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Patterns of tree height growth in upland forests of northern Lower Michigan

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Peter J. Greaney

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Kurt S. Pregitzer
Major professor

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PATTERNS OF TREE HEIGHT GROWTH IN UPLAND FORESTS OF NORTHERN LOWER MICHIGAN

By

Peter J. Greaney

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ABSTRACT

PATTERNS OF TREE HEIGHT GROWTH IN UPLAND FORESTS OF NORTHERN LOWER MICHIGAN

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Community composition and potential height growth were determined in 74 upland forest stands located throughout northern Lower Michigan. Based on the analysis of ground flora (all vegetation < 4.5 ft. in height), 5 recurring vegetation types were identified and described. Productivity estimates, based on site index, were obtained from stem analysis conducted on Quercus rubra L., Populus grandidentata Michx., Pinus resinosa Aiton, Acer saccharum Marsh., Tilia americana L., and Fraxinus americana L.. Sample stands were stratified by vegetation type and soil type to assess the ability of each to predict site index. The three soil types studied (Emmet loamy sand, Roselawn sandy loam, and Rubicon sand) displayed significant differences in site index for all but one species/soil type comparison. Approximately one-half of the within-species, across-vegetation-type site index comparisons were significantly different. Height growth curves displayed moderate to pronounced polymorphism for many of the species studied.

This work is dedicated to my father.

ACKNOWLEDGEMENTS

I would like to thank Dr. Kurt Pregitzer for his calculated blend of guidance and autonomy. From him I have learned approaches and perspectives that will remain with me throughout my life. I would also like to extend my appreciation to Dr. Carl Ramm and Dr. George Host for their valuable advice throughout the course of this study. Thanks also go to Bill Botti and the many DNR field foresters for their aid in stand selection and housing, and to Pete Giordano and Rich Stevenson for their help with data collection. A special debt of gratitude is owed to Don Zak, George Host, and Bill Cole for sharing a passion for enjoyment and fine coffee.

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INTRODUCTION

The assessment of site quality has long been recognized as a vital component of forest management. Knowledge of forest site quality can enable the forest manager to effectively select those sites which are best suited to a particular use. If that use should entail the production of wood, knowledge of species-site relations will enable forest managers to choose the most productive species for a given site. Westveld (1951) summarized this concept quite succinctly in the following words:

> "The key to sound silviculture is ecology: intelligent management of our forests cannot be achieved without thorough knowledge of the behavior of tree species and stands and their relationship to their habitat."

From a management perspective, knowledge of the spatial distribution of site quality would be of tremendous value. Indeed, this is a major goal of ecological site classification, a discipline that has been the focus of much attention over the last two decades. Ecological site classification systems strive to relate vegetation, physiography, and soils in such a way as to identify recurring landscape ecosystems (Barnes et al., 1982). A less intensive approach involves basing land classification on a single factor, commonly vegetation or soils. Regardless of approach, all methods of forest site classification have the goal of predicting the timber growth potential of a given segment of forested land. The overall objective of this study was to evaluate the height growth potential of commercial trees in the upland forests of northern Lower Michigan.

The utility of site classification systems lies in the information that they provide about the land that they characterize. Of particular interest to forest managers is information concerning the productivity of a given site. Many methods have been employed to estimate the potential productivity of forest sites. Carmean (1975) provides a thorough discussion of the various methods of site quality estimation in the United States. The most widely accepted method of estimating site productivity in the United States is the site index method.

The basic assumption of site index is that the height growth of dominant trees reflects the ability of a given site to produce wood. Height growth as an indicator of site quality enjoys the benefits of being easy to accurately measure, is relatively free from the effects of stand density, and is closely associated with volume production (Carmean, 1975). The reliability of this method declines, however, at extremes in stand density.

For most tree species in the eastern United States, site index is defined as the average height attained by free growing stand dominants and codominants at age 50 years. The stand is assumed to be even aged, fully stocked, and undisturbed. A site index value is read from a family of curves representing the range of site quality (as determined by the relationship of height to age). Originally, this family of curves was developed by the "guide curve" or "proportionality" technique. This approach involves obtaining a single growth curve from the average of height/age data collected from the full range of site quality. This average or guide curve was then proportionally adjusted up and down to represent the better and poorer sites, resulting in a "harmonized" set of curves. The assumption of proportionality of growth curves from trees growing on different sites has been shown to be invalid (Cajander, 1926; Spurr, 1956; Grosenbough, 1960; Daubenmire, 1961; Carmean, 1972; Beck and Trousdell, 1973; Monserud, 1984, 1985). A superior method of constructing site index curves involves the stem analysis approach, which reveals any polymorphic growth patterns that may exist (Johnson and Worthington, 1963; Curtis, 1964; Dahms, 1968; Heger, 1968; Carmean, 1972, 1975; Erdmann and Peterson, 1982). Because factors that effect tree growth vary from region to region, site index curves are assumed to be valid only within the region from which the data were collected for their construction. Monserud (1985) found that differences in height growth patterns of Douglas-fir increased with increasing geographic separation.

In the Western United States, habitat typing has become a valuable aid to forest management. Habitat type is a term applied to all the land capable of supporting a particular association of overstory and understory vegetation at climax (Steele et al., 1981). This natural classification scheme views the climax vegetation as the "algebraic sum of all environmental factors important to plants" (Daubenmire, 1976). As such, the habitat type is thought to reflect not only those environmental factors that we, as scientists, consider to be important, but also additional factors that may not be apparent. It is important to bear in mind that habitat typing seeks to classify land, not vegetation. Vegetation is merely a convenient integrator of the environmental factors associated with a particular landscape. Several investigators have quantified differences in site index between habitat types (Roe, 1967; Mathiasen et al., 1986).

One specific objective of this study was to identify recurring vegetation types, based on ground flora, occurring throughout the uplands of northern Lower Michigan. Upon identification, it was also our goal to provide estimates of forest productivity for each of these vegetation types.

Soils have also been used extensively to indicate site quality in the United States. A list and discussion of these studies may be found in Carmean (1975). The typical soil-site study tries to relate specific soil properties to tree growth via multiple regression. Some studies, however, have taken a simpler approach to this problem by trying to relate forest productivity to soil map units. For a variety of reasons, these studies have typically failed to provide reliable estimates of productivity. Grigal (1984) addresses the weaknesses in soil-site studies, citing the following factors as contributing towards their failure: 1) soil map units do not always reflect those soil properties that are important to tree growth, 2) variability within soil map units often reaches the extent of including wholly different soil taxa, 3) harmonized site index curves commonly used are inadequate and do not accurately reflect the productive capacity of a site.

During the 1920's and 1930's, Land Economic Surveys were conducted for much of northern Lower Michigan. The purpose of these surveys was largely to assess the capability of these lands to support crops, grasses, and trees. The resultant soil maps are unique in that they were developed with ecological principles in mind. According to Foster et al. (1939), emphasis was placed on the original vegetation during mapping. These maps, then, are a reflection of the edaphic and vegetative components of the site, two very useful components when considering forest productivity. A second specific objective of this study was to assess the feasibility of using these Land Economic Survey maps to predict forest productivity, as measured by site index, in northern Lower Michigan. We were trying to answer the simple question: Can soil map units be created that relate reasonably well to site index?

STUDY AREA

Sampling was conducted on a total of 74 stands located throughout northern Lower Michigan (Fig. 1). Stands were located on Michigan state-owned lands, encompassing the Mackinaw, Pere Marquette, and Au Sable State Forests. The study area lies within Region II - Northern Lower Michigan, as defined by Albert et al. (1986). Within this broad physiographic/macroclimatic region, stands were located in the following Districts: Highplains, Newago, Leelanau, and Presque Isle.

Climatically, the study area is quite variable, with inland portions being less moderated by the effects of Lake Michigan. Mean annual precipitation ranges from 28 to 32 inches, with mean annual temperatures ranging from 42 F to 45 F. Average frost-free periods range from 70 days in the interior to 150 days along the coast of Lake Michigan.

Physiographically, the study area consists of a matrix of glaciofluvial deposits, originating from the Wisconsinan ice shield. Deglaciation began in the southern portion of the study area some 13,800 ybp, with the northern extent becoming ice-free about 10,000 ybp (Farrand and Eschmann, 1974). Prominant physiographic features of the area include medium to coarse textured morainic till, ice contact features such as kames, eskers, and kettle holes, outwash plains, and lacustrine deposits in the extreme north.

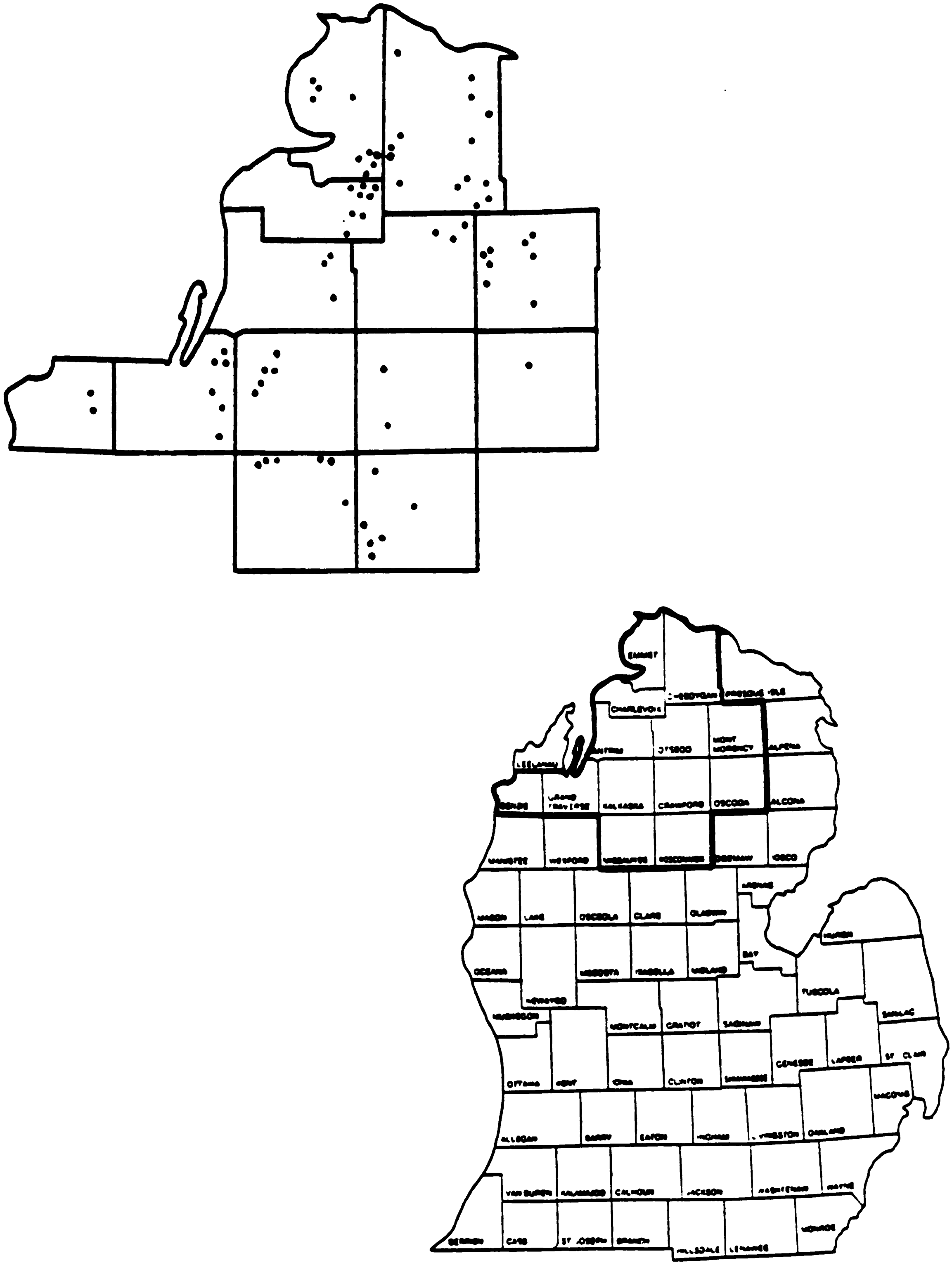


Figure 1. Study area, showing locations of each sample stand.

While soils vary extensively throughout the study area, sampling was most commonly conducted on medium to coarse textured Spodosols. The vast majority of sampled plots occurred on one of three soil series: Rubicon (sandy, mixed, frigid Entic Haplorthod), Emmet (coarse-loamy, mixed, frigid Alfic Haplorthod), and Roselawn* (sandy, mixed, frigid Alfic Haplorthod).

* The Roselawn series is no longer recognized by soil taxonomists. The current analogs are Leelanau, Mancelona, Melita, and Blue Lake.

METHODS

STAND SELECTION

Preliminary stand selection was based on field reconnaisance and information supplied by local Michigan DNR foresters. Final stand selection was based on field observation of the following features:

Age Structure

An effort was made to select only even aged stands for sampling. For the most part, this constraint was satisfied due to the past history of clearcutting in Michigan (most stands originated as even aged stands following clearcutting). In some cases, however, this even aged constraint was relaxed. In such cases, extreme care was taken to select sample trees that were free from evidence of past suppression. This was accomplished through inspection of increment cores, with periods of slow growth being sufficient cause for rejection. It was felt that occasional departures from this constraint were acceptable in light of the rigor exercised in sample tree selection. In a similar study by Monserud (1984), height growth patterns of Douglas-fir dominants were unaffected by stand age structure.

History of Disturbance

Suitable sample stands were free from evidence of growth retarding disturbances such as wind damage, fire, insect or disease infestations, or past cutting events. The disturbance history of each stand was determined by field inspection, and was supported by a series of increment cores that were inspected for growth irregularities.

Stocking

An effort was made to avoid stands that exhibited extremes in stocking density. Incomplete crown closure or obvious deficiencies in stand density were cause for rejection of mixed hardwood stands. This constraint was waived in certain outwash situations where complete crown closure simply does not occur in naturally regenerated forests.

Soil Map Unit

Because one objective of the study was to relate forest productivity to soil map units, stands were initially located on one of three commonly occurring soils. In an effort to avoid bias and realistically assess the variability within map units, the only restriction on stand location was that it fall within the physical confines of the delineated map unit. A second objective of relating productivity to vegetation type required additional stands be sampled on various soil types.

TREE SELECTION

An effort was made to select three trees of each species being studied from each site on which they occurred. Occasionally, however, only one or two individuals of a given species were suitable for selection. Proper sample tree selection was considered to be critical to the validity of this study. As such, extreme care was taken to ensure that each sample tree met the following criteria:

Stand Dominance

All sample trees occupied the dominant or codominant stand positions as described by Spurr and Barnes (1980).

Form

Sample trees were selected on the basis of superior form. Suitable trees were single stemmed, straight, and free from major forks in the crown.

Vigor

Only the most apparently healthy and vigorous trees were sampled in suitable stands. The occurrence of obvious defects such as dead or broken limbs, rotten cores, or major wounds of any kind were cause for rejection.

Species

The species considered in this study include red oak (*Quercus rubra* L.), bigtooth aspen (*Populus grandidentata*

Michx.), sugar maple (Acer Saccharum Marsh.), red pine (Pinus resinosa Aiton), basswood (Tilia americana L.), and white ash (Fraxinus americana L.). Red oak, red pine, and bigtooth aspen were the preferred sample species as their relative ubiquity allowed for comparison of a wide range of habitat conditions.

SAMPLING PROCEDURES

Upon selection of suitable sample trees, circular 150 m^2 plots were established using the tree as plot center. Within this plot, all herbaceous and woody plants less than 4.5 ft. in height were recorded and assigned a coverage value. Coverage values were based on an ocular estimate, and adhered to the following scale:

1	<1%	5	50% - 75%
2	1% - 5%	6	75% - 95%
3	5% - 25%	7	95% - 100%
4	25% - 50%		

Soil was described from a soil pit, which was located near the center of each sample stand. Soil samples were collected from each horizon for future verification of the soil map unit. Additional site information collected for each sample tree included percent slope, aspect, and slope position. After the felling of each sample tree, the stump was used as a platform from which a BAF 10 point sample was conducted with a Relaskop. Species and diameter were recorded for each "in" tree.

Stem Analysis

Sample trees were marked at 4.5 feet, and dbh was recorded. Each tree was then felled, limbed, and measured for total height. One-inch thick radial sections were removed at breast height, and every four feet thereafter. These sections were transported from the field for analysis.

Sections were analyzed for age and diameter inside bark shortly after they were collected. In addition, 10 year growth increment was measured from the breast height section. For most species, age determination was easily accomplished. With aspen, however, it was neccessary to use a staining agent to enhance the contrast between early and late wood. Phloroglucinol proved to be a useful staining agent.

Before proceeding with the data analysis, plots of height versus age were produced for each sample tree. These graphs were inspected for signs of early height growth suppression and other growth abnormalities such as top breakage. Any tree showing evidence of suppression or breakage was eliminated from the study. All growth curves were based on age 0 at breast height, which alleviates the problem of erratic height growth associated with establishing seedlings (Carmean, 1978).

Data Analysis

Stands were stratified by both soil map unit and vegetation type for statistical analysis. Vegetation type determinations were based on the characteristics of the woody and herbaceous ground flora occurring in each sample stand. Analysis of the ground flora was conducted with the use of TWINSPAN (Two-Way INdicator SPecies ANalysis), a computer package that classifies stands according to their floral characteristics (Hill, 1979). The program classifies sample stands based on differential species through a series of dichotomies of ordinated stands. This procedure assigned each stand to a particular vegetation type based on the characteristics of the ground flora.

For each species, individual tree height growth curves were averaged by stand. Averaging the height growth curves of individual trees served to mitigate the effects of individual tree characteristics on the overall assessment of the site. These average height growth curves were used in all subsequent analyses.

