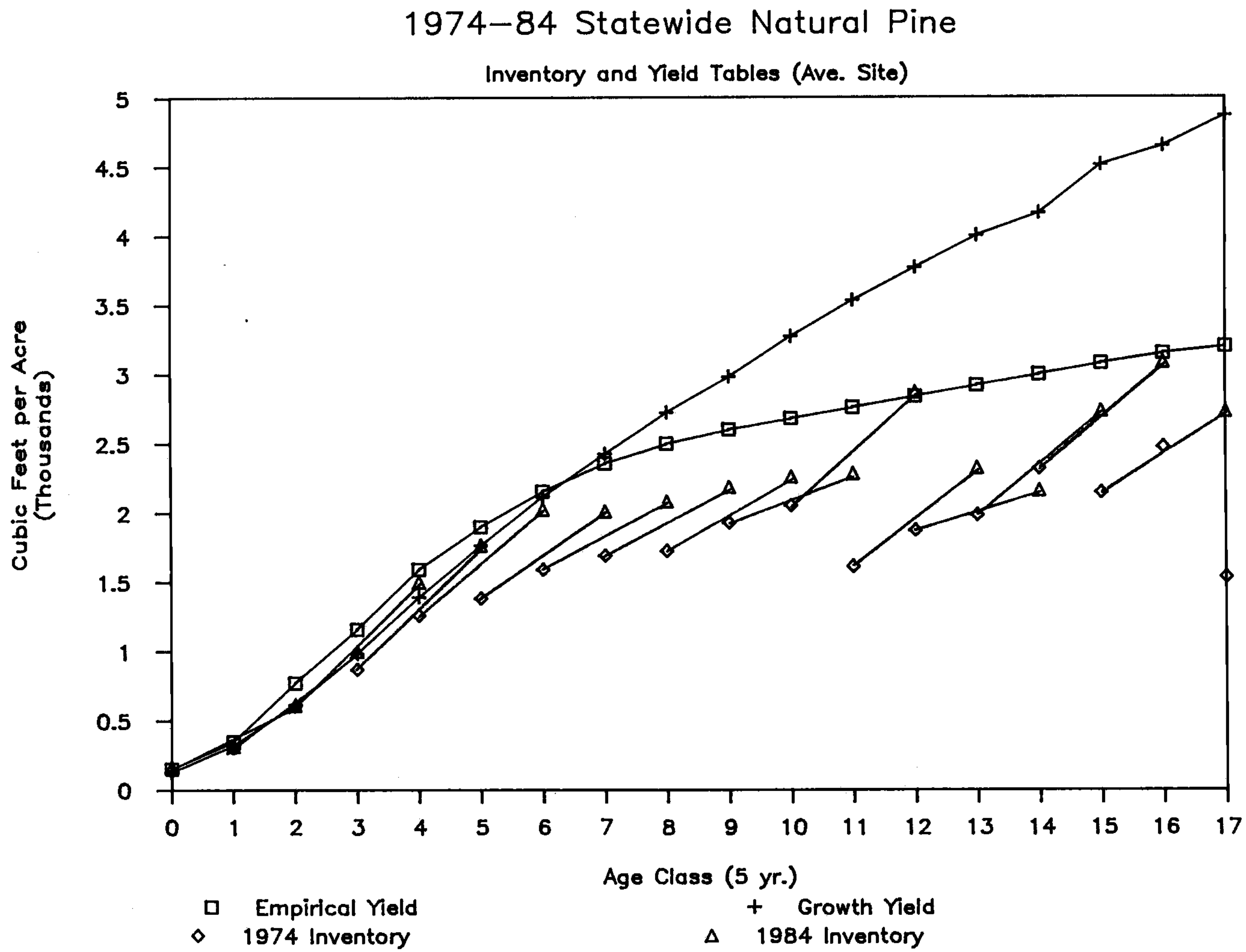
Net Change

On average, stocking did increase on North Carolina's natural pine acres between surveys. As can be seen in Figure 18, when all acres were averaged, the volume per acre increased in almost all age classes between 1974 and 1984. This increase would support the measured acre shifts into higher site productivity. It should be mentioned that this study did not investigate the variability which surrounds the average volume per acre. It is possible the average volumes are not "significantly" different, but it can said that the averages are consistently higher in 1984. Investigation of the variability surrounding these points should be conducted as future research.

Figure 18 also illustrates the change in average volume per acre in relation to the empirical and growth yield tables developed from the data in the 1-site aggregation scheme. Solid lines between inventory points represent 10-year trajectories made by the 1974 inventory. Reasons for an upward net change can include both growth, and the harvest of below average stands.

Looking at the change in inventory volume and comparing it to the two yield tables in Figure 18 it becomes rather obvious why the empirical yield failed to provide adequate growth. TRIM projected growth would move the inventory somewhat <u>parallel</u> to the yield table, it is the growth yield table which these stands appear to parallel. (When stocking represents the proportion of total volume, a stand <u>is</u> increasing in stocking when it moves parallel to an upward trending yield curve.)

Figure 18. **Statewide natural pine by 1-site aggregation, showing the derived growth and empirical yield tables plotted with the 1974 and 1984 Survey inventory volumes. Solid lines which connect inventory values represent the growth trajectories between 1974 and 1984.**



It must be remembered that these changes in the inventory represent a "snap-shot" of the average timber stands over a 10-year time period. We should not expect this improvement in stocking to continue at the current rate for two reasons. First, as has been discussed, stands are known to approach the "normal" stocking level asymptotically. So if left undisturbed, we expect the upward shift in stocking to level off at some height (maybe at 132 percent FIA stocking or some other value for which there are a only few stands). The second reason goes back to what Davis and Johnson (1987) presented and the data supported. These stands are subject to periodic disturbances which act to reduce the volume per acre. At some point in the future we could see the average volume per acre level off or drop, and start back up again.

The key to successful long-term projections with growth yield curves would be the proper application of mortality and harvest across the age classes. TRIM allows for thinning yield tables which can be used to represent declines in volume per acre of stands which then can recover and grow. Because the measured thinning harvest volume and area affected were both less than 10 percent of the totals, thinning was not put into these projections. With the addition of thinning, it might be possible to "fine tune" these results.

A final question which needs to be addressed deals with the difference between statewide and survey unit results. Why were the statewide projections so much further off target than the survey unit projections when the base harvest level was used? When the removals derived from the Survey data were used, all three types of yield tables failed to maintain the statewide inventory.

The reason for this is not exactly known. It is interesting that the mixed yield scheme produced a closer 1984 inventory than did the growth-drain equation. The problem must lie in either the growth or the removal figure, or both. If growth were higher statewide, then the growth-drain result would improve as well as the growth yield projections due to higher growth curves. If removals were lowered to improve the growth-drain result (as was done) then the projections are more like those of Survey Unit 3. But as was seen, reducing removals lowers the higher statewide removal as a percent of inventory down close to the NIPF figure on Survey Unit 3. According to the individual survey unit publications for North Carolina, a greater percent of the natural pine acres are being harvested in the two Coastal survey units. Thus we should expect the state harvest rate to be higher than the rate on NIPF lands in the Piedmont.

The growth rate as a percent of inventory is the same in both the survey unit and the state (3.9 percent). Is this possible? Should there be a faster growth rate where there is a faster removal rate? This can only be addressed by looking at the volume statistics. For all Survey Unit 3 natural pine, 61 percent of the acres are supporting fully stocked stands as compared to 45 percent statewide. The empirical yield curves, developed independent of one another, also match up very closely for both the state and survey unit. This is not proof that the growth measurements are correct, but it does indicate that Survey Unit 3 was representative. In Survey Unit 3, the growth-drain identity did work, so adjustment to growth would not be welcome. It should be remembered that the survey unit is a subset of the state, so any adjustment statewide has the potential to affect the values in the survey unit.

As mentioned earlier, the survey unit projection only used NIPF acres and it is possible that the removal level was too low. If NIPF acres were purchased by forest industry and then harvested between 1974 and 1984, only the acre change would be reflected in the calculations. Removals were derived from acres which were still in NIPF ownership in 1984. Increasing removals at the survey unit level would probably cause the base-removal projections to look more like those at the state level.

SUMMARY AND CONCLUSIONS

Initial TRIM projections of timber growth in a regional timber supply study conflicted with estimates of growth based on field measurements. Errors could not be found in either the model or the field growth calculation techniques and there was a loss of confidence in the model's ability. The analysis presented here was an effort to evaluate the model projections of growth and inventory by comparing them to field measurements. This study used both the 1974 and 1984 timberland inventories of the state of North Carolina with the objective to model, as closely as possible, what took place in that 10-year period. It examines the growth mechanism in TRIM and its response to changes in harvest levels and area changes. It also tests the model's ability to produce consistent results as inputs are aggregated.

The yield table is the heart of the TRIM projection mechanism. It was found in earlier work that TRIM projections could be duplicated outside of the model by applying the model's technique to spreadsheet analysis. A review of the literature (presented here) considered these techniques to be valid methods of projecting inventories with a yield table.