Nonlinear regression analysis was performed on the height/age data for each species, with stands grouped by both soil type and vegetation type. While height growth patterns of forest trees are normally considered to be sigmoid (Husch et al., 1972), the truncation of our data below 4.5 ft. effectively eliminated the point of inflection, resulting in a hyperbolic height growth pattern. The following first order monomolecular function proved to be well suited to the height/age data:

$$H = B(1) * (1.0 - B(2) * EXP(-B(3) * A))$$

Where H equals total tree height, A equals age from breast height, and B(1), B(2), and B(3) are regression parameters estimated for each combination of species and soil type and species and vegetation type. Parameter estimation and nonlinear regression were performed using the PLOTIT statistical program (Eisensmith, 1983). The Marquardt compromise method of parameter estimation was employed throughout this study.

The height growth data from each species/stand combination were evaluated at age 50. The resulting stand-specific site index values were used as the unit of observation in subsequent tests for differences in site index among soil types and vegetation types.

RESULTS

VEGETATION ANALYSIS

The TWINSPAN analysis of the ground flora data revealed 5 logical groupings of the 74 upland sample stands (Table 1). The groupings are a result of hierarchical divisions of stands ordinated along a composite moisture-fertility gradient. Major breaks in similarity of ground flora delineated the divisions between groups. With the exception of one grouping, the primary division separated those sites capable of supporting northern hardwood stands from those that typically support red maple, oak, or pine. Further divisions yielded two logical subdivisions of each of these two groups, and one apparent successional/edaphic intergrade between the two (floristically distinct, however). It is important to note that grouping of stands was made irrespective of the current overstory composition. They are based solely on the composition and abundance of the vegetation less than 4.5 ft. in height.

Using characteristic and differential species, a key was developed to distinguish among the 5 upland forest vegetation types encountered in the study area (Fig. 2).

Table 1. Ordination of sample stands based on the similarity of the ground flora.*

	NORTHERN HARDWOOD DOMINATED ECOSYSTEMS		OAK AND PINE DOMINATED ECOSYSTEMS		
	SMO	SMM	RMOT	RMOW	OPV
	55 756777566656445666 7	6 1111 11 162244	22222	121333333	444453445 17 233 2553
SPECIES	64891582346579905711340	6302365494124606	01328	855578036	1234798931758924770212
Actaea pachypoda	--223-2223--12-2--111--	-1--111-1----1--	-----	---------	----------------------
Allium tricoccum	-312-22133-1-1--1------	----------------	-----	---------	----------------------
Arisaema triphyllum	---211-323--1----------	-1--------------	-----	---------	----------------------
Cornus alternifolia	333--1-1-3-111-1--3----	------1-1-------	-----	---------	----------------------
Dryopteris spinulosa	-3--2233231-3222-2----1	1--1---------1--	-----	---------	----------------------
Epipactis helleborine	----------31-3-3--3----	----1-----------	-----	---------	----------------------
Polygonatum pubescens	---212-2232332231---2-2	----1----1-2-1--	11---	---------	----------------------
Sambucus pubens	--132-23131--2---------	---------1------	-----	---------	----------------------
Caulophyllum thalictroides	--1-11222-1-211-1------	----------------	-----	---------	----------------------
Botrychium virginianum	33321221-3232-2232--11-	11----2-2-1-12--	-----	---------	----------------------
Carex plantaginea	-313313112111311-33--23	1--------------1	-----	---------	--------1-------------
Osmorhiza claytonii	3-323334431323-123-32--	12---11121---1--	-----	---------	----------------------
Ulmus americana	--2--22212-2-2--3-1322-	1-----1--1-1-2--	-----	---------	-1--------------------
Hepatica americana	-3--------1---2-12-----	1---------------	-----	---------	----------------------
Adiantum pedatum	------1-----22-123-----	----------------	-----	---------	----------------------
Tilia americana	-31223112-3333322232321	1221223-3--2-212	1111-	---------	----------------------
Acer saccharum	54545544434544433343333	4445433335434-33	1131-	---------	1--------1------------
Fraxinus americana	5332333333332133-313131	232333334213-223	1331-	---------	1---------------------
Ostrya virginiana	443223413244434342-1342	3333433342333343	22411	---------	---------1------------
Trillium grandiflorum	--22-2211-2233333----2-	32-2322221-2-121	1111-	---------	1---------------------
Uvularia sessilifolia	----------11----22-----	----11--------11	-----	---------	----------------------
Galium sp.	--323133232333--33312-1	12---2223--112-1	-1---	--11--32-	---------------1----1-
Viola sp.	3-323233432133123323122	11---11-1--2--2-	-12--	--11---31	---------13-----------
Acer pensylvanicum	----3--22--1--23-----11	2132331321-2-1--	-12--	---------	----------------------
Lycopodium lucidulum	----1------------------	---2--1--2112---	-----	---------	----------------------
Taxus canadensis	--3--------------------	5-----------11--	-----	---------	---------1------------
Betula papyrifera	-----------------------	-----1132--1----	-1---	---------	--------------1-1-----
Fagus grandifolia	--224332324213331323223	43442413343342-3	312-3	--1------	---1----1121-2--111---
Mitchella repens	------1-------113----1-	1--212-33112213-	--21-	------2--	---------12----1------

Table 1. - continued page 2

SPECIES	NORTHERN HARDWOOD DOMINATED ECOSYSTEMS		OAK AND PINE DOMINATED ECOSYSTEMS		
	SMO	SMM	RM OT	RMOW	OPV
	55 7567775666564456667	6 1111 11 162244	22222	121333333	444453445 17 233 2553
	6489158234657990571340	6302365494124606	01328	855578036	1234798931758924770212
Medeola virginiana	----------------------	---1-1--1--31---	--1--	----1----	---------------1------
Monotropa uniflora	-------------1--------1	1----1-1----1---	-11-1	---------	---------1------------
Uvularia perfoliata	----------11----23-----	----1121121-2-11	-11--	---11---2	----------------------
Aralia nudicaulis	--4-1-----2312-1-2---11	--2123--212311--	1212-	--1342---	----------1-1-3-------
Lonicera canadensis	--2-1-2--2-2-21-----1-2	----1-----11222-	11---	--12212--	---------------1------
Smilacina racemosa	-1--------- 1-12----1--	----1------221--	-1112	---2----1	----------------------
Rubus sp.	--333111--1------2--452	-1-1-11-3-32-1-1	-11--	331-2-333	3-----1121------------
Anemone quinquefolia	-----------1------122--	----------------	---1-	-3-------	----------------------
Fragaria virginiana	----------1-----1-24431	----------------	-----	---1-2-32	------11------11------
Aster macrophyllus	--1---2222-1-3--132-3-2	1---11212-1111-2	43443	333333333	13-----3-11---11------
Chimaphila umbellata	----------------------	-----------11-1-	-1---	--12-----	----------------------
Pyrola rotundifolia	----------1-----1-2---2	----1122--1-11--	21112	1-22----1	---------122----------
Cornus rugosa	----------------------	-----1--1----1--	-121-	---------	----------------------
Viola pubescens	----------------------	-----1222---11--	12-1-	3--------	----------------------
Apocynum androsaemifolium	----1------21--------1-	-1--1-1-1----1--	2111-	111-12---	1-----------1--1------
Potentilla simplex	-------------------232-	-1------1---11--	1112-	231------	----------------------
Hieracium sp.	----3-------22--1222323	------11-1-112-1	1112-	-211---23	11113-11-21----1---1--
Maianthemum canadense	--123121221111221---21-	21-33221332332--	21231	333332322	------2--1321332----2-
Populus grandidentata	--3---12-21---121-3-12-	-1-11121--221122	-1-11	-12121312	3-21-3-111--1--11-1--2
Prunus serotina	--3-313133223---3233333	-331-11111-322-3	22-33	333323333	33323--331311-13------
Abies balsamea	----1------1----2---113	------3---3-12--	-111-	--11---1-	11----------12--2---23
Amelanchier sp.	--3---1----2-2112333333	--32111321332233	33333	333333333	3333333-13333333232324
Lonicera sp.	--------1------11------	----------------	1--1-	131------	------1--23-----------
Prunus virginiana	----------1--1--------1	------1-2-1-112-	1112-	211------	--33--------2----------
Carex pensylvanica	--2-111-12331-233413-2-	11-322322--1233-	2-1--	-1-21333-	323334433-333-33--3443
Pinus resinosa	-------------------2121	---------1---11--	---11	--------2	-----2---1-1----11-2-2
Trientalis borealis	---------------------1	------11213-2---	33213	1--23-321	--3--121---22333------
Lycopodium trystachium	----------------------	------------11--	-1-1-	-1-------	1---1131--------------
Acer rubrum	3-32------1------2---12	-113111-2333223-	33233	333333334	3333333333333333331323

Table 1. - continued page 3

SPECIES	NORTHERN HARDWOOD DOMINATED ECOSYSTEMS		OAK AND PINE DOMINATED ECOSYSTEMS		
	SMO	SMN	RMOT	RMOW	OPV
	55 7567775666564456667	6 1111 11 162244	22222	121333333	444453445 17 233 2553
	64891582346579905711340	6302365494124606	01328	855578036	1234798931758924770212
Pteridium aquilinum	--3-2-----1-----25--2-	-1--111---4442-4	54355	555555555	5545545525544555555545
Quercus rubra	--------------3-3-1---	-1-222-33-1--133	33333	322333333	3333333333323133-3333-3
Populus tremuloides	----------------------	------1-1-------	21111	1--------	-------------2--------
Prenanthes alba	----------------------	-----11-1-------	-212-	-1-1-1212	------11--------------
Streptopus roseus	-----1----1-1---12----	-1-1-11-1-11--21	2211-	1--332222	2-22-1-2---1----------
Viburnum acerifolium	---------------2------	----111------133	-3311	1131133-1	3--1--22--2-----------
Corylus cornuta	--2---1------------212	-------------1--	13123	-3-33432-	---------------11-----
Polygala paucifolia	----------------------	----------------	-2133	--1-1-2--	-------1------1-------
Oryzopsis asperifolia	-----------21---------	---111-2--1-1-1-	43333	334233331	--221-232322--1311---3
Hamamelis virginiana	---------------1------	------1---------	-1---	--22323-1	3-31-323---1--1-1-----
Vaccinium myrtilloides	----------------------	----------------	1--1-	3323113--	-312-23--13312----2---
Diervilla lonicera	----------------------	------------11--	-----	-1--112-2	11--1----------12---1-
Gaultheria procumbens	----------------------	----------13----	12124	333333433	33233332-3332433333332
Quercus alba	----------------------	----------------	---1-	---33232-	----13334---1-2---431-
Epigea repens	----------------------	----------------	----2	--1-1----	---2--31-132-511---1-2
Melampyrum lineare	----------------------	----------------	---1-	3--3--322	131-2322-3--2-232-3333
Pinus strobus	------1---------------	------------2--1	22113	3-322--2-	-2221332-133-24131323-
Vaccinium angustifolium	----------------------	----------------	-1112	233322-33	1233133333124444333354
Cladonia rangiferina	----------------------	----------------	-----	---------	-----2---1-11---1-----
Comptonia peregrina	----------------------	----------------	---1-	-------11	-----3-13---3--1----32
Gaylussacia baccata	----------------------	----------------	-----	------2-2	------------332-------
Quercus velutina	----------------------	----------------	---1-	-3-------	------------3--3----4-
Cornus canadensis	----------------------	----------------	-----	---------	-------------322-1----
Cypripedium acaule	----------------------	-----------1----	-----	---------	-3--112-31-2----21-12-
Hieracium venosum	----------------------	----------------	-----	1--------	---------1--1--------3
Pinus banksiana	---------------------1	----------------	-----	---------	---------1--1----3-33-
Lycopodium complanatum	---------2------------	----------------	-----	---------	-------1-1-----------3

* Values represent coded TWINSPAN coverage classed, and adhere to the following scale:

1 <.25%
2 .25% - 1%
3 1% - 5%
4 5% - 25%
5 >25%

- Common reproduction of sugar maple, white ash, and ironwood
  Rattlesnake fern common
  Blueberry, wintergreen, and polygala usually absent
  - Abundant sweet Cicely and violet sp. Spinulose woodfern blue cohosh, and alternate leaved dogwood common
    Partridgeberry and shining clubmoss rare or absent
    — **SUGAR MAPLE OSMORHIZA**
  - False lily-of-the-valley and partridgeberry common
    Shining clubmoss and red maple reproduction often present
    Jack-in-the-pulpit, elderberry, and wild leek absent or rare
    — **SUGAR MAPLE MAIANTHEMUM**
- Blueberry and wintergreen usually common
  Sweet Cicely, spinulose wood fern, and rattlesnake fern absent
  - Hazelnut and polygala common
    Reindeer lichen and moccasin flower usually absent
    - Reproduction of ironwood, sugar maple, beech, and white ash usually present - scattered trillium
      Witch-hazel and bush honeysuckle rare or absent
      — **RED MAPLE OAK TRILLIUM**
    - Cow-wheat, bush honeysuckle, and witch-hazel often present
      Lacking reproduction of ironwood sugar maple, basswood, and ash
      — **RED MAPLE OAK WITCH-HAZEL**
  - Moccasin flower often present in low abundance
    Blueberry present in high abundance
    Hazelnut and polygala usually absent
    — **OAK - PINE VACCINIUM**

Figure 2. Key to 5 upland forest vegetation types occurring in northern Lower Michigan.

DESCRIPTION OF VEGETATION TYPES

Sugar Maple - *Osmorhiza* (SMO)

The SMO vegetation type represents the most mesic of the sampled stands. Ground flora species characteristic of this type and differential with respect to other types include *Allium tricoccum* Aiton, *Arisaema triphyllum* (L.) Schott, *Caulophyllum thalictroides* (L.) Michaux, and *Sambucus pubens* Michaux. Also characteristic, but not differential, are *Osmorhiza claytonii* (Michaux) C. B. Clarke, *Dryopteris spinulosa* (O.F. Mull.) Watt., *Botrychium virginianum* Swartz, *Polygonatum pubescens* (Willd.) Pursh, *Actaea pachypoda* Ell., and *Trillium grandiflorum* (Michaux) Salisb.. The seedling layer is composed of relatively high coverages of *Acer saccharum*, *Tilia americana*, *Fraxinus americana*, and *Ostrya virginiana*. Stands of this type typically support a northern hardwoods overstory, most commonly the Sugar Maple-Basswood and Beech-Sugar Maple cover types (Eyre, 1980). Ephemeral cover types on this vegetation type include *Populus grandidentata* and *Pinus resinosa* plantations. The SMO type is restricted to medium textured soils associated with rolling morainal topography.

Sugar Maple - *Maianthemum* (SMM)

The SMM vegetation type represents the mesic to sub-mesic portion of our sample stands. It is characterized by a relatively depauperate herbaceous ground flora, with seedlings often comprising the dominant ground cover. Differential species for the SMM type include Lycopodium lucidulum Michaux and Polygonatum pubescens, although these species tend to have a relatively low constancy. This type can be distinguished from the SMO type by the lack of Caulophyllum thalictroides, Allium tricoccum, and Sambucus pubens. Species characteristic of this type include Maianthemum canadense Desf., Mitchella repens L., Trillium grandiflorum, Galium sp., Viola sp., Acer pensylvanicum L., Aralia nudicaulis L., Amelanchier sp., Carex pensylvanicum Lam., and seedlings of Acer saccharum, Tilia americana, Fraxinus americana, Ostrya virginiana, and Acer rubrum L.. The SMM type typically supports a northern hardwood overstory similar to that of the SMO type, although Acer rubrum tends to become a more important associate here. Common seral species on this type include Acer rubrum, Populus grandidentata and Pinus resinosa plantations. The SMM type occurs on medium to coarse textured soils associated with rolling morainal topography. Emmet loamy sand and Kalkaska loamy sand were the typical soils supporting the SMM type.

Red Maple - Oak - Trilluim (RMOT)

The RMOT type represents an apparent successional/edaphic intergrade between the northern hardwood sites and the oak-pine sites. Species differential with respect to the SMM type include Vaccinium angustifolium Aiton, Polygala puacifolia Willd., and Gaultheria procumbens

L., while those differential with respect to the oak-pine sites include the seedlings of Acer saccharum, Tilia americana, Fraxinus americana, and Ostrya virginiana. Species characteristic of this type include Pyrola rotundifolia L., Corylus cornuta Marshall, Gaultheria procumbens, Maianthemum canadense, Oryzopsis asperifolia Michaux, Amelanchier sp., Trientalis borealis Raf., Vaccinium angustifolium, Pteridium aquilinum Kuhn, and seedlings of Quercus rubra, Pinus strobus L., and Fagus grandifolia Ehrhart, as well as those mentioned above. The dominant overstory composition of these stands include Quercus rubra, Acer rubrum, Populus grandidentata, and Acer saccharum. The RMOT type occurred exclusively on the Roselawn soils in our study area. The characteristic topography was gently rollong to nearly level.

Red Maple - Oak - Witch-hazel (RMOW)

The RMOW type represents the dry mesic to sub-xeric sites occurrring in the study area. Species occurring in this type that are differential with respect to the RMOT type include Melampyrum lineare Desr. and Hamamelis virginiana L.. No northern hardwood seedlings occur in the RMOW type. Species characteristic of this type include Vaccinium angustifolium, Gaultheria procumbens, Oryzopsis asperifolia, Hamamelis virginiana, Viburnum acerifolium L., Corylus cornuta, Streptopus roseus Michaux, Pteridium aquilinum, Maianthemum canadense, and seedlings of Amelanchier sp., Quercus rubra, Acer rubrum, and Prunus serotina Ehrhart. The dominant overstory species occurring on the RMOW are Quercus rubra, Pinus resinosa, Acer rubrum, Pinus strobus, and Pinus banksiana Lambert. Populus grandidentata is the dominant seral species. The RMOW type occurred on coarse textured outwash plains, typified by the Rubicon soil series.