Three different types of yield tables were developed to compare their effects on projected inventory growth. The empirical yield tables were developed from volume data on "fully stocked" acres. These were almost exact copies of the natural pine empirical yields used in the Southern Timber Supply Study. The growth yield tables were developed from growth data on all acres. They represent the cumulative net growth per acre which took place across all age classes in the 10-year projection period. The mixed yield tables were a combination of growth data, averaged with an empirical yield table which represented a very high growth rate. This was done in an effort to create a more "normal" yield table (at the state level only).

The inventory and yield tables were aggregated (averaged) at two levels in each of two geographic regions. The smaller geographic region being a survey unit within the larger region which was the state. Two types of acreage shift mechanisms were used. One type moved acres out of the inventory from all age class, the other shifted acres from the base after they were harvested. Acre shifts, timber removals, growth, and the inventory "targets" were calculated from the 1984 data.

Projection results were evaluated by how well the model projected the 1984 inventory (using the field sampling error as upper and lower bounds). Removal levels were adjusted by <u>their</u> sampling errors and the effects on projections investigated.

The results indicate that empirical yields developed from inventory data do not adequately represent stand growth when stocking is increasing. The empirical yield tables present a picture of current stand volumes, but they may not represent the individual stand trajectories over time. They flatten off and produce no growth in the older age classes while the inventory data indicated growth continued for older stands. Turning off the approach to normal for older stands only makes this problem worse under a flat yield table.

Yield tables developed from growth data were much more successful in projecting inventories. They did not produce growth numbers as high as those measured in the field but it is thought that fine tuning the approach-to-normal function would increase their growth projection accuracy.

The mixed yield tables were able to produce both growth and inventory at higher levels than measured in the field. They best maintained the inventory under the range of removals used. But they should not be considered valid natural pine yield tables since they were a composite from two unrelated sources.

From the results it was determined that neither aggregation of inventory or changes in harvest levels (those used) had a significant effect on model calculated growth. The most significant changes in projected growth were due to the different yield tables used and the methods used to handle acre shifts.

The objective to investigate the definitional status of the term "growth" was conducted early in this study. A meeting with the Southeastern Forest Inventory and Analysis Unit took place to address the definition of growth as calculated from the field measurements. Based on this meeting and the earlier work with TRIM, it was determined that there was not a definitional problem between what TRIM reported as growth and what the field-based calculations reported as growth. Comparing the growth yield tables developed in this study to measured changes in the survey inventory volume supported this.

The second objective was to investigate the effects of TRIM input aggregation on model projections. This involved carrying the inventory in three modules with three yield tables vs. aggregating the same inventory into one module to be represented with one yield table. No significant differences could be found in the projections using the criterion established to evaluate the results.

The final objective was to determine if the TRIM growth projection method should be modified. The results presented here indicate that the TRIM projection method functions as it was designed to do. The question is whether or not TRIM is using the right yield tables. How can yield tables be developed which will better represent growth in TRIM calculations? Yield tables which fit closer to the classical definition of the term "normal" were able to work with the TRIM mechanism to produce growth which was closer to the field reports. Do we need to find a way to develop normal yield tables from the data?

It is noticeable in Figure 1 that the "new" projections from the Southern Timber Supply Study show much more timber volume but yet only a small increase in growth over the initial projections. The biggest reasons for these changes are improvements in handling area shifts and increased use of yield tables reflecting better timber management practices. Growth still does not match up well with the field trends in the first few periods. Based on the study presented here, it could be hypothesized that improvements in growth are shown as acres get shifted under the higher yield curves (reflecting improved management). The Southeast also has a fairly large distribution of hardwoods on the older, "flat" part of the yield curve. Growth increases as these stands get recycled. It could be argued that if the higher (steeper) yield curves were used to represent all acres in the initial inventory then start-up growth would be closer to the field reported growth. There is no evidence to support the hypothesis that

TRIM is projecting a major growth decline which the Survey has been unable to measure in the field.

In concluding, the significance of timber projections must be discussed. This study illustrates the variation possible in predicting timber supplies for North Carolina. Under the base removals, the 10-year projection of natural pine timber supplies dropped between 18.6 to 2.5 percent depending on the yield table used. Meanwhile, the 1984 survey indicated these inventories actually rose by 5.4 percent. What would a 20-year projection indicating a 30 percent drop in softwood supplies do for expected stumpage and lumber prices? What would this mean to the land owner, investor, or policy-maker?

The analysis of the southern timber situation done by Data Resources, Inc. used TRIM with empirical yield tables (derived as these were for North Carolina). The 30-year projections predict a steadily decreasing softwood timber supply in the South due to growth being less than removals. The report predicted stumpage price increases in "real" terms of between 50 and 71 percent (Data Resources, Inc. 1985).

Anticipation of real price increases make investments in timberland management much more attractive because of the greater return expected with present net worth analysis. On the other hand, a company wanting to make a 30 year investment in a pulp and paper plant may avoid a region if the supplies of raw materials were predicted to decline and prices were predicted to increase. This would be a signal to policy makers to investigate ways to buffer the effects of downturn in timber supplies (i.e. public and private money funding extension and reforestation for the NIPF lands). A decrease in supply with an increase in price would make the South less competitive as a region, which could lead to a loss of investment capital and jobs.

It is important to continuously refine models and their inputs. We need models which will help us manage for the future. TRIM will be implemented nationwide over the next two years and more research should be conducted to improve the current system. Results from this study indicate four areas which need further research or refinement.

First, work needs to be done to find ways to develop yield tables that represent stand potential rather than current stand condition. Variation surrounding the fully stocked values should be investigated. It might be possible to develop a "normal" yield curve from the inventory data.

Second, what is the relationship of stocking increases measured in the field to the approach-to-normal function used in TRIM. Does stocking always trend upward or are there periodic disturbances which temporarily reduce stocking? Should the approach-to-normal function be allowed to adjust stocking over all age classes?

Third, is the model sequencing removals, area change, and growth with a method to capture and report growth in an unbiased way? Is it possible that some elements of periodic change such as growth on harvest and growth on acre shifts are not represented in TRIM as they are in the field measurements?

And fourth, how well will the model project slower growing stands subject to multiple cuttings such as northern hardwoods? Can thinning yield tables be used and the approach-to-normal function adjusted to represent unevenage management of those stands?

The modeling process moves on, always searching for better ways to predict the future. This study is just a very small part of that search.

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APPENDIX

APPENDIX

The Timber Resource Inventory Model

TRIM was initially developed at Oregon State University between 1982 and 1985. It is actually a subset of the TREES model (Tedder et al, 1980) which was developed at Oregon State University by K. Norman Johnson, H. Lynn Scheurman, and John H. Beuter. The "official" main-frame version is an update by Jonna Kincaid who in now at the University of Washington, Seattle.

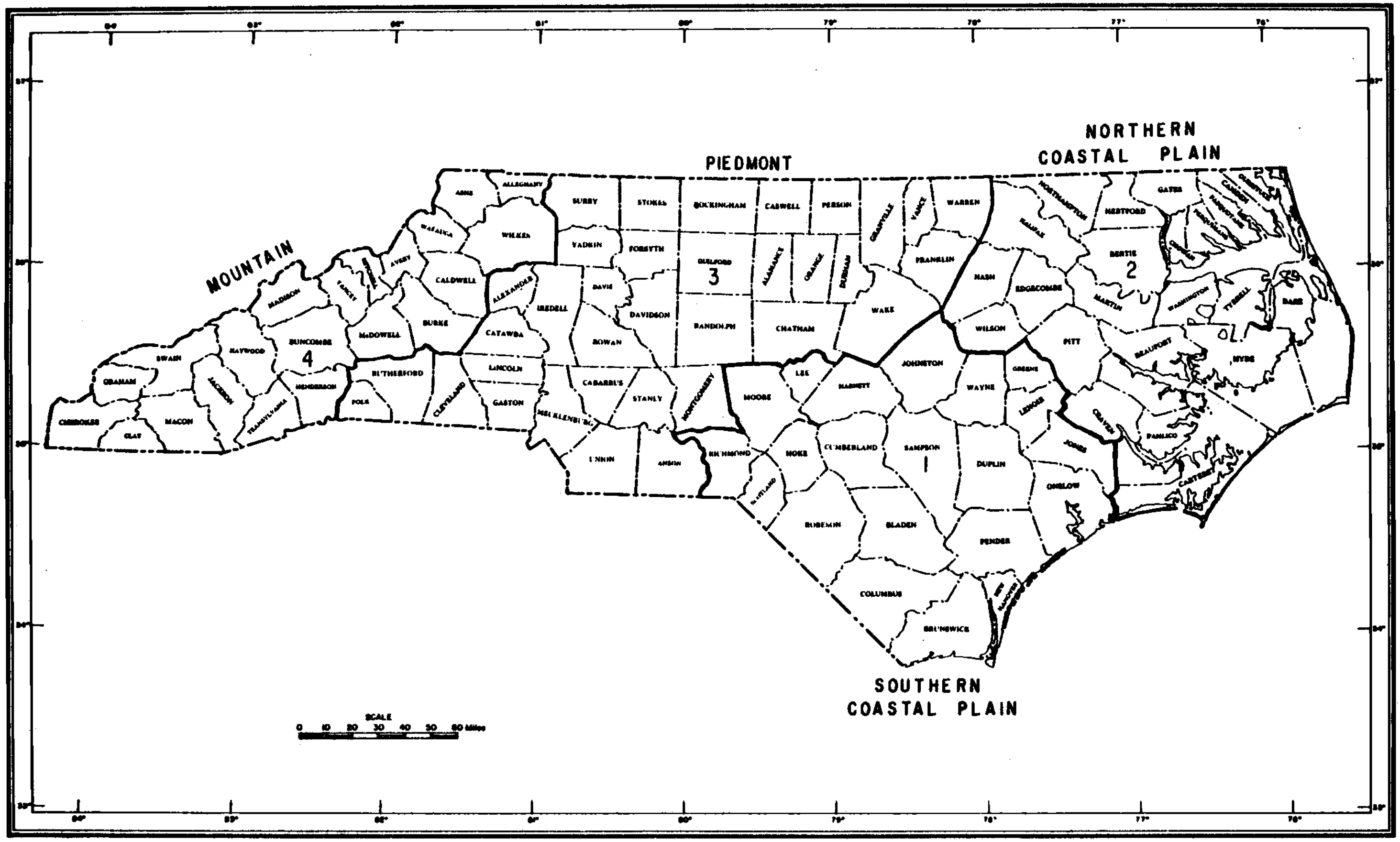
The version of TRIM used for this analysis runs on a micro-computer (PC-TRIM). It was converted from the original mainframe version through the efforts of K. Norman Johnson at the College of Forestry, Oregon State University.