Oak - Pine - Vaccinium (OPV)

The OPV type represents the most xeric of our sample stands. This vegetation type is characterized by high coverages of Vaccinium angustifolium, Gaultheria procumbens, Pteridium aquilinum, and seedlings of Amelanchier sp., Acer rubrum, Quercus rubra, and Pinus strobus. Carex pensylvanicum, Oryzopsis asperifolia, and Melampyrum lineare are also quite common. Species differential with respect to the RMOW type include Cypripedium acaule Aiton and Cladonia rangiferina, the latter having a relatively low constancy. Species common in the RMOW type but absent or rare in the OPV type include Apocynum androsaemifolium L. and Lonicera canadensis Marshall. This type typically supports Quercus rubra, Quercus velutina Lamarck, Acer rubrum, Pinus resinosa, Pinus strobus, and Pinus banksiana, alone or in association. Populus grandidentata is the common seral species. The OVP type occurred on droughty outwash plains. Rubicon sand and Grayling sand were the typical soils supporting the OPV vegetation type.

HEIGHT GROWTH CURVES

For each vegetation type and soil type, average stand height/age data were combined into a single scattergram by species, upon which nonlinear regression analysis was performed. Figure 3 depicts the height growth of basswood growing on the SMO vegetation type. Evident from this plot is the rather close clustering of the data within the soil-vegetation types. The height growth patterns of each species on the three soil types are presented in Figures 15 - 23, Appendix A. Similarly, Figures 23 - 42, Appendix B show the height growth patterns for each of the vegetation types. Table 2 shows the coefficients of determination for each of the species/soil combinations. Similarly, Table 3 shows the coefficients of determination for each of the species/vegetation type combinations.

Of particular interest to us was the shape of the height growth curves for a single species growing on differing soil or vegetation types. While differences in the magnitude of the curves would be expected, deviations from proportionality in their shape would indicate that polymorphic height growth patterns do occur. Inspection of the fitted regression lines plotted on a common axis for each species reveals moderate to pronounced polymorphism (Figures 4 - 12). The most pronounced polymorphism occurs with *Populus grandidentata*, where the height growth pattern on the better sites differs drastically from those on the poorer

Figure 3. Height growth of basswood growing on the SMO vegetation type.

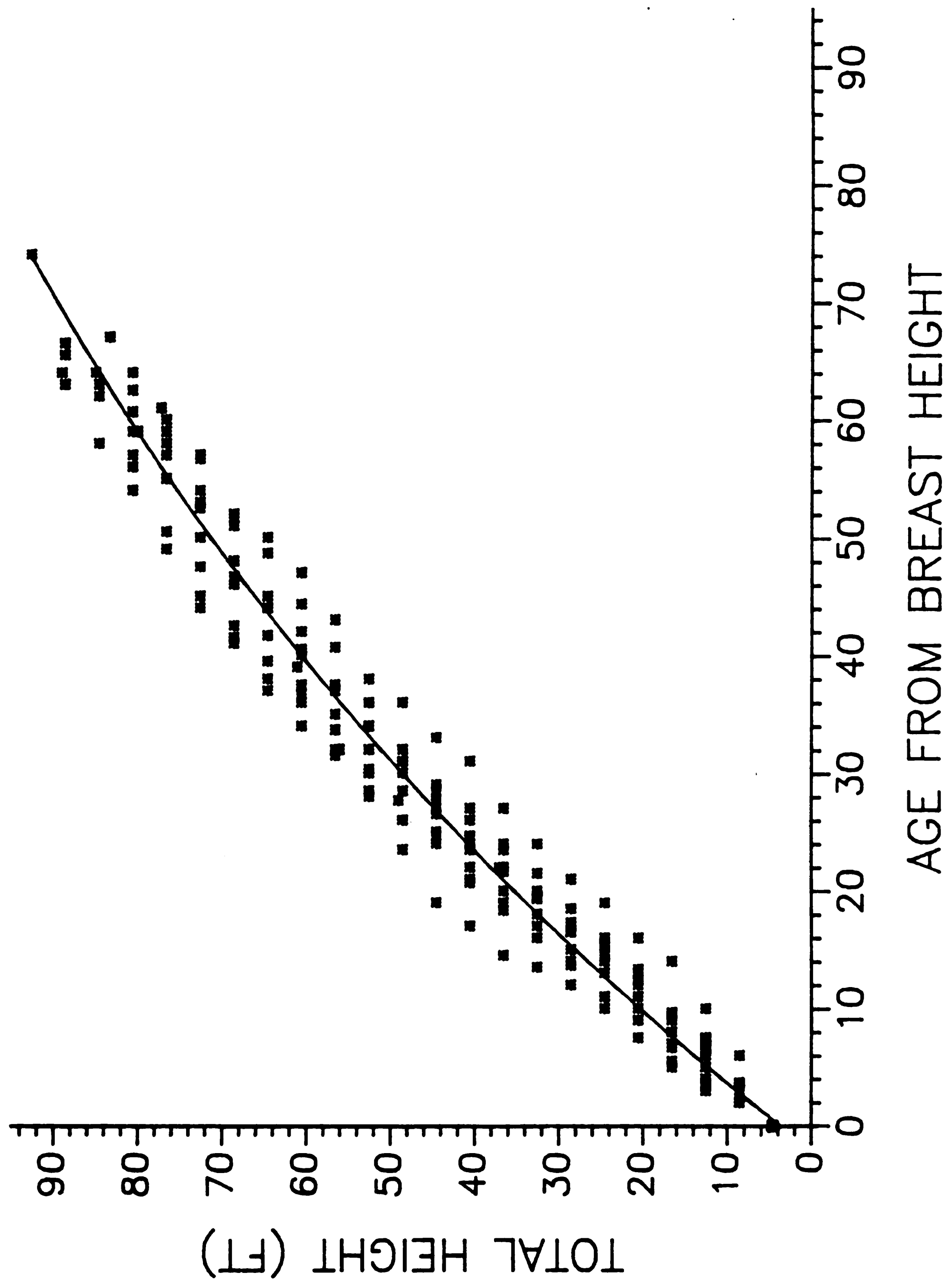

TOTAL HEIGHT (FT)
0 10 20 30 40 50 60 70 80 90
AGE FROM BREAST HEIGHT
0 10 20 30 40 50 60 70 80 90

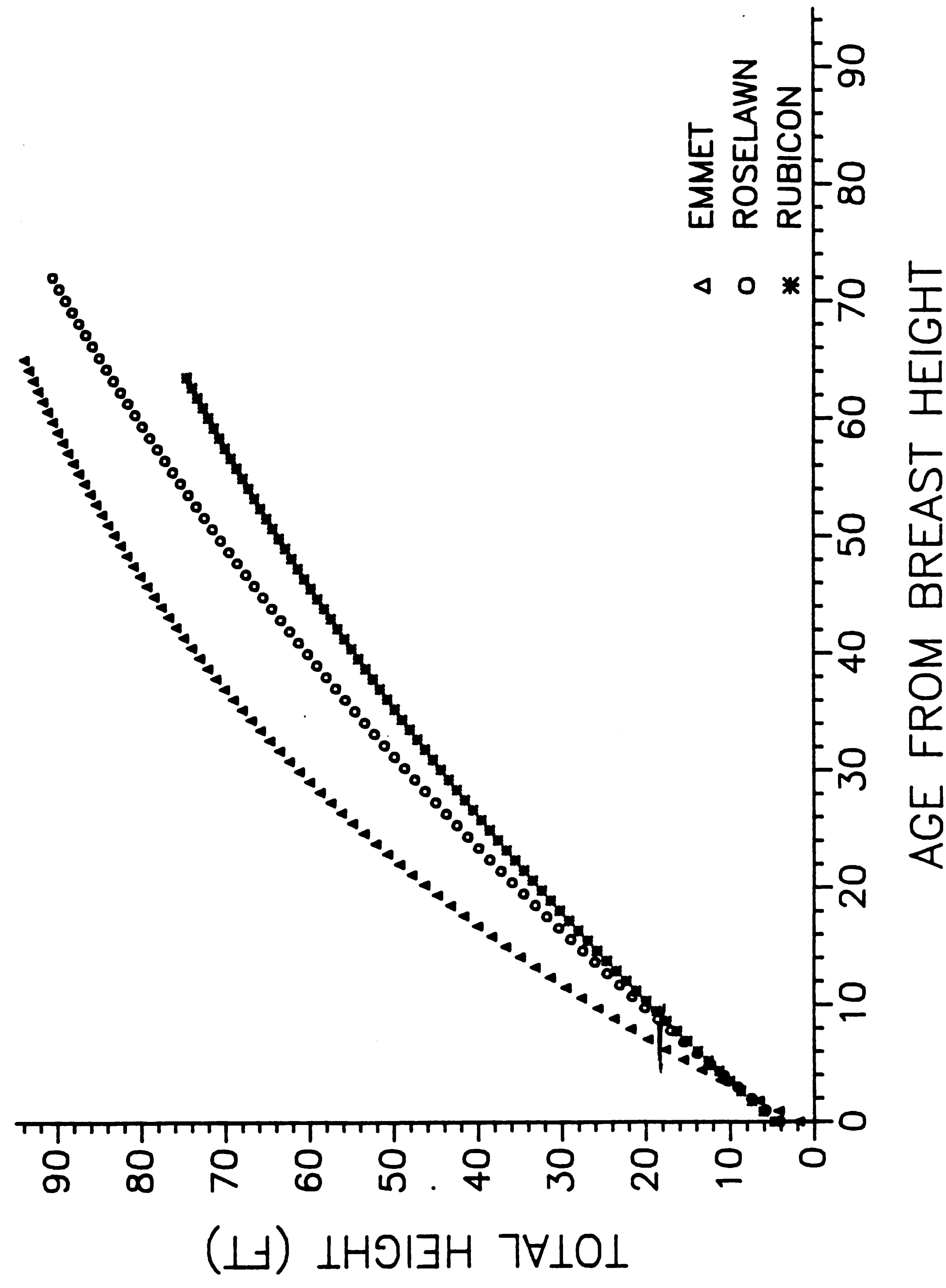
Table 2. Coefficients of determination by species and soil type.

	SOIL TYPE		
	RUBICON	ROSELAWN	EMMET
SPECIES	COEFFICIENT OF DETERMINATION		
RED OAK (*Quercus rubra*)	.967	.983	.980
RED PINE (*Pinus resinosa*)	.967	.959	.986
BIGTOOTH ASPEN (*Populus grandidentata*)	.975	.922	.919

Table 3. Coefficients of determination by species and vegetation type.

	VEGETATION TYPE				
	SMO	SMM	RMOT	RMOW	OPV
SPECIES	COEFFICIENT OF DETERMINATION				
RED OAK (*Quercus rubra*)	---	.981	.983	.975	.965
RED PINE (*Pinus resinosa*)	.964	.986	.958	.953	.970
BIGTOOTH ASPEN (*Populus grandidentata*)	.947	.934	.931	.924	.966
SUGAR MAPLE (*Acer saccharum*)	.956	.972	---	---	---
WHITE ASH (*Fraxinus americana*)	.947	.985	---	---	---
BASSWOOD (*Tilia americana*)	.974	.962	---	---	---

Figure 4. Mean height growth of bigtooth aspen growing on three soil types.


TOTAL HEIGHT (FT)
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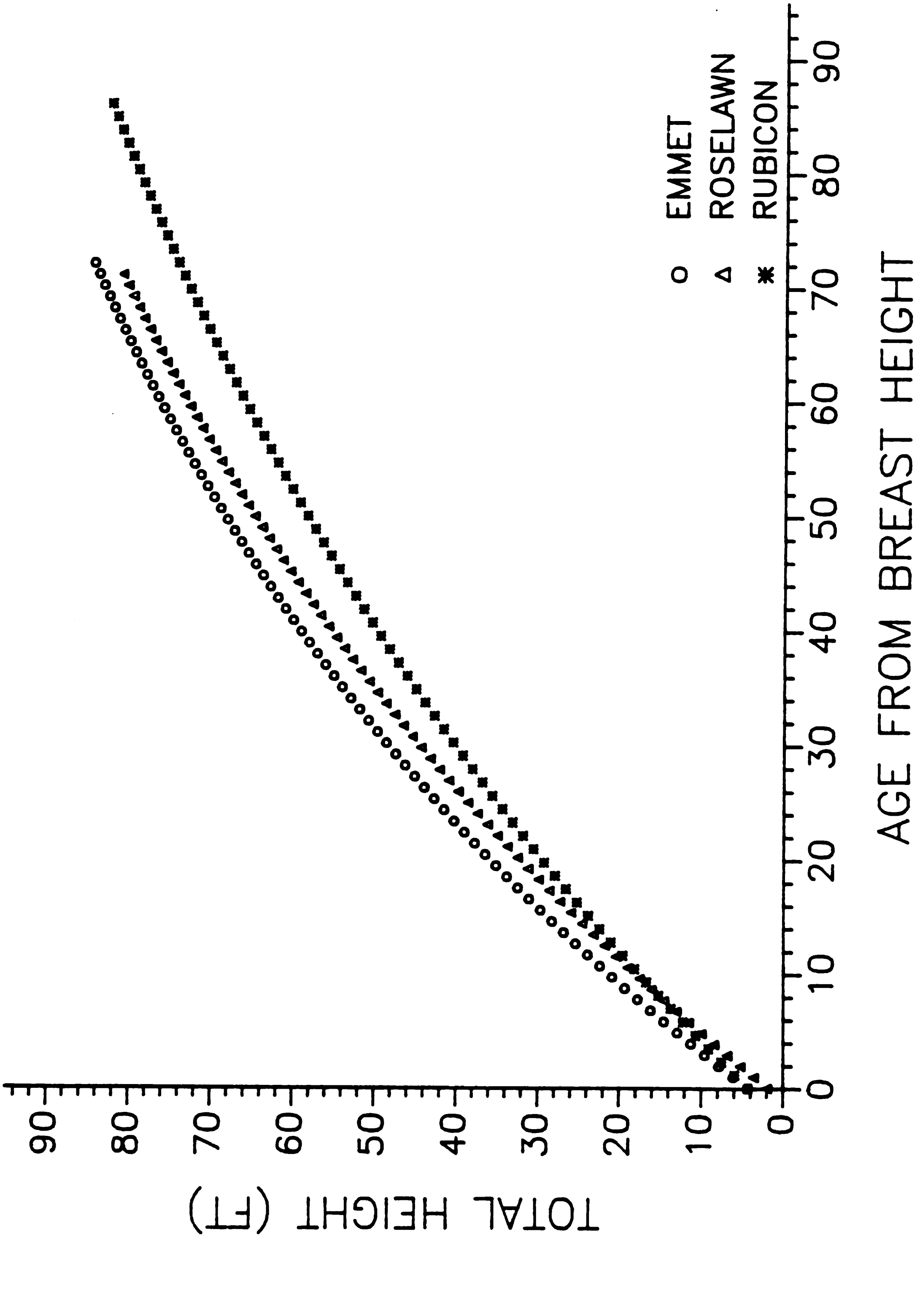
50
60
70
80
90
AGE FROM BREAST HEIGHT
△ EMMET
o ROSELAWN
✱ RUBICON

Figure 5. Mean height growth of red oak growing on three soil types.


TOTAL HEIGHT (FT)
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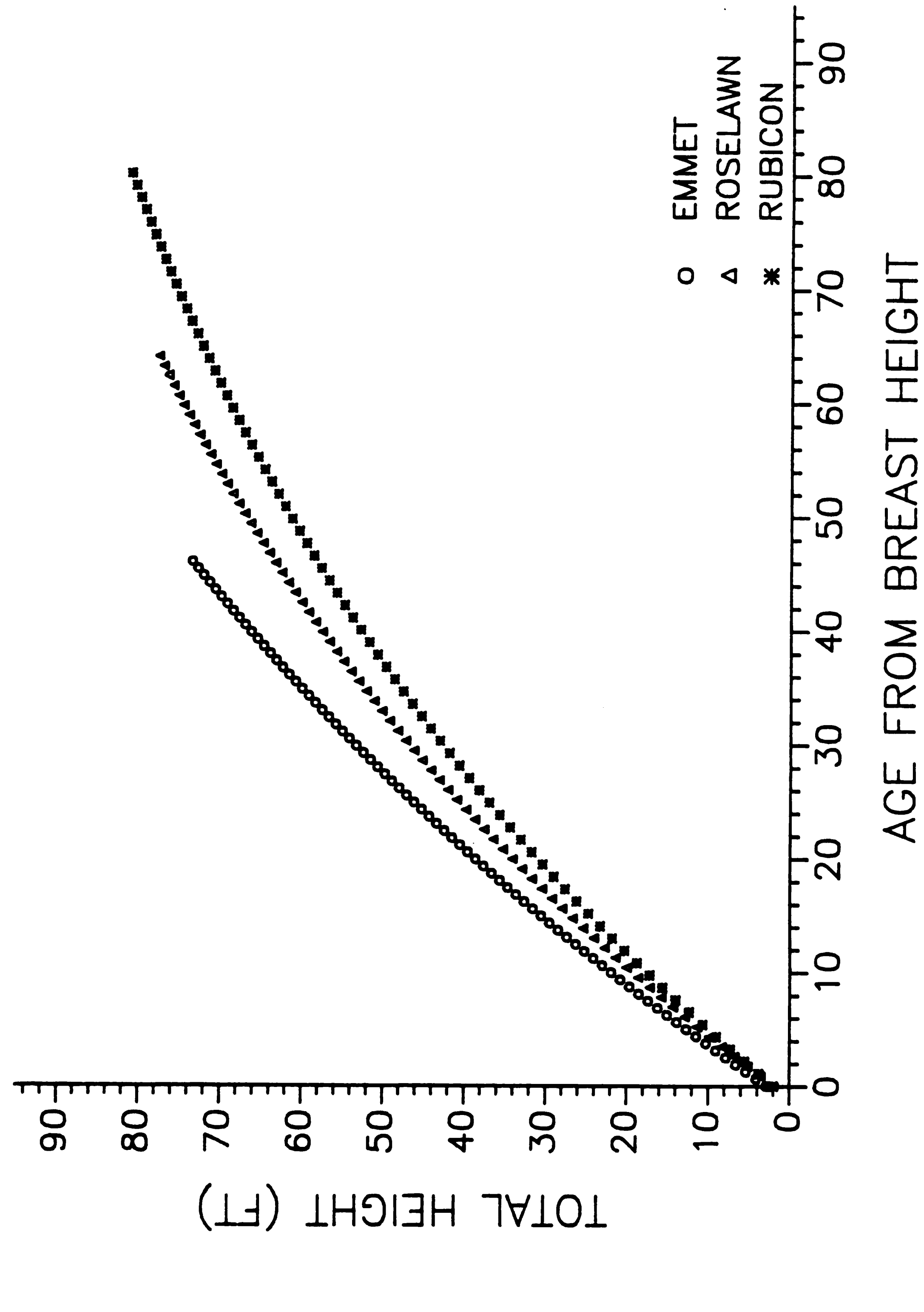
AGE FROM BREAST HEIGHT
○ EMMET
△ ROSELAWN
✱ RUBICON

Figure 6. Mean height growth of red pine growing on three soil types.