The Inventory

The data for this analysis was provided on magnetic tape from the Forest Inventory and Analysis Unit at the Southeastern Forest Experiment Station, Asheville, North Carolina. The 1974 natural pine inventory in North Carolina was represented by 1,662 plot summary records representing roughly 5.8 million acres. The 1984 natural pine inventory was represented by 1,658 plot summaries but acres dropped to about 4.6 million.

Survey Unit 3 is the Piedmont region of North Carolina (see Figure 19). Natural pine inventory in 1974 was represented by 432 plot summary records (1.9 million acres). In 1974, of the four survey

Figure 19. Map of North Carolina showing the division into four survey units



units, this region contained 31 percent of the timberland acres, 32 percent of softwood inventory volume, and the highest amount of removals and mortality (Knight and McClure 1975). Growth in the Piedmont was inflated by a large amount of ingrowth from farm field to pine reversion. This ingrowth accounted for 23 percent of the total growth compared to 14 percent in the other regions. This growth rate was not expected to continue. The total 1974 growth rate for the states timberland was up 21 percent from the 1964 measurement. Eighty two percent of the 1974 softwood inventory was in the nonindustrial private (NIPF) ownership.

The Basic Resource Unit Inventory

Inventory is aggregated to the Basic Resource Unit (BRU) level for input into TRIM. The BRU inventory represented below consists of an average volume per acre by age class and stocking level for a group of acres which will be treated alike, i.e. yield and timber management parameters input into TRIM apply to all the acres in the BRU. One or several BRU's can be applied to yield table in the Grouped Resource Unit (GRU) file. If more than one BRU belongs to a GRU, the BRU inventories are averaged together to form one GRU inventory.

Figure 20. A BRU inventory representing:

Georgia
Survey Unit 3
Non-industrial Private Ownership
Natural Pine
Site 1

Stocking Level:	1		2		3	
Age Class (5 yr.)*	Acres	CF/A	Acres	CF/A	Acres	CF/A
0	10595.0	70.5	.0	.0	104 31.0	.0
1	7937.0	791.6	10728.0	901.0	.0	.0
2	3844.0	266.6	2831.0	878.1	7401.0	364.1
3	11013.0	877.3	11566.0	801.1	.0	.0
4	18683.0	1255.6	16292.0	737.5	15864.0	783.5
5	41430.0	2091.7	26579.0	1337.2	7697.0	884.9
6	43420.0	2216.7	43811.0	1548.7	15342.0	848.8
7	59356.0	2443.1	39939.0	1719.1	24153.0	711.9
8	40885.0	3176.2	24556.0	2101.7	14224.0	1544.9
9	45864.0	3069.1	37248.0	1907.2	3839.0	1488.9
10	15801.0	4098.4	11610.0	2092.5	.0	.0
11	7049.0	3822.0	10395.0	2183.1	4430.0	919.4
12	.0	.0	14665.0	1442.7	.0	.0
13	.0	.0	3839.0	1461.6	.0	.0
17	.0	.0	4170.0	3543.6	.0	.0

* Age class 0 = 0-5 years, age class 17 = 86-90+ years of age.