TOTAL HEIGHT (FT)
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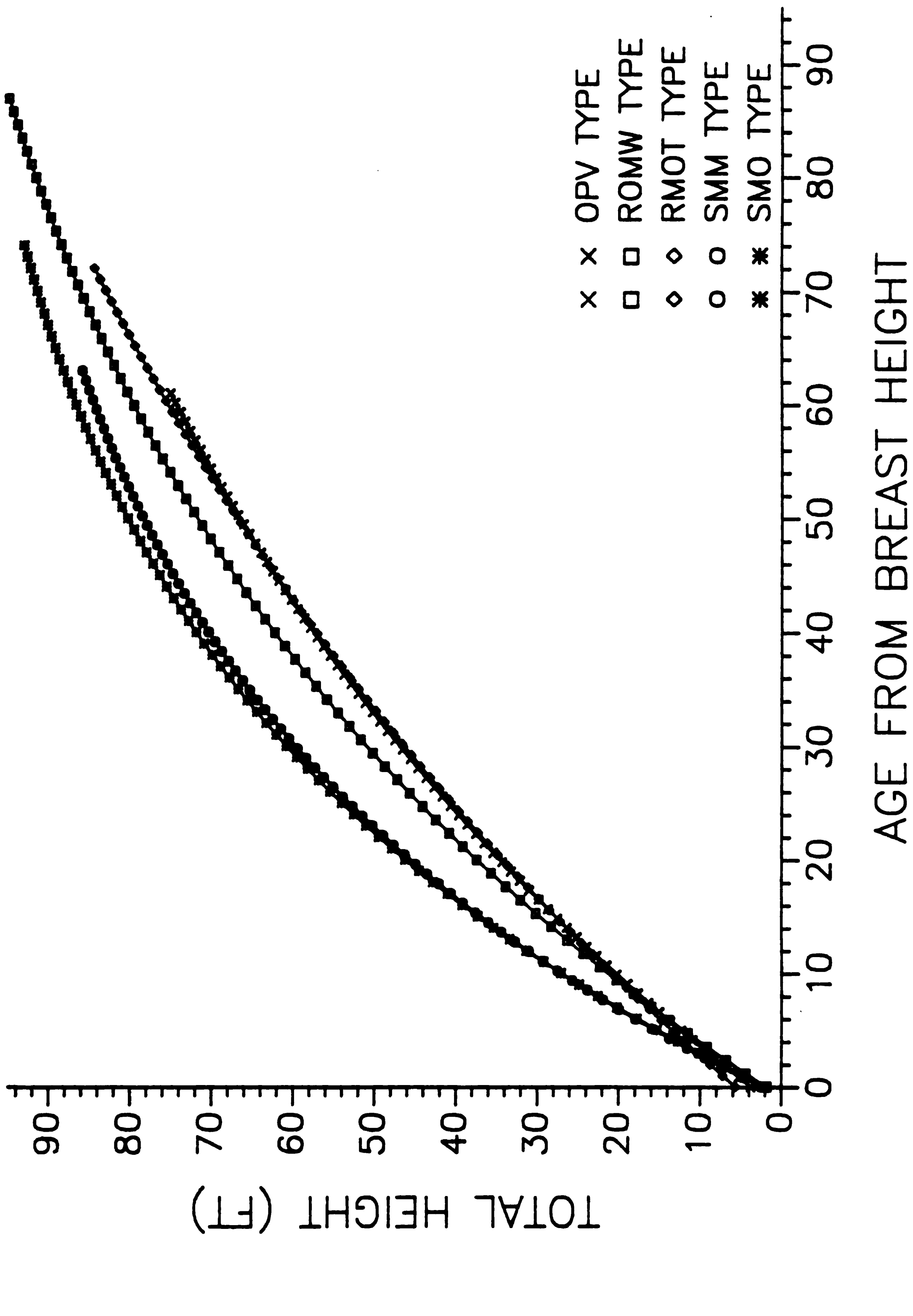
90
AGE FROM BREAST HEIGHT
EMMET
ROSELAWN
RUBICON

Figure 7. Mean height growth curves for bigtooth aspen growing on five vegetation types.


TOTAL HEIGHT (FT)
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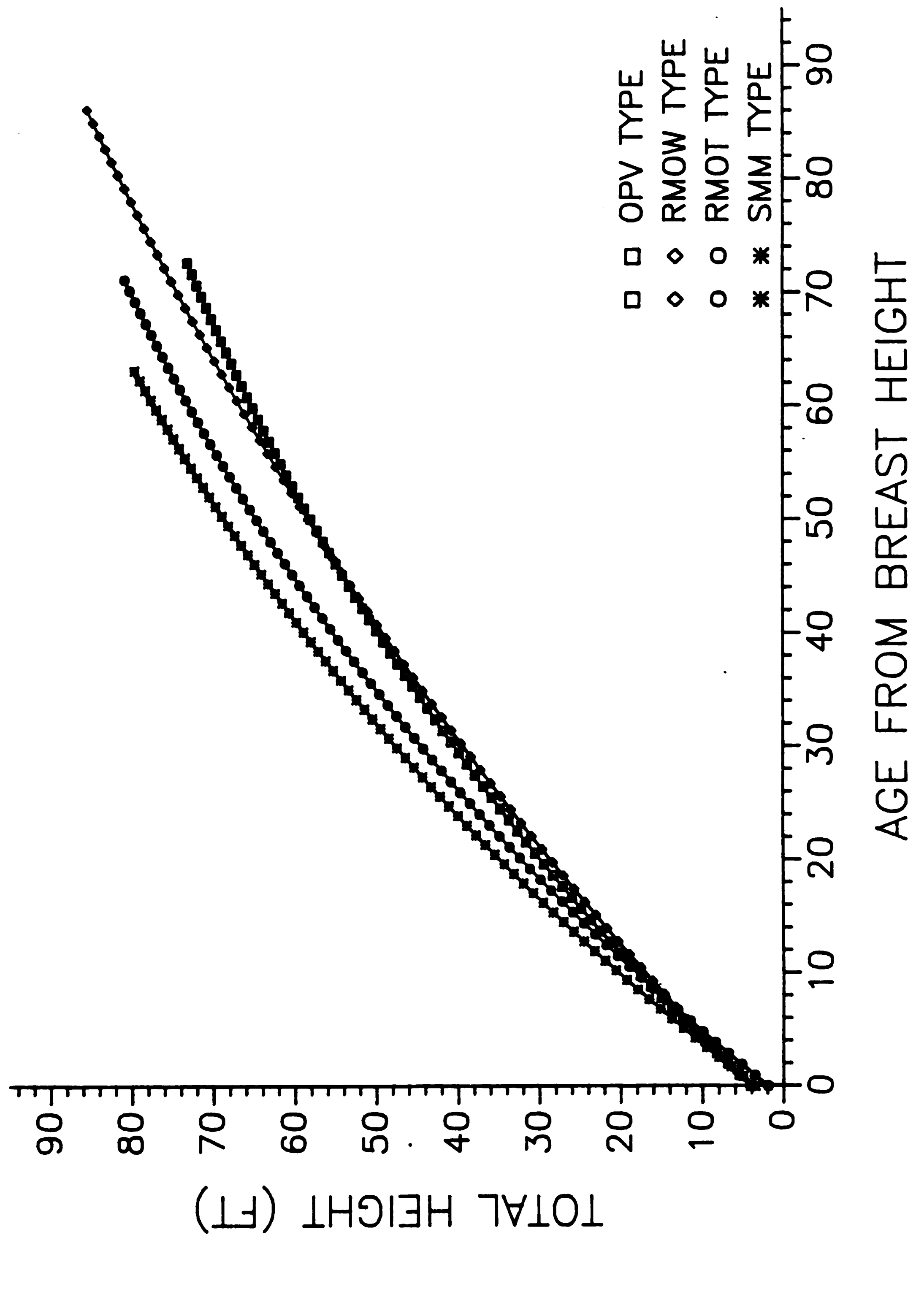
× OPV TYPE
□ ROMW TYPE
◇ RMOT TYPE
○ SMM TYPE
✱ SMO TYPE

Figure 8. Mean height growth curves for red oak growing on four vegetation types.


TOTAL HEIGHT (FT)
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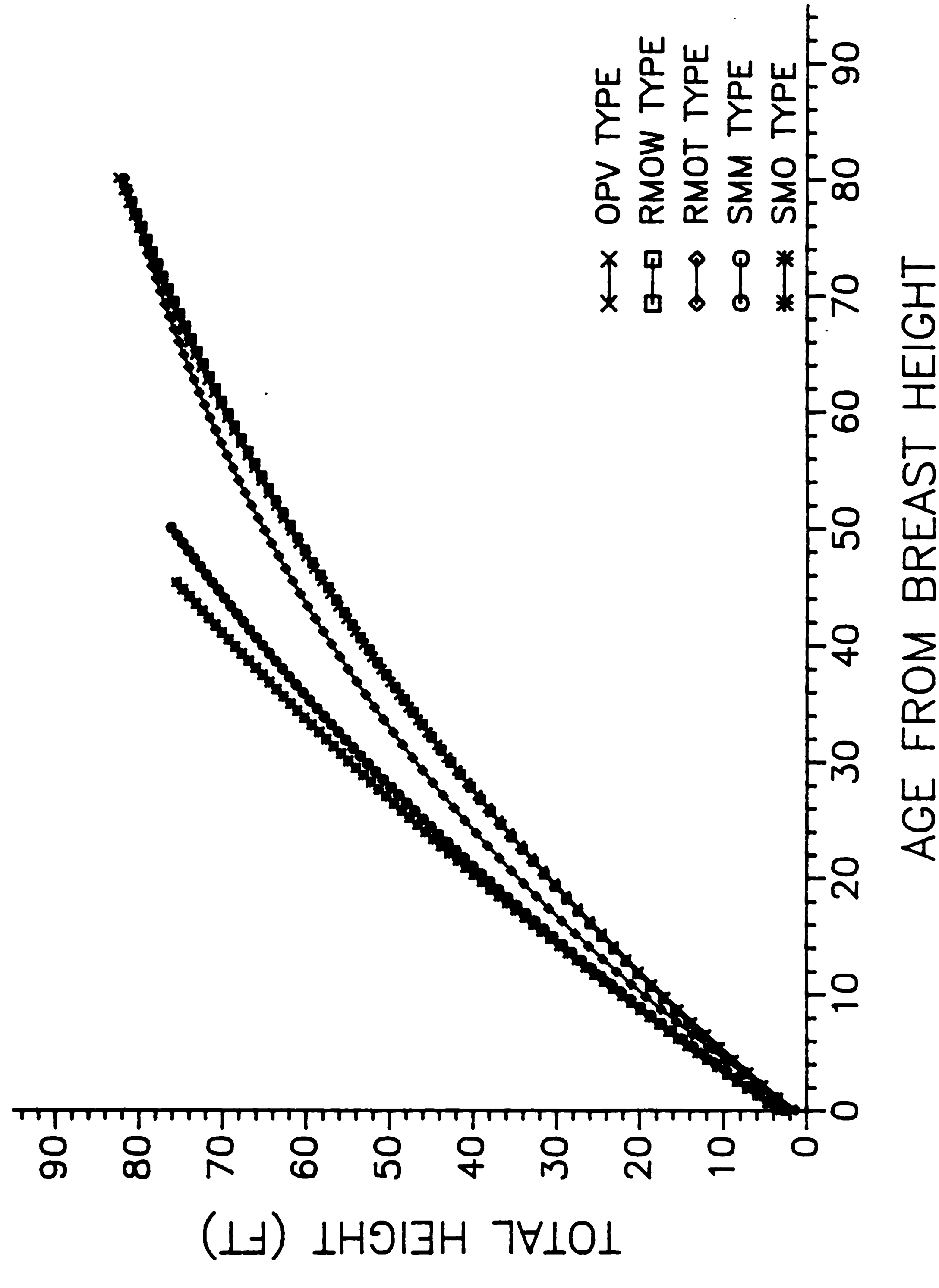
AGE FROM BREAST HEIGHT
OPV TYPE
RMOW TYPE
RMOT TYPE
SMM TYPE

Figure 9. Mean height growth curves for red pine growing on five vegetation types.



TOTAL HEIGHT (FT)
AGE FROM BREAST HEIGHT
OPV TYPE
RMOW TYPE
RMOT TYPE
SMM TYPE
SMO TYPE
0
10
20
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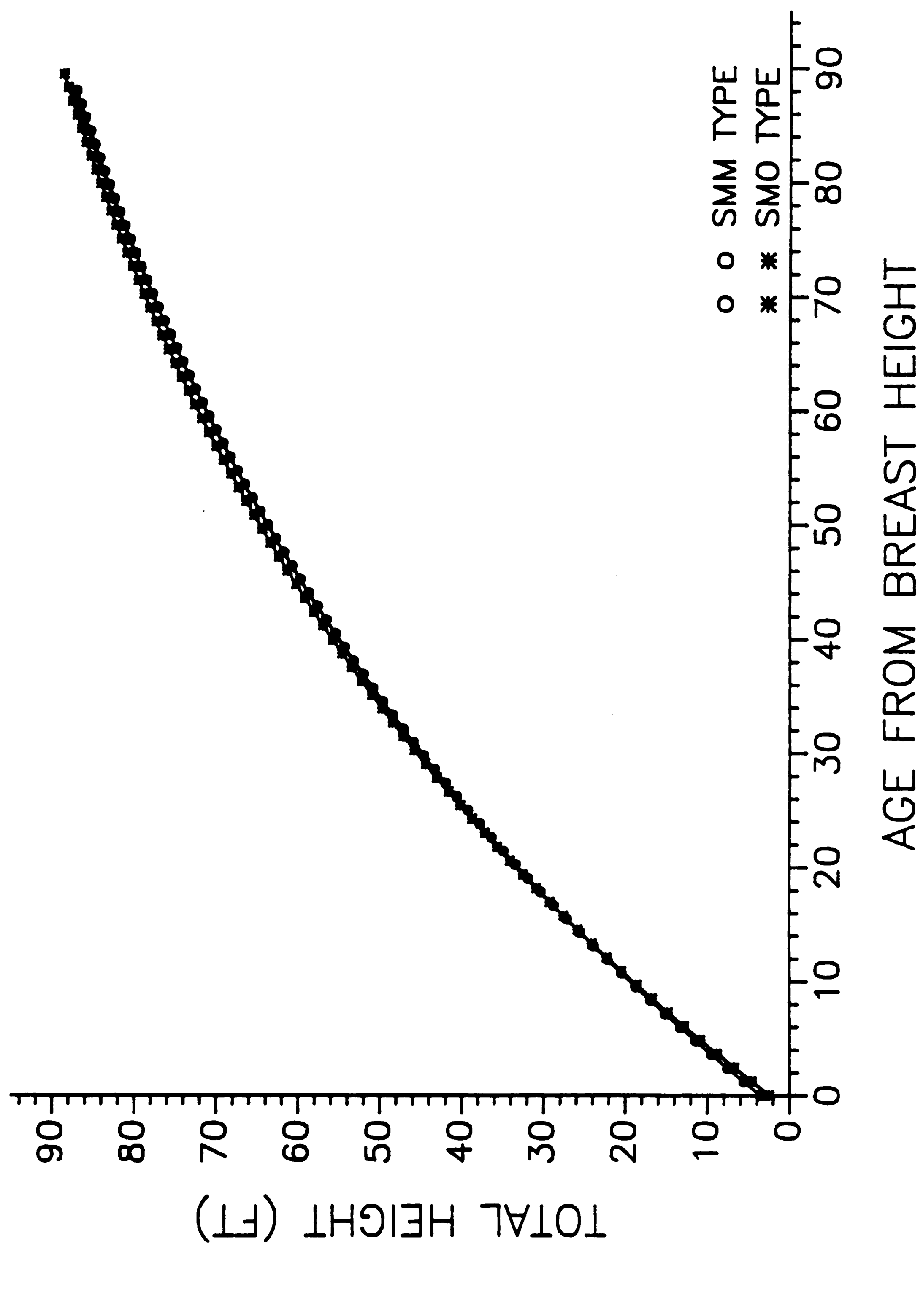
Figure 10. Mean height growth curves for sugar maple growing on two vegetation types.