Productivity Site Class

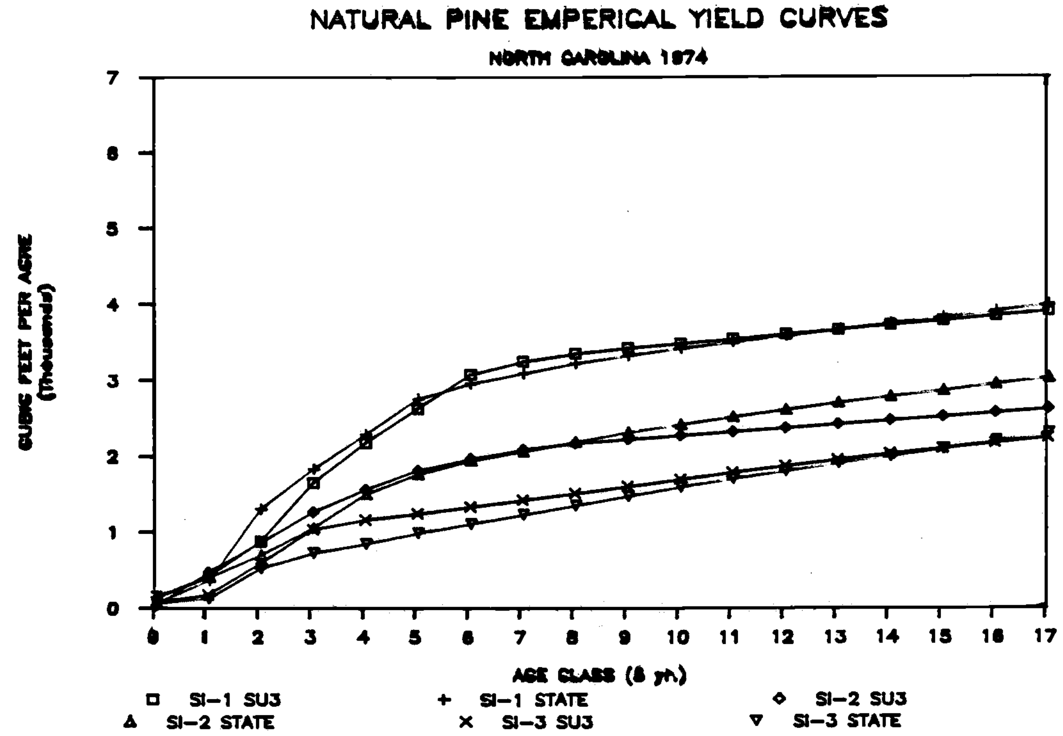
The productivity site class is presented by Knight and McClure (1984) as growth expressed in cubic feet of annual net growth per acre at the culmination of mean annual increment . Site class 1 would include all stands capable of producing at least 85 cubic feet per acre, site class 2 stands would be in the range of 50 - 85 cubic feet per acre, and site class 3 between 20 and 50 cubic feet per acre.

The Yield Table

For the empirical development, only fully stocked 1974 inventory plots were used. There were 690 plot records at the state level and 234 at the survey unit level on all ownerships (in Survey Unit 3 it was thought that a better yield table could be developed using all ownerships rather than just the NIPF plots). The data is aggregated to the species type level by age class and an average volume per acre is calculated. This aggregation produces the array of volume per acre by 18 age classes. In the final process this array of aggregate volume per acre can be "smoothed" with the regression of a cubic polynomial using volume per acre is the dependent variable and age, age squared, and age cubed as independent variables. This result can be graphed and adjusted by hand to smooth out the endpoints. The full set of empirical yield tables developed for North Carolina are shown in Figure 21.

The growth yield tables represent a slightly different concept.