TOTAL HEIGHT (FT)
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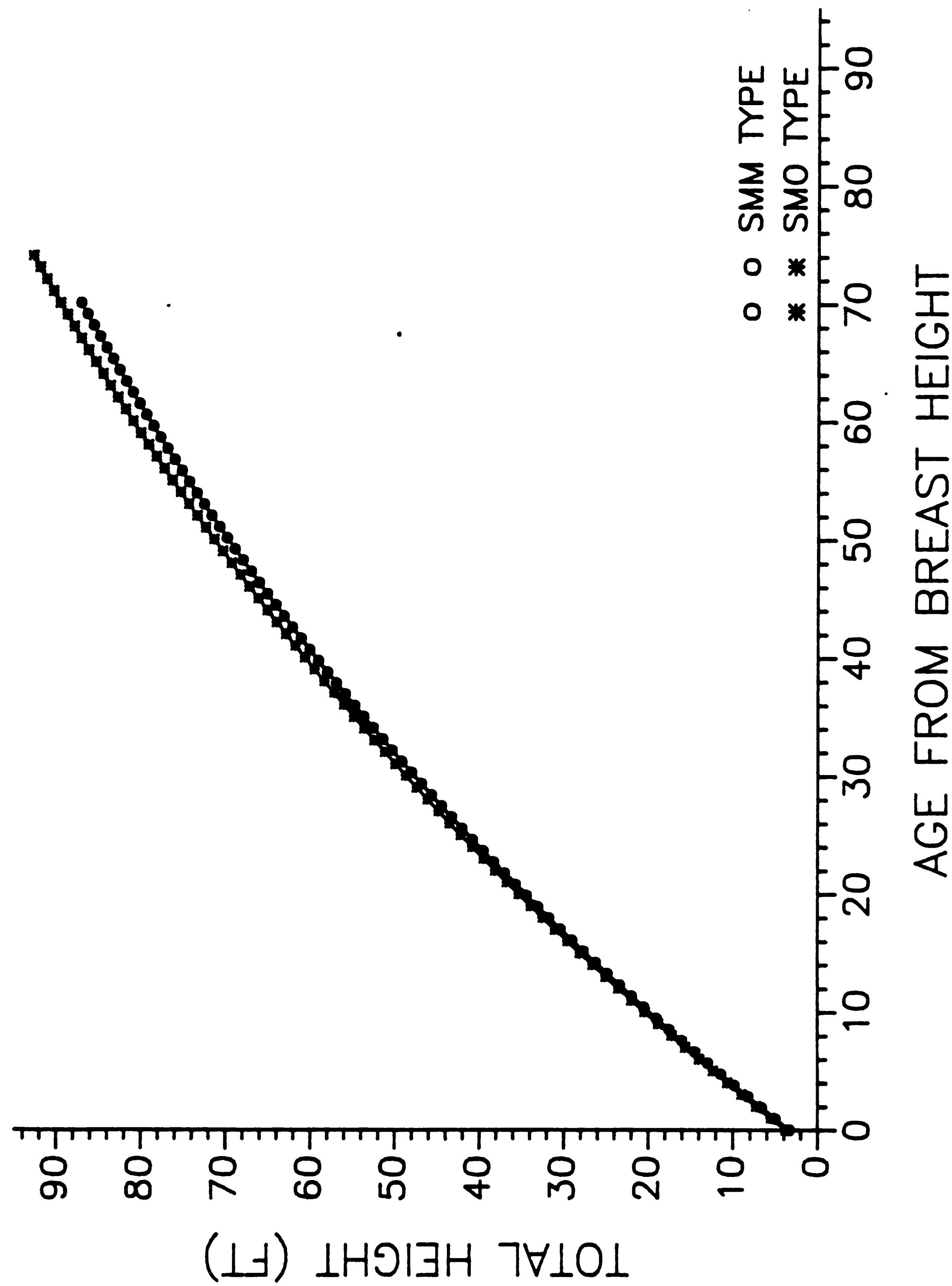
AGE FROM BREAST HEIGHT
o o SMM TYPE
* * SMO TYPE

Figure 11. Mean height growth curves for basswood growing on two vegetation types.


TOTAL HEIGHT (FT)
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AGE FROM BREAST HEIGHT
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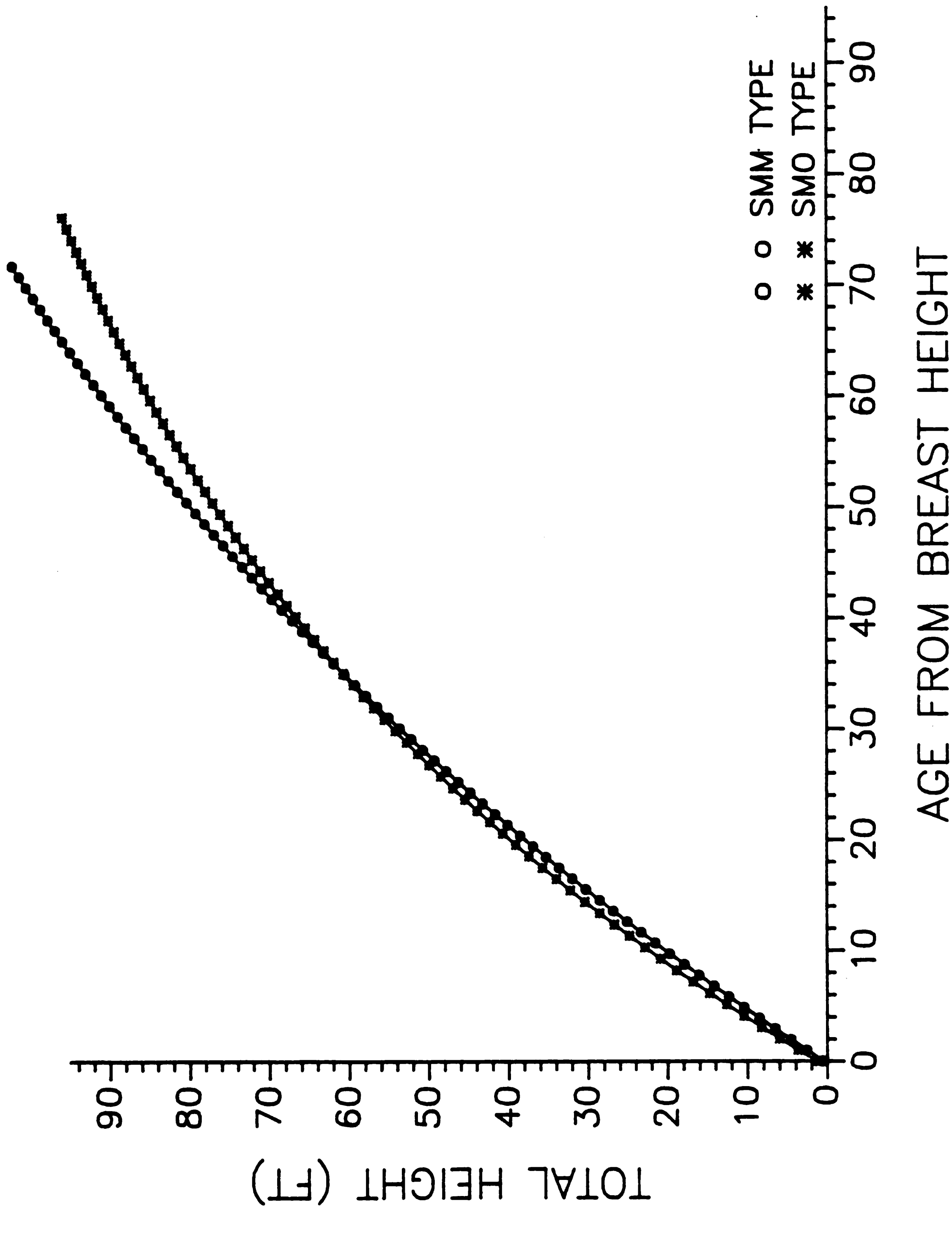
70
80
90
o o SMM TYPE
* * SMO TYPE

Figure 12. Mean height growth curves for white ash growing on two vegetation types.


TOTAL HEIGHT (FT)
AGE FROM BREAST HEIGHT
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50
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o o SMM TYPE
* * SMO TYPE

sites.

MEAN SITE INDEX COMPARISONS

Soil Type

Mean plot site index values were stratified by species and soil type for statistical analysis. Table 4 shows the mean site index values and the associated standard deviations for each of the species-soil combinations. For those species that occurred on all soil types, Roselawn soils are consistently intermediate between Emmet and Rubicon. Site index values within each of the species-soil combinations were tested for normality using the Chi-square goodness of fit test. All groups but one were normally distributed. Both the two sample t-test and the nonparametric Mann-Whitney U-test were employed to test for differences in mean site index among groups. Both tests yielded identical results. Of the nine possible within species comparisons, eight are statistically different at the .05 level.

Vegetation Type

Similar analyses were performed on each of the species-vegetation type combinations. Because the northern hardwood species were not amenable to accross-soil-type comparisons (they were restricted to the better soils) they were often sampled without regard to soil type. As such, their results will be presented in the context of vegetation types. Table 5 shows mean site index values and associated

Table 4. Mean site index values by species and soil type. Means with the same letter are not significantly different.

	SOIL TYPE		
SPECIES	EMMET	ROSELAWN	RUBICON
	Mean Site Index (Standard deviation)		
Populus grandidentata (#Stands/#Trees)	87.2 (7.5)a 7/11	70.2 (8.0)b 5/9	61.2 (1.1)c 7/17
Pinus resinosa (#Stands/#Trees)	79.1 (4.6)a 3/7	68.0 (6.3)b 6/18	61.5 (5.3)c 9/24
Quercus rubra (#Stands/#Trees)	68.8 (5.3)a 5/11	64.8 (4.4)a 4/11	56.8 (5.5)b 8/21

standard deviations for each of these stratifications. Fifteen of the 29 within species comparisons were statistically different at the .05 level.

Another interesting outcome of the mean site index comparisons involves the productivity relationships of the individual species. The results show that *Pinus resinosa* and *Populus grandidentata* posess similar mean site index values over most of the range of soil and vegetation types, with aspen generally being slightly higher. *Quercus rubra* site index is consistently and substantially lower than either *Populus grandidentata* or *Pinus resinosa* throughout the range of soil and vegetation types studied. On the northern hardwood sites, *Fraxinus americana* substantially outgrows *Tilia americana*, which in turn out permforms *Acer saccharum*.

Table 5. Mean site index by species and vegetation type. Means with the same letter are not significantly different.

	VEGETATION TYPE				
	SMO	SMM	RMOT	RMOW	OPV
SPECIES	Mean Site Index (Standard Deviation)				
Populus grandidentata (#Stands/#Trees)	84.3 (8.1)a 8/14	82.7 (8.2)a 9/17	67.9 (7.7)b 3/5	70.9 (8.5)b 6/15	64.9 (5.7)b 8/19
Pinus resinosa (#Stands/#Trees)	81.2 (4.3)a 4/12	77.8 (4.4)a 5/12	67.2 (6.8)b 5/15	62.5 (7.4)b 4/11	62.7 (4.8)b 8/22
Quercus rubra (#Stands/#Trees)	----	69.0 (4.7)a 6/15	64.8 (4.4)ab 4/11	57.6 (8.3)bc 2/4	57.1 (5.2)c 9/21
Fraxinus americana (#Stands/#Trees)	78.2 (7.8)a 7/11	82.1 (3.6)a 4/8	----	----	----
Tilia americana (#Stands/#Trees)	71.4 (4.3)a 10/17	70.3 (5.4)a 7/19	----	----	----
Acer saccharum (#Stands/#Trees)	63.9 (7.5)a 9/15	64.1 (6.9)a 5/12	----	----	----

DISCUSSION

The five upland forest vegetation types identified in the study area occurred irrespective of the composition of the overstory. This point is well illustrated by the distribution of aspen stands and red pine plantations within the ordination of stands. Both of these cover types occurred over the entire range of the ordination. This suggests that ground flora associations are capable of indicating the quality of the site, at least in general terms, regardless of the seral stage or artificial manipulation of the overstory.

With one exception, each vegetation type occurred on more than one soil type. Table 6 shows the relative frequency with which each vegetation type occurred on the three most frequently sampled soil types. The Emmet soil series supported roughly equal amounts of both the SMO and the SMM vegetation types. In a similar manner, Rubicon soils supported both the RMOW and the OPV vegetation types. Of the 7 stands sampled on Roselawn soils, however, 6 supported the RMOT type. No other soils supported this type. This nearly 1:1 correspondance of soil to vegetation type may not, however, be causal in nature. As mentioned earlier, the RMOT type appears to be partially environmental and partially successional in origin. The type appears to be capable of supporting sugar maple, but now characteristically supports an overstory of red maple and red oak. The ground flora of this type consists of members of both the mesic and the xeric

Table 6. Frequency of occurrence of vegetation types on the three most commonly sampled soil types.

	SOIL TYPE		
Vegetation type	Emmet	Roselawn	Rubicon
SMO	100%	----	----
SMM	100%	----	----
RMOT	----	100%	----
RMOW	----	33%	66%
OPV	----	----	100%

forests. It is possible that the moisture and nutrient status of the Roselawn soils may mediate a different successional pathway, thus contributing to this atypical association of species.

For those species that occurred over all vegetation types, there emerged a general trend in productivity as measured by site index. As shown in Table 4, mean site index values tended to be highest in the SMO type and lowest in the OPV type. This follows the ranking of the types as outlined by the ordination of stands (Table 1). In many cases, however, differences in mean site index between the most silmilar vegetation types (those adjacent on the ordination of stands) are not significantly different. The most common pattern that emerges is one in which those vegetation types on any one side of the primary TWINSPAN division are not statistically different from each other, but are statistically different from those vegetation types on the other side of the division. Thus, mean site index values for the SMO and SMM types are statistically indistinguishable. Both the SMO and SMM types are, however, statistically different from the RMOT, RMOW, and OPV types. Similarly, mean site indices within the RMOT, RMOW, and OPV types are most commonly statistically indistinguishable, yet statistically different from the SMO and SMM types.

These results indicate that the vegetation types that we defined are of only limited value in assessing forest productivity. One possible explanation for this outcome may be that the vegetation comprising the ground flora may reflect only a portion of the environmental variables that are important to tree growth. For example, textural discontinuities at depths of up to 9 feet have been shown to increase forest productivity in northern Lower Michigan (Hannah and Zahner, 1970; Cleland et al., 1985; Host et al., 1987). This phenomenon of deep banding may have little or no effect on the moisture available near the surface of the soil, the area most likely to be exploited by roots of ground flora species (Carmean, 1975).

While only slightly over half of the 29 possible within species mean site index comparisons were statistically different at the .05 level, caution should be observed before branding the results insignificant. The strong trends apparent from Table 4 suggest that additional sampling may reduce the variability within each vegetation type, resulting in more statistical differences.

The trends in productivity associated with soil types are stronger and more clearly defined than those associated with the vegetation types. Previous studies that have sought to relate forest productivity (as measured by site index) to soil series have typically met with limited success (Carmean, 1961, 1965; Farnsworth and Leaf, 1963; Van Lear and Hosner, 1967; Craul, 1968; Watt and Newhouse, 1973; Post and Curtis, 1970; Shetron, 1972). Excessive variability in site index within soil series has been the common pitfall of such studies. The vast majority of these studies have relied on existing site index curves to arrive at their estimates of plot site index. This approach is subject to two main sources of error, each of which may inflate the variability within the data set. First, estimates of site index based on the observation of total tree height and age are woefully inadequate in that they ignore any injuries or damage that a tree may have sustained throughout its life. Such injuries can drastically underestimate the productive potential of the site on which they occur. Sporadic occurrences of such growth inhibiting injuries (which must be expected) will result in an artificial inflation of the variability of the entire data set. Even after rigorous sample tree selection, 59 of the 334 trees sampled were rejected based on inspection of the plotted height growth curves. Figure 13 depicts the retarded early height growth of a suppressed red oak tree.

A second source of variability may be a consequence of the particular set of site index curves used for site index determination. Many of the existing site index curves were developed by the guide curve technique, which assumes a proportional relationship between the height growth patterns of trees growing on different quality sites. This assumption has been proven to be invalid in many cases (Spurr, 1956; Daubenmire,1961; Carmean, 1972; Beck and Trousdell, 1973; Monserud, 1984, 1985). Additional error may result if uneven sampling of different age classes has occurred in the

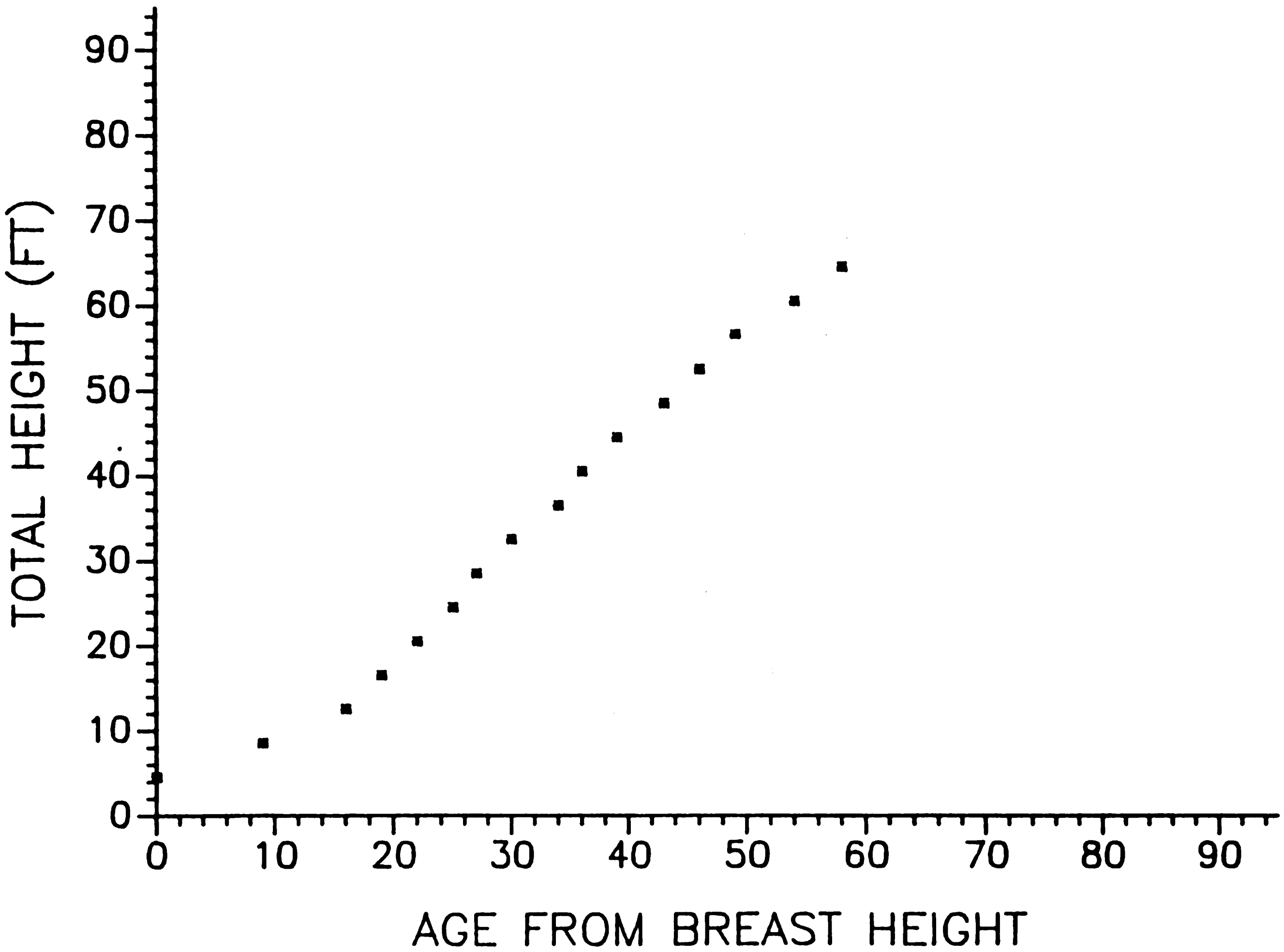

Figure 13. Example of a suppressed red oak tree.

development of these curves. All of these sources of error, and consequent variability, can be obviated through the use of stem analysis on sample trees. Stem analysis affords a means to observe the height growth of a tree throughout its life, and provides a direct measure of site index.

In comparison to other soil-site index studies, variability within the soil map units was low. We attribute this to two of our methodological approaches. First, our results are based on actual growth data obtained by stem analysis. As discussed above, stem analysis proceedures eliminate many sources of variability typically associated with soil-site index studies. Secondly, we feel that the quality of the LES maps contributed to our rather low variability. Again, these maps were developed with ecological relationships in mind.

The results indicate that, for the species and soil types studied, Land Economic Survey Map units are an efficient and effective way to stratify the landscape according to potential productivity. In a practical sense, this information can allow for more judicious selection of sites upon which to apply more intensive forest management.

Another interesting aspect of our results is the shape of the height growth curves developed for the different stratification units. As seen in Figures 4 - 12, some families of height growth curves show marked polymorphism. This phenomenon renders site index curves developed by the guide curve technique inaccurate and obsolete. Site index curves developed by the guide curve technique fail to recognize or accommodate these deviations from proportionality, yielding misleading results, especially as the age of the sample tree departs significantly from the base age.

This point is further illustrated by Figure 14. This figure depicts the height growth of bigtooth aspen growing on Roselawn soils, which averages 70 feet at age 50. Superimposed on this curve are two curves representing site index 70 taken from harmonized site index curves developed by Gevorkiantz (1956) and Graham et al. (1963). By definition, these curves must coincide at age 50 years and height 70 feet. Exclusive of this point, however, the published curves overestimate height growth at young ages and underestimate height growth at older ages. The management implications of such a misrepresentation are considerable. Curves such as Graham's indicate nearly total stagnation in height growth beyond 50 years of age, which would imply that harvesting should not be postponed beyond stand age 50 years. Our stem analysis data, however, indicate that substantial gains in height growth, and therefore volume, can be expected well beyond age 50.

Comparison of our curves with site index curves developed by stem analysis yields more similar results. Site index curves developed by Carmean (1978) corresponded quite

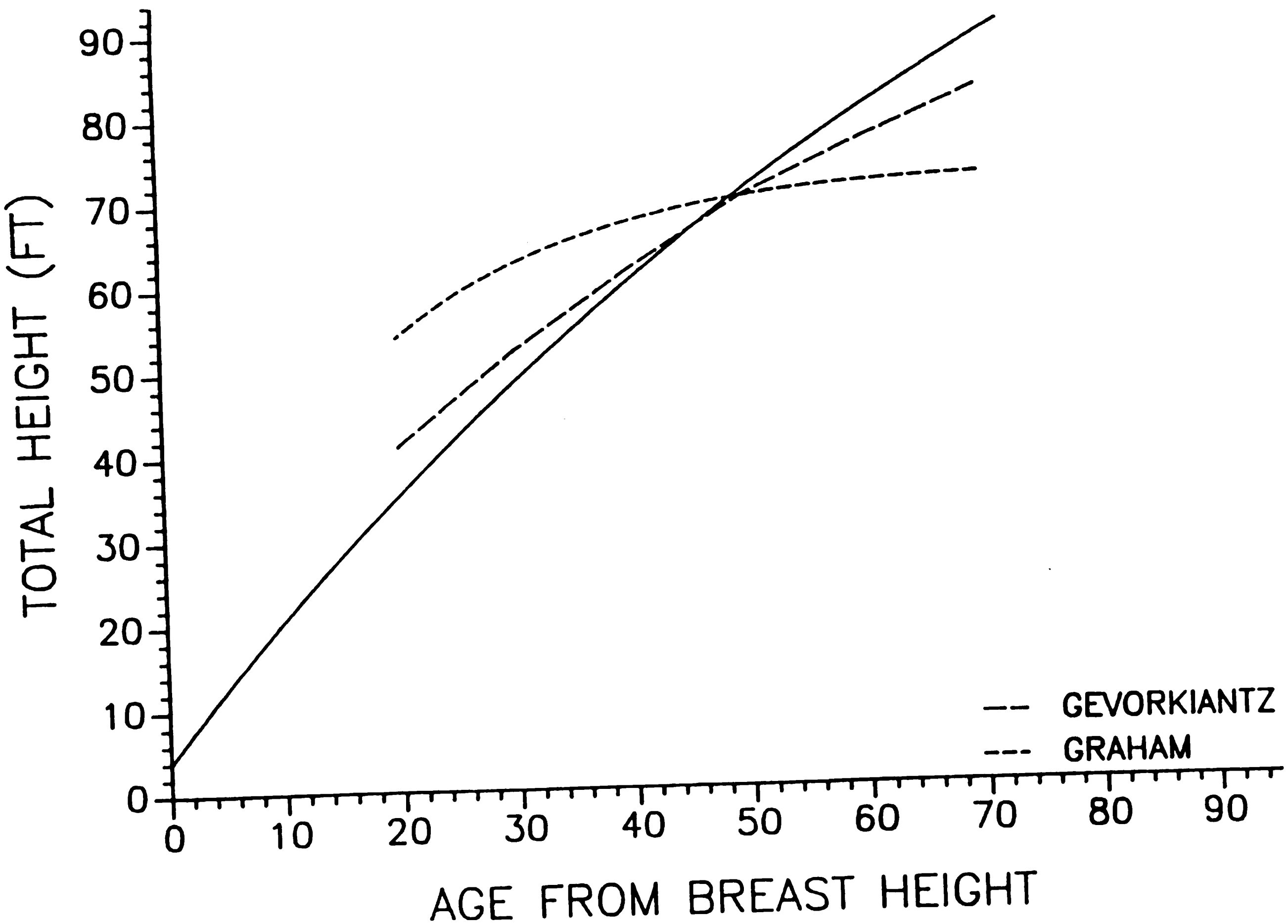

Figure 14. Empirical curve representing site index 70 for bigtooth aspen growing in northern Lower Michigan. Superimposed on this curve are site index 70 curves taken from Graham et al. (1963) and Gevorkiantz (1956).

closely with our curves. Although Carmean's curves were developed within a different geographic area, they appear to be much more realistic than the harmonized curves developed for northern Lower Michigan.

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CONCLUSIONS

1. Five vegetation types were identified and described for upland forests of northern Lower Michigan. These vegetation types were identifiable in the field without regard to the composition or seral stage of the overstory.

2. While clear trends were apparent, no unique correspondence existed among ground flora assemblages and site index. For example, northern hardwoods growing on two quite distinct vegetation types displayed nearly identical site index values and height growth patterns. Increased sampling may reduce the variability within vegetation types enough that more significant differences occur among types. The vegetation types might also be defined in another way so as to better predict site index and height growth patterns. For productivity interpretations, combinations of vegetation types may be sufficient to predict height growth of important commercial trees.

3. The Land Economic Survey soil map units considered in this study are capable of predicting site index with a reasonable degree of accuracy. It is possible, then, to map land according to differences in potential height growth of commercially important tree species. Existing Land Economic Survey maps hold promise for the identification of the spatial distribution of site quality in northern Lower Michigan.

4. Stem analysis revealed that polymorphic height growth patterns do occur in northern Lower Michigan. This finding invalidates the use of site index curves developed by the guide curve technique for this geographic area.

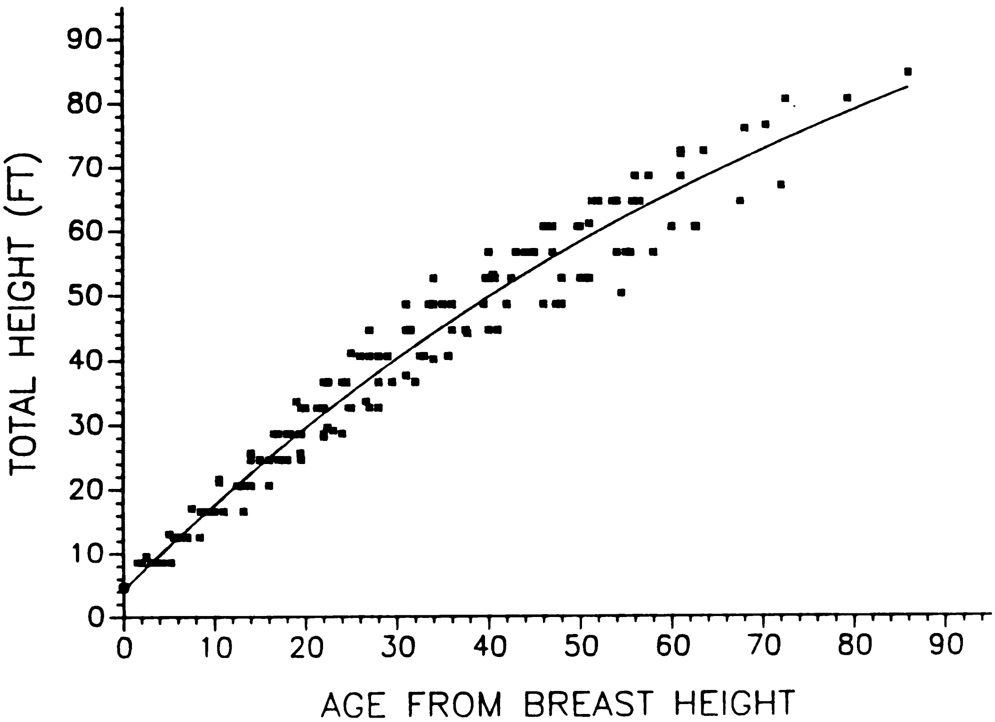
APPENDICES

APPENDIX A

Height growth curves for each of the species/soil type conbinations

Figure 15. Height growth of red oak growing on Rubicon soils.

Figure 16. Height growth of red oak growing on Roselawn soils.


TOTAL HEIGHT (FT)
AGE FROM BREAST HEIGHT
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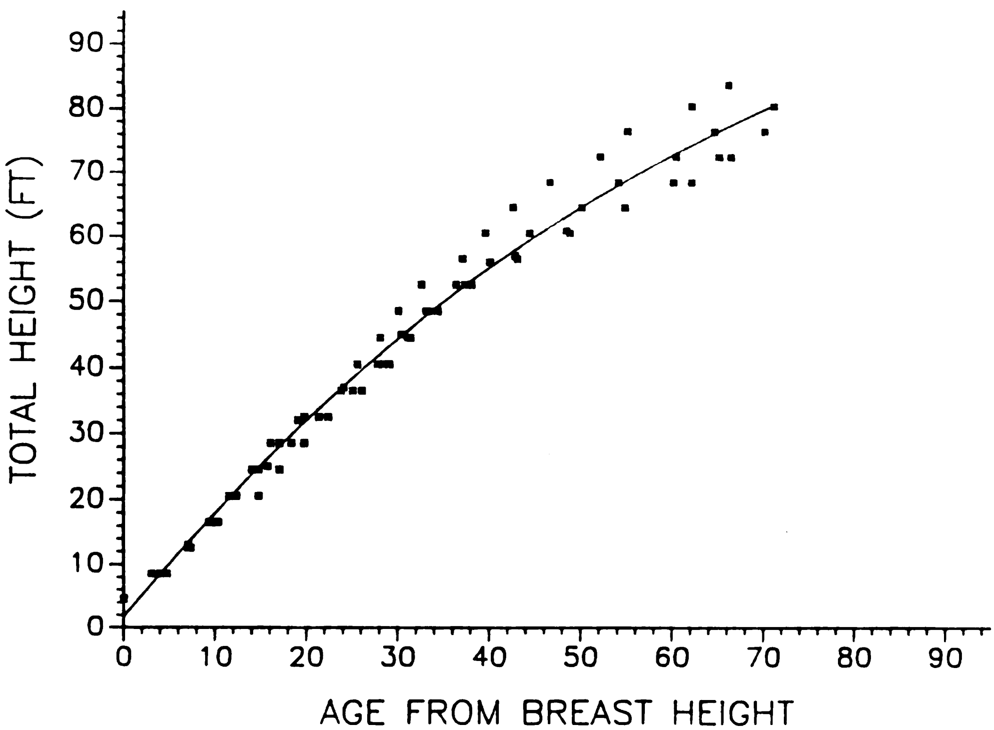
TOTAL HEIGHT (FT)
AGE FROM BREAST HEIGHT
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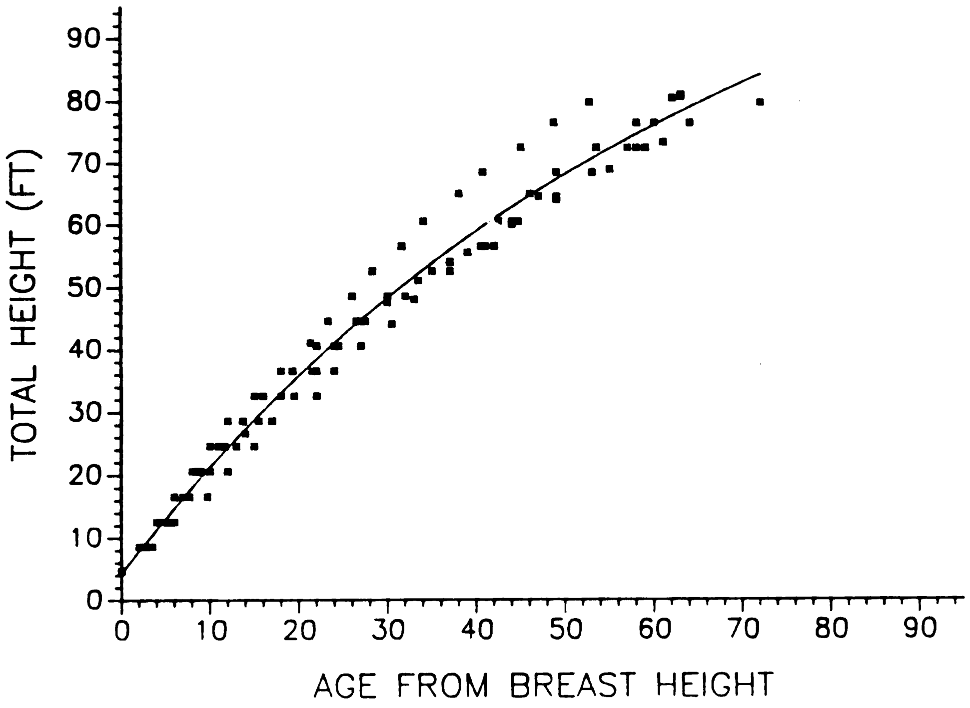
Figure 17. Height growth of red oak growing on Emmet soils.

Figure 18. Height growth of red pine growing on Rubicon soils.