Figure 21. Empirical yield tables derived from North Carolina's 1974 inventory data. Includes the yield tables by 3 site classes and aggregate site (1-site) at both the state and survey unit level



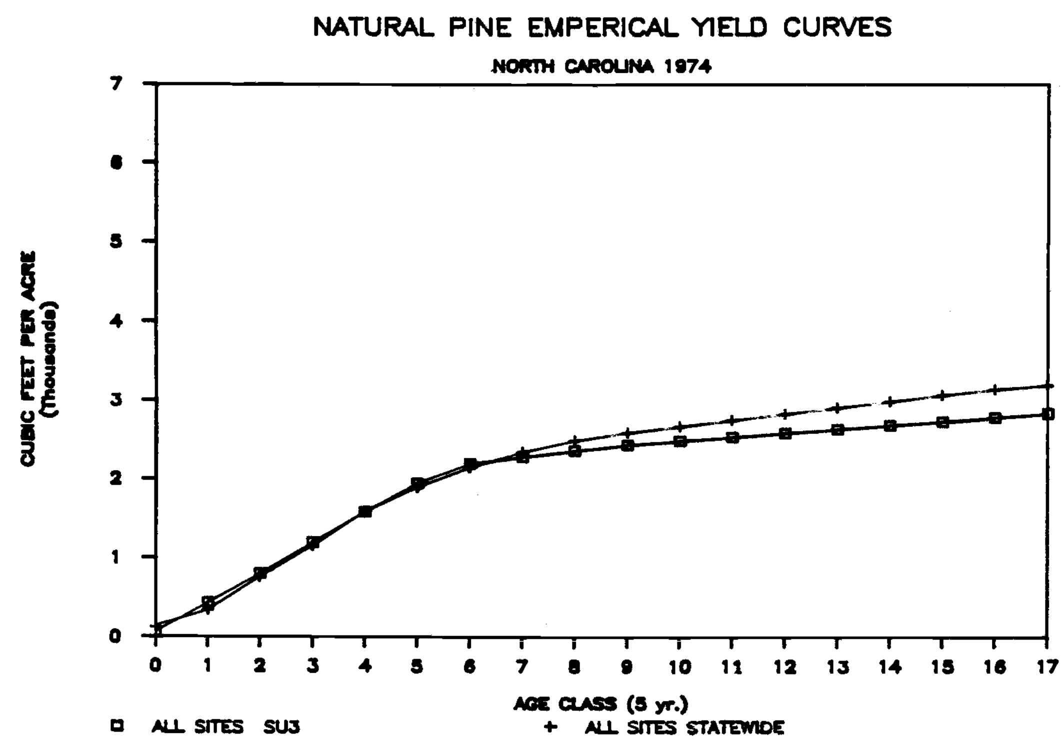
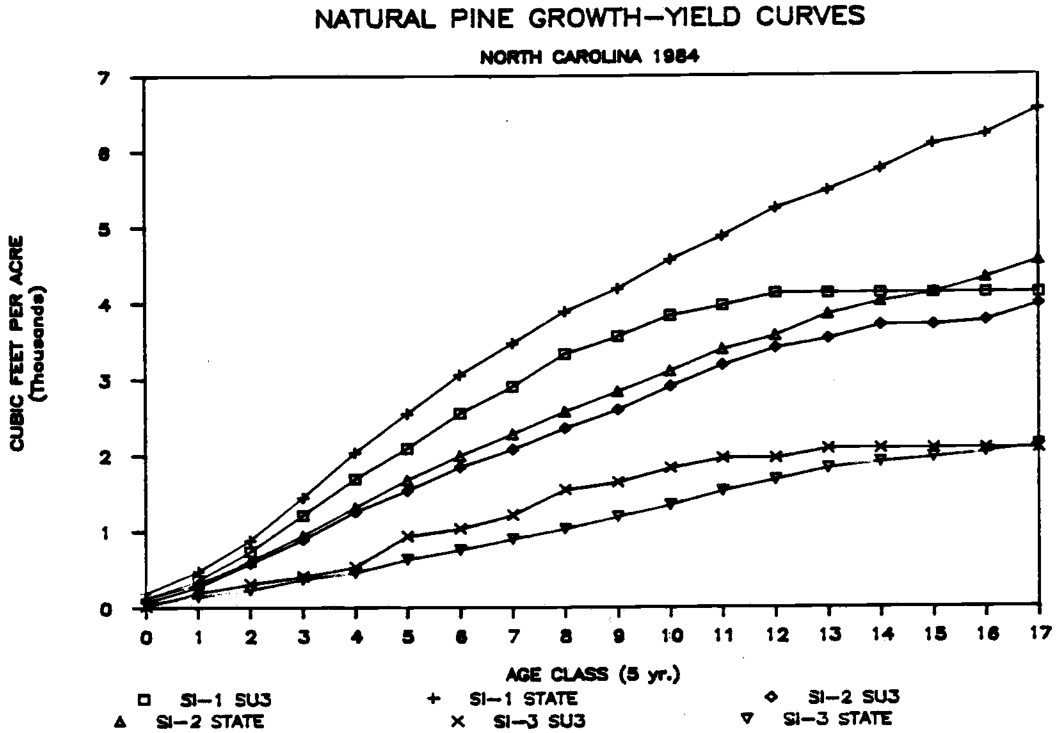
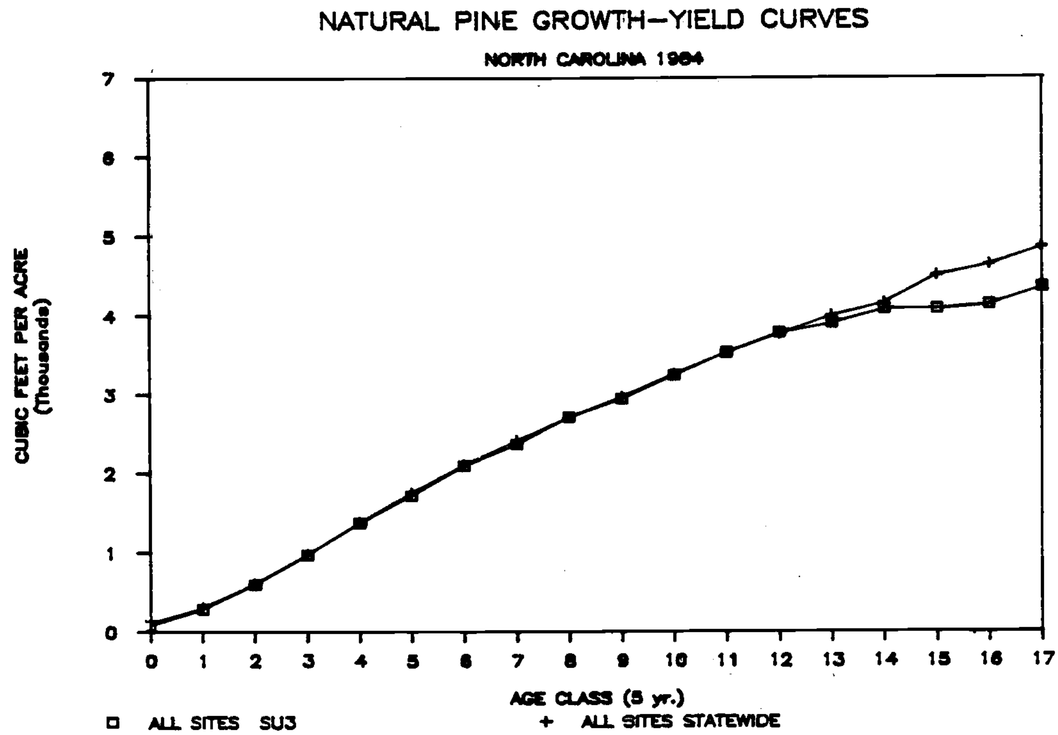