TOTAL HEIGHT (FT)
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AGE FROM BREAST HEIGHT

TOTAL HEIGHT (FT)
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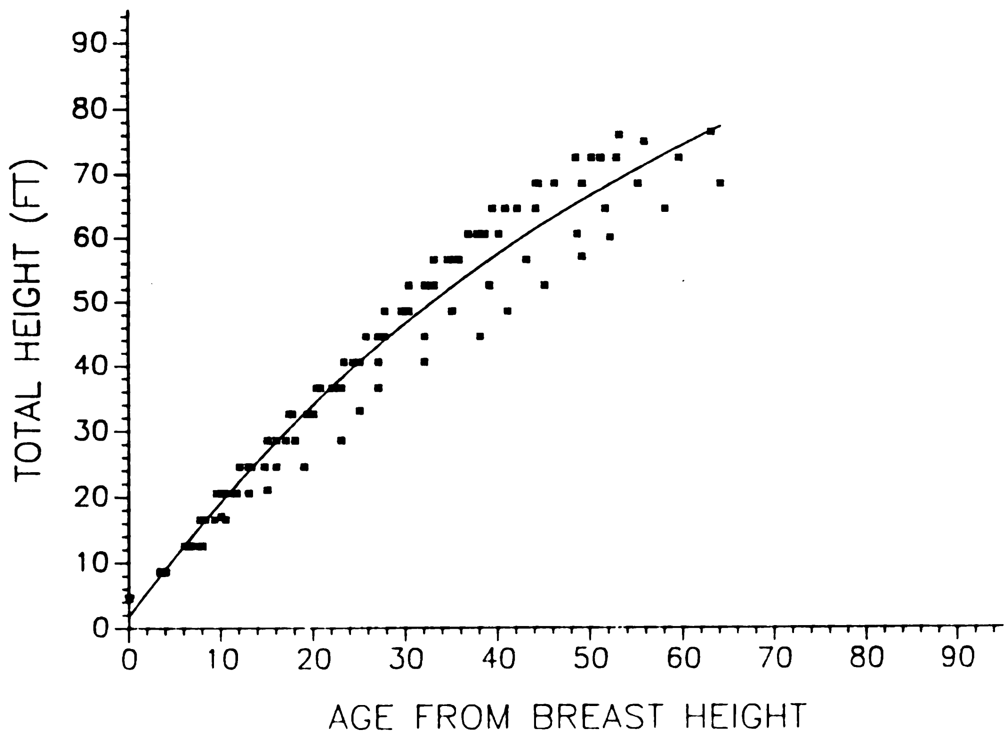
AGE FROM BREAST HEIGHT

Figure 19. Height growth of red pine growing on Roselawn soils.

Figure 20. Height growth of red pine growing on Emmet soils.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AGE FROM BREAST HEIGHT
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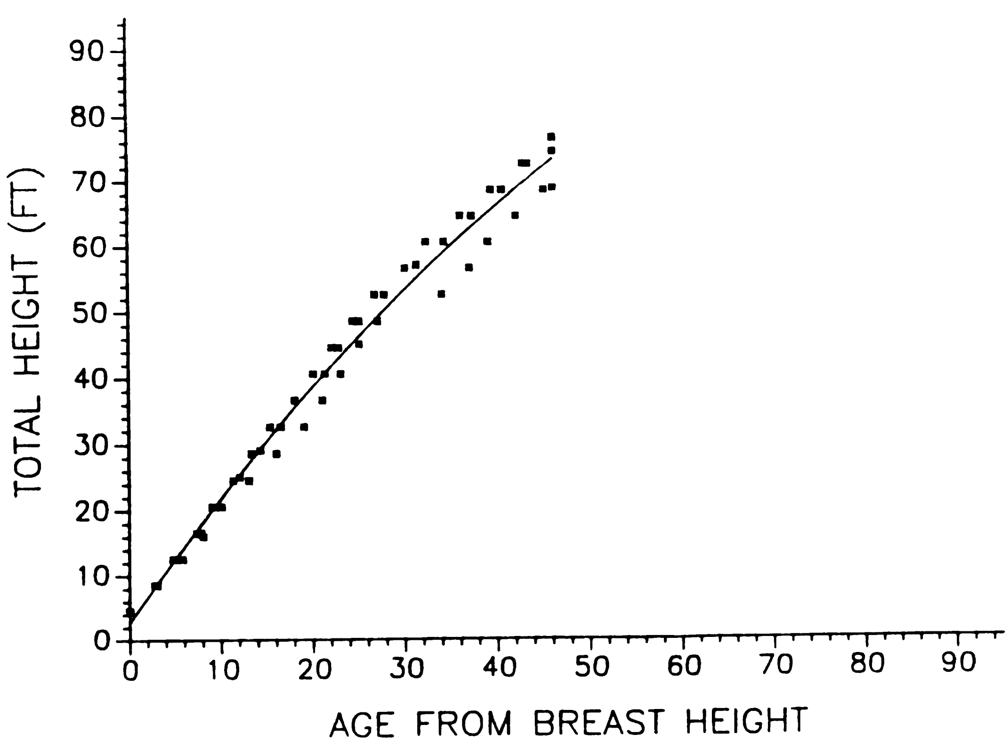
TOTAL HEIGHT (FT)
AGE FROM BREAST HEIGHT
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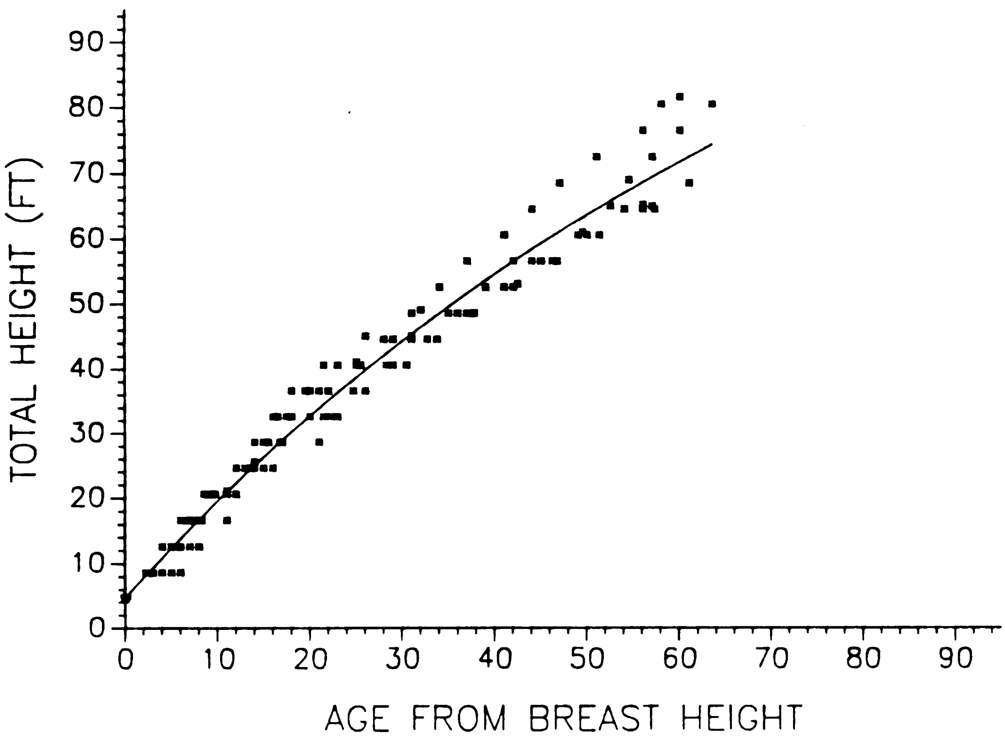
Figure 21. Height growth of bigtooth aspen growing on Rubicon soils.

Figure 22. Height growth of bigtooth aspen growing on Roselawn soils.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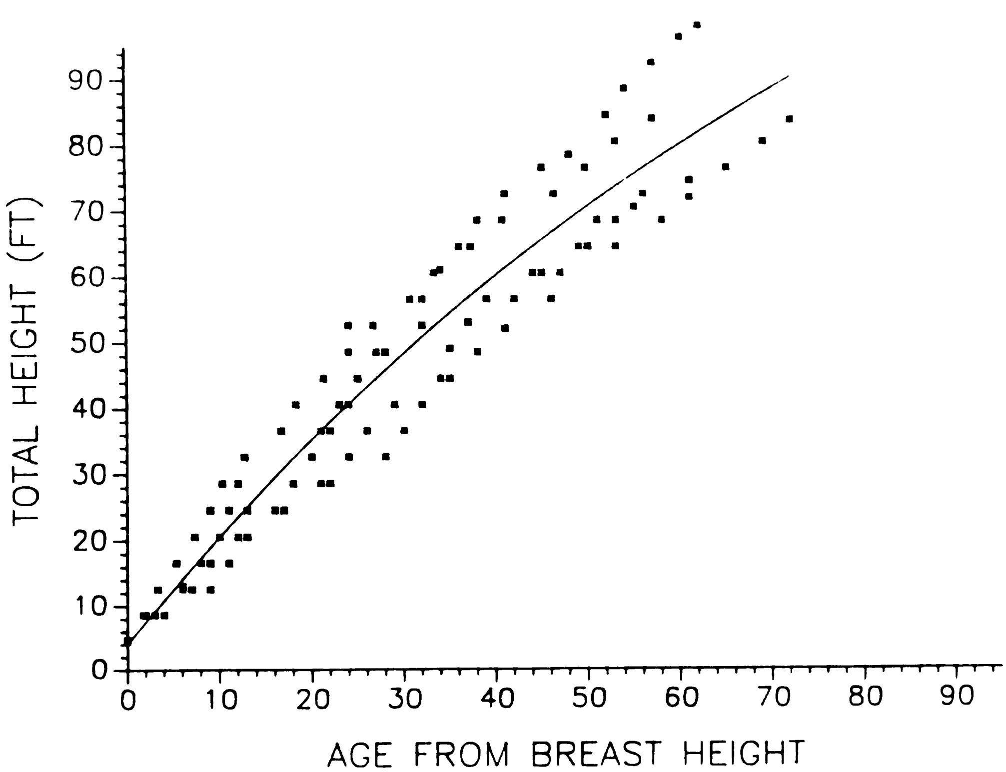
AGE FROM BREAST HEIGHT


TOTAL HEIGHT (FT)
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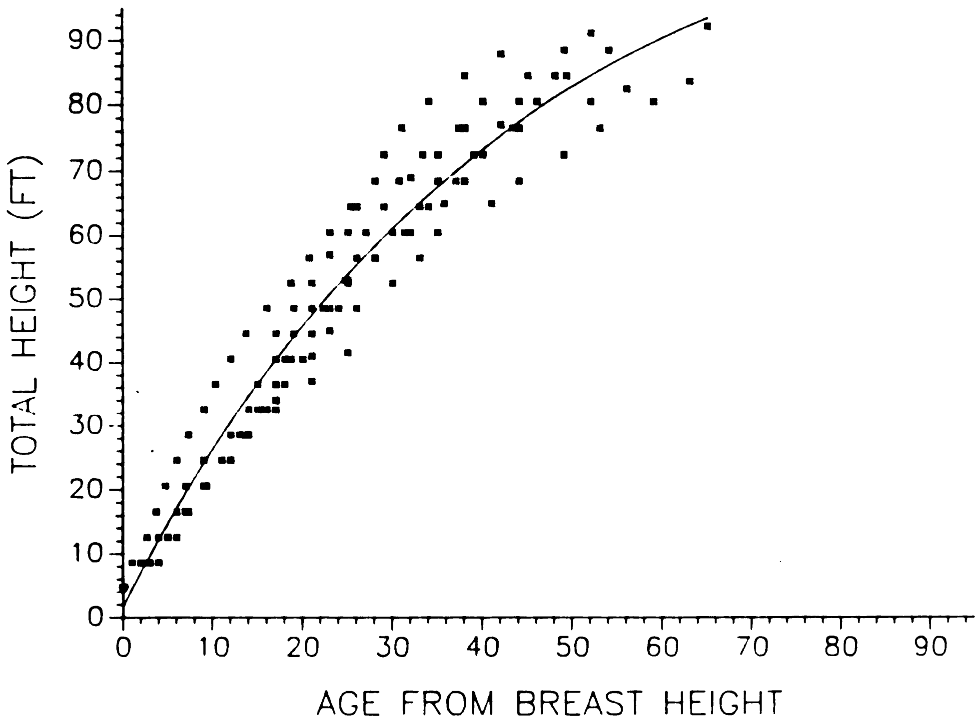
AGE FROM BREAST HEIGHT

Figure 23. Height growth of bigtooth aspen growing on Emmet soils.


TOTAL HEIGHT (FT)
AGE FROM BREAST HEIGHT
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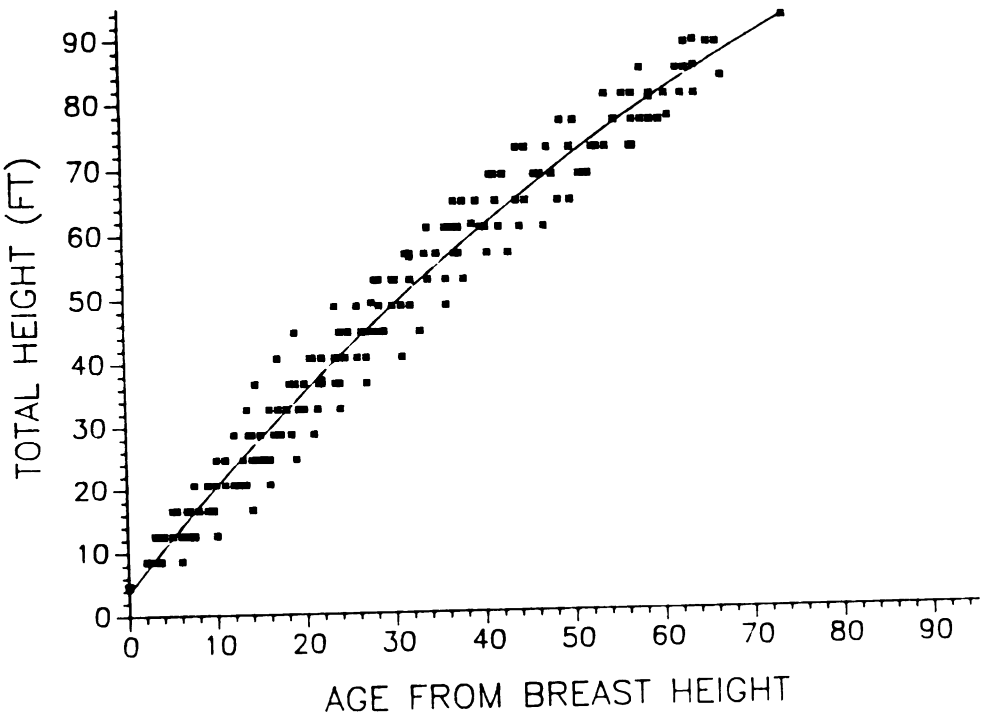
APPENDIX B

Height growth curves for each of the species/vegetation type combinations

Figure 24. Height growth of basswood growing on the SMO vegetation type.


TOTAL HEIGHT (FT)
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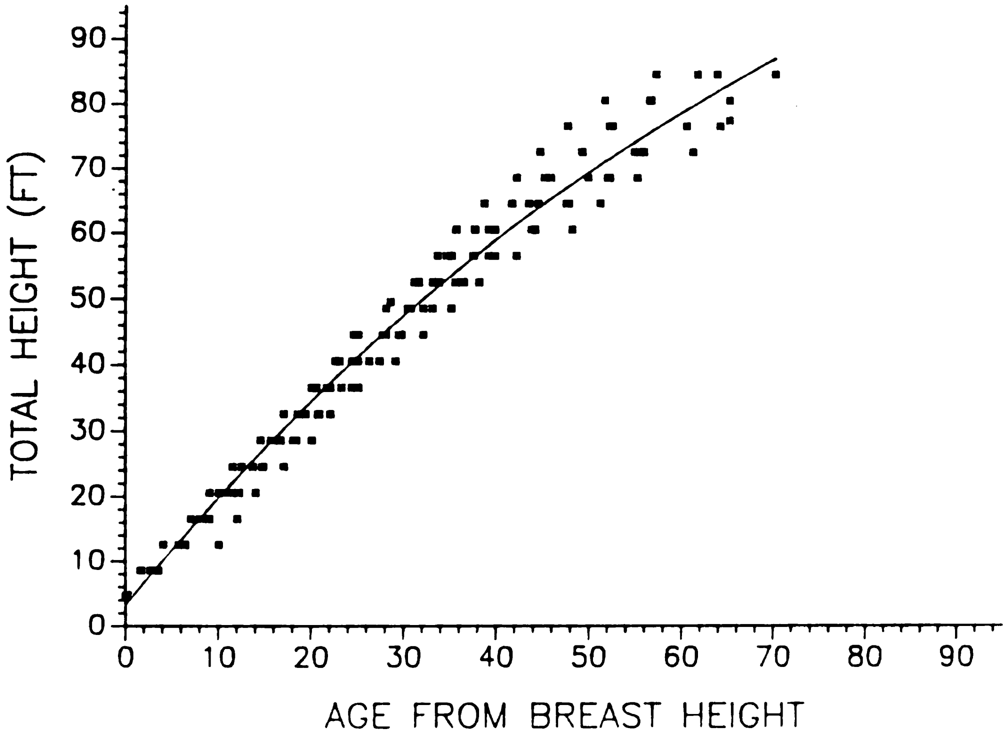
AGE FROM BREAST HEIGHT

Figure 25. Height growth of basswood growing on the SMM vegetation type.

Figure 26. Height growth of sugar maple growing on the SMO vegetation type.