Figure 22. Growth yield tables derived from North Carolina's 1984 inventory data. Includes the yield tables by 3 site classes and aggregate site (1-site) at both the state and survey unit level





They were developed from average growth on the inventory. Adding this growth over the range of age classes is then a representation of inventory volume accumulated by age. This is within the definition of compatible growth and yield which Buckman (1962) and Clutter (1963) developed mathematically. In Figure 22 are the growth yield tables developed for this analysis.

TRIM Growth and Approach to Normality

In the simulation TRIM reports <u>total</u> growth, which is the sum of multiplying the stand growth per acre times the total acres in each stand. When stands are grown using the approach-to-normality method, actual initial inventory volume (at the aggregate yield table level) is the first period starting point. For each age class a stocking percent is calculated by dividing this actual volume by the input yield table volume. Inventory in the next period is "grown" from this starting point by multiplying the stocking percent times the yield table value found at the next age class. (The gain in volume from this multiplication is the reported growth.)

When approach to normality is used, this stocking percent is changing from period to period in the direction of the fully stocked stand (to a value of 10 times the function intercept). The rate of change is determined by the approach-to-normal equation, which calibrates this stocking percent. Below is the functional form of the equation used in this analysis:

$$SL_{i+1} = (SL_i * 0.90) + 0.10$$

where: SL = Stocking Level (or percent)
i = projection period
0.90 = slope term
0.10 = intercept term

The approach-to-normal function can be turned off or adjusted to get a variety of results. Turning it off causes all the inventory in the GRU to "jump" to the regeneration stocking percent which is used for all age classes. Stocking percent does not change over time.