TOTAL HEIGHT (FT)
AGE FROM BREAST HEIGHT
0 10 20 30 40 50 60 70 80 90

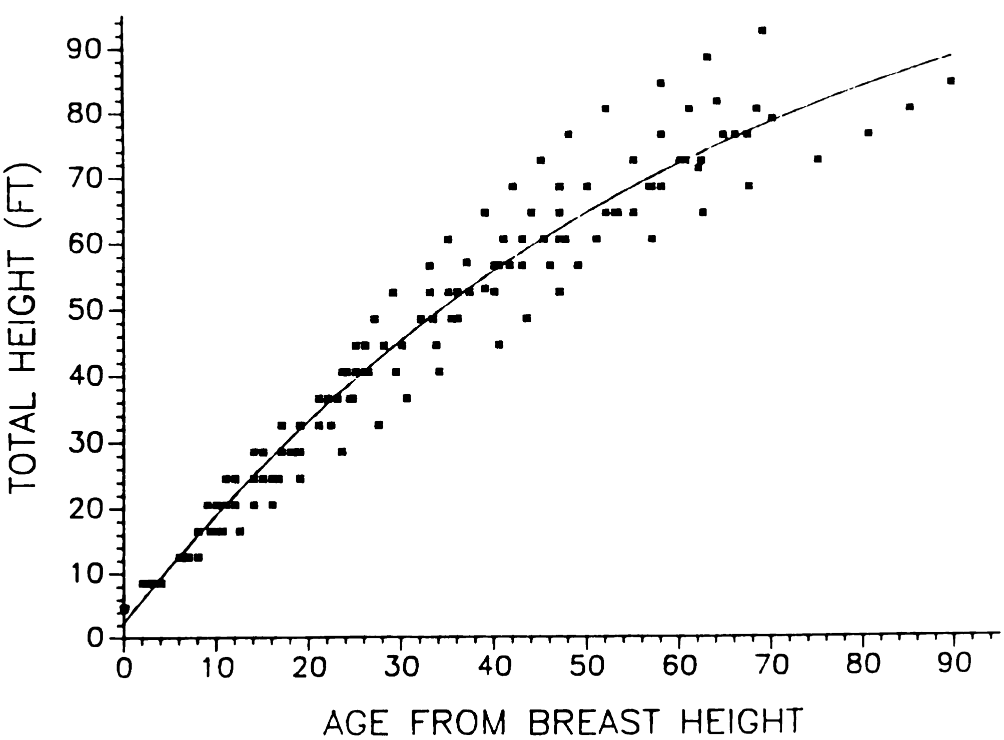
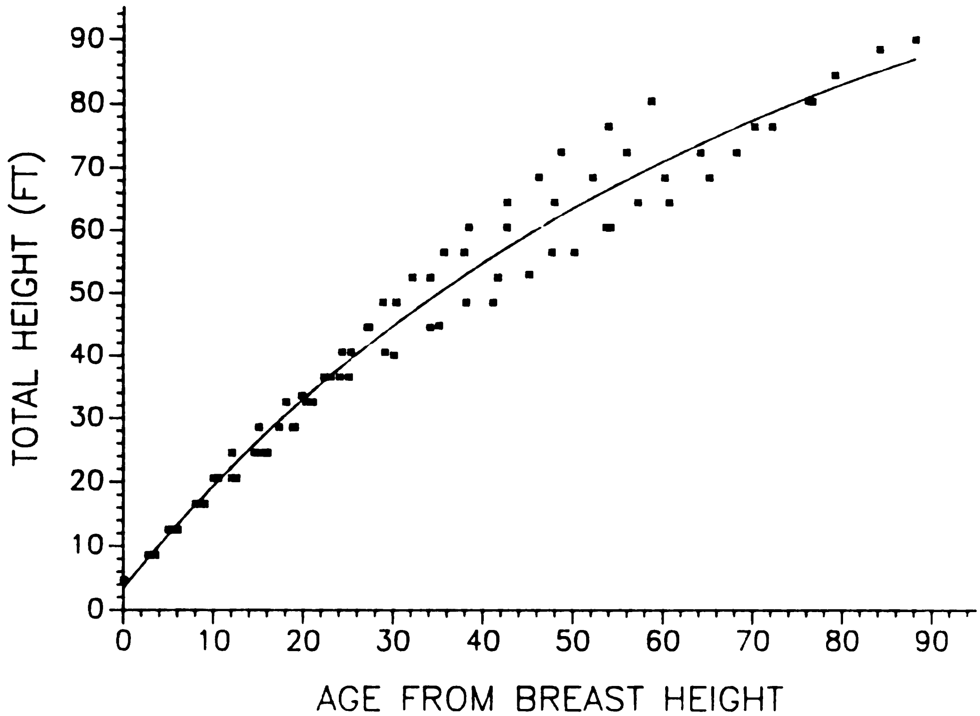

TOTAL HEIGHT (FT)
AGE FROM BREAST HEIGHT
0 10 20 30 40 50 60 70 80 90

Figure 27. Height growth of sugar maple growing on the SMM vegetation type.

Figure 28. Height growth of white ash growing on the SMO vegetation type.



TOTAL HEIGHT (FT)
AGE FROM BREAST HEIGHT
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TOTAL HEIGHT (FT)
AGE FROM BREAST HEIGHT
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Figure 29. Height growth of white ash growing on the SMM vegetation type.

Figure 30. Height growth of bigtooth aspen growing on the SMO vegetation type.


TOTAL HEIGHT (FT)
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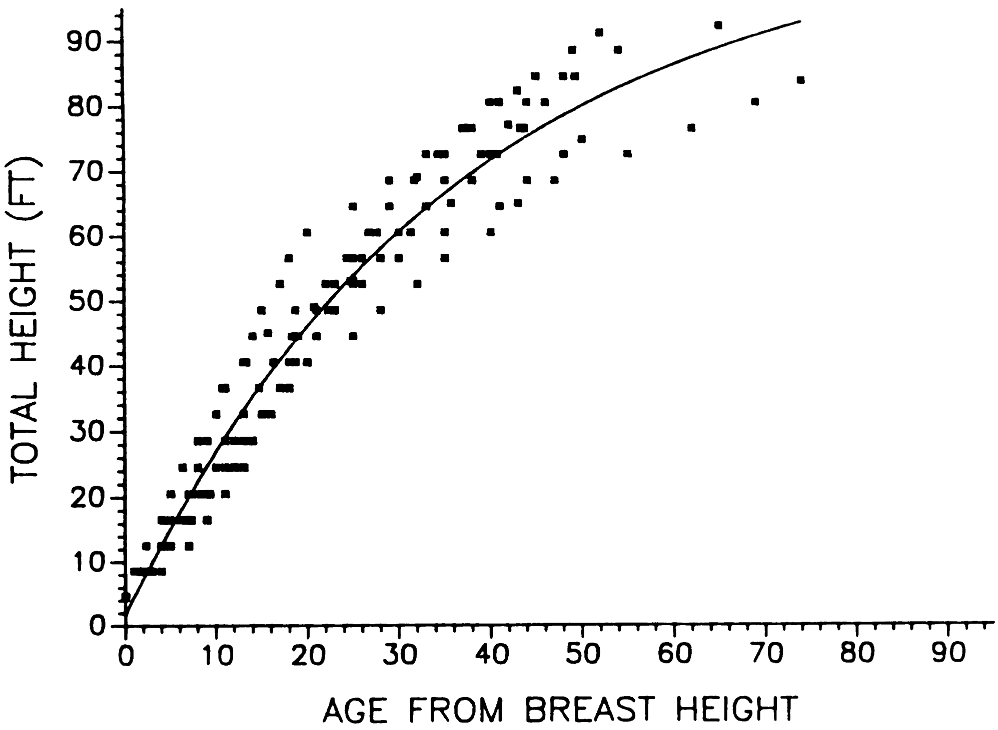
AGE FROM BREAST HEIGHT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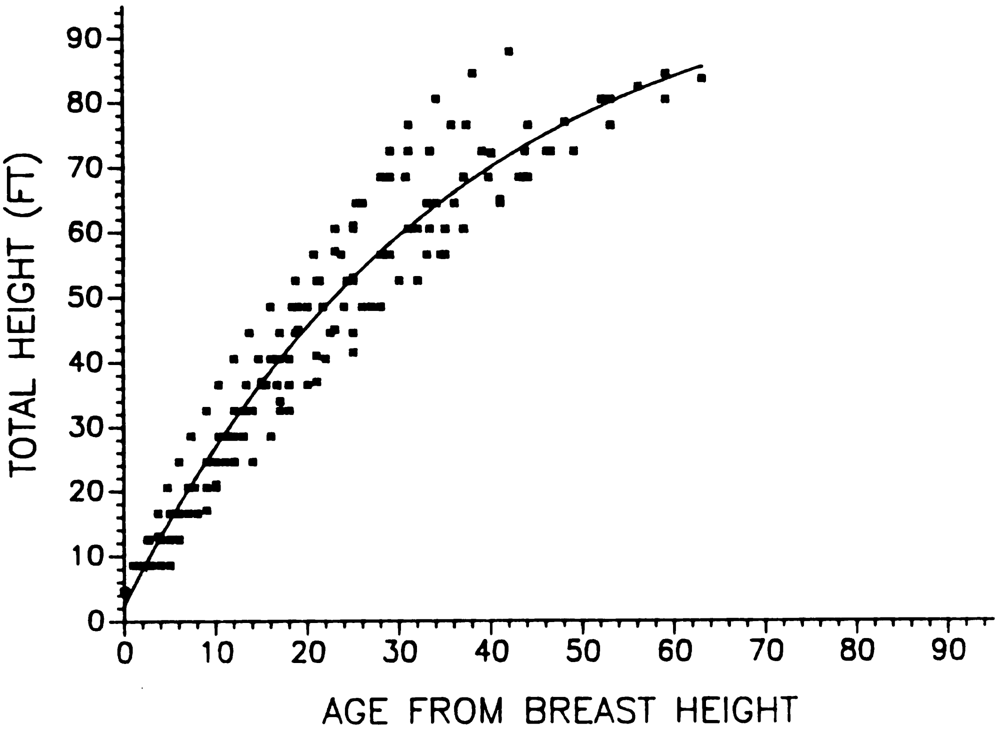
AGE FROM BREAST HEIGHT

Figure 31. Height growth of bigtooth aspen growing on the SMM vegetation type.

Figure 32. Height growth of bigtooth aspen growing on the RMOT vegetation type.


TOTAL HEIGHT (FT)
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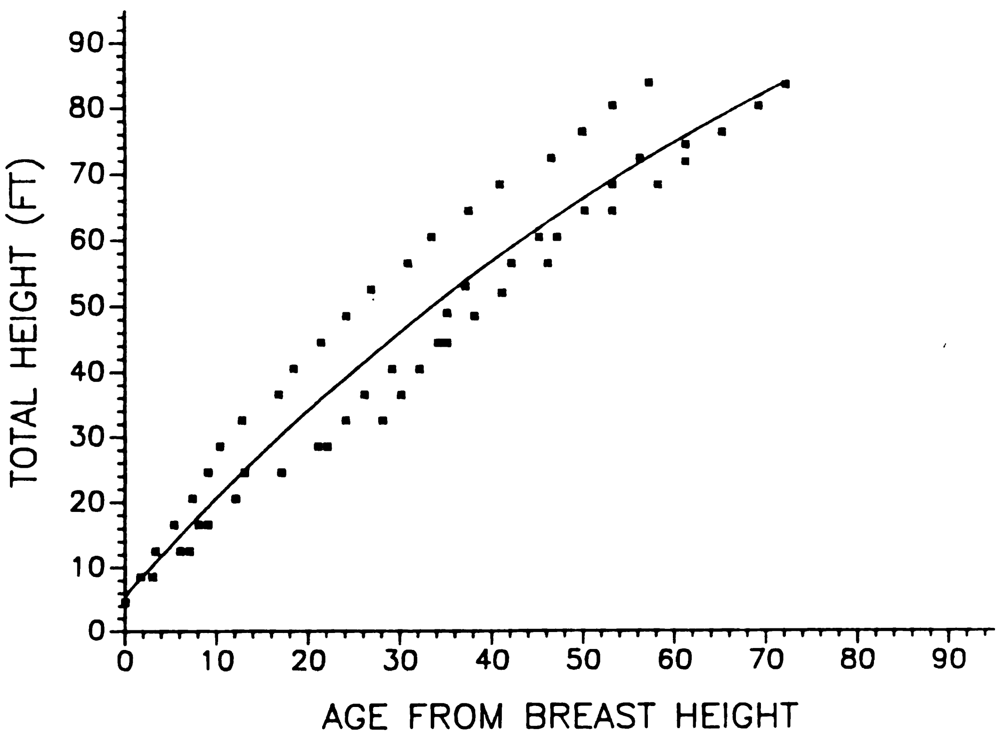
AGE FROM BREAST HEIGHT


TOTAL HEIGHT (FT)
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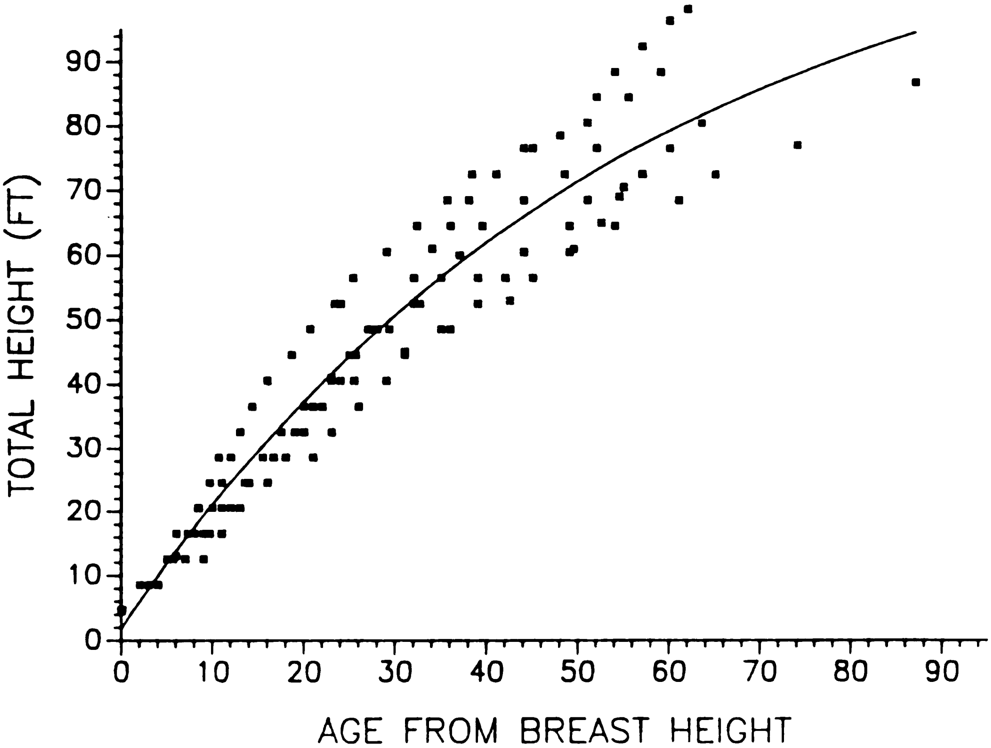
AGE FROM BREAST HEIGHT

Figure 33. Height growth of bigtooth aspen growing on the RMOW vegetation type.

Figure 34. Height growth of bigtooth aspen growing on the OPV vegetation type.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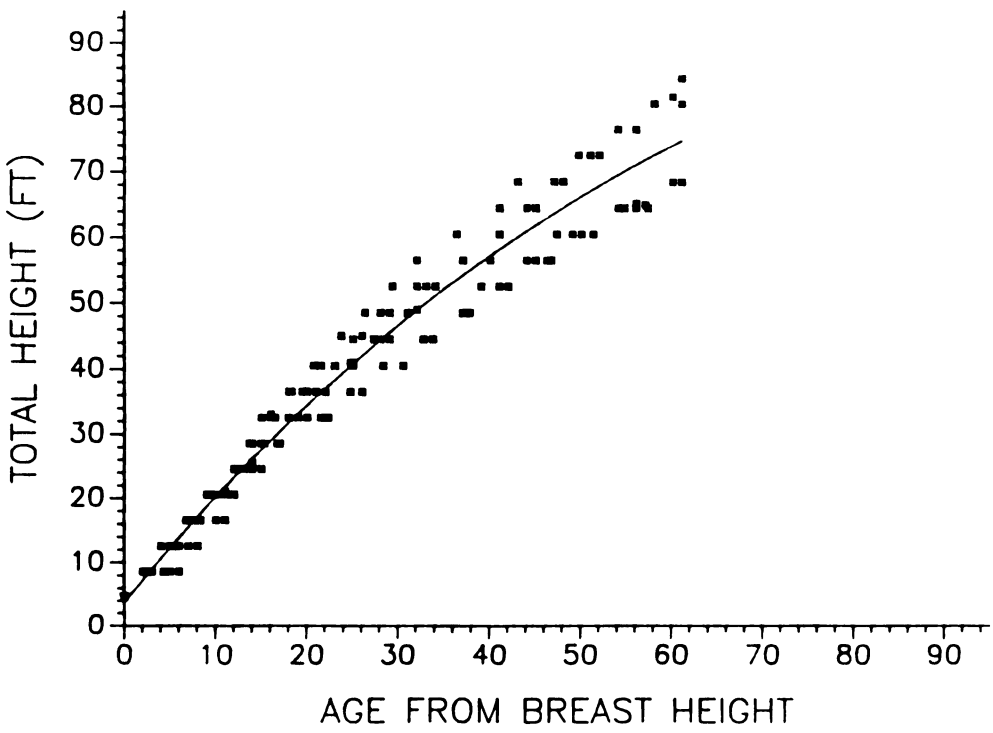
AGE FROM BREAST HEIGHT


TOTAL HEIGHT (FT)
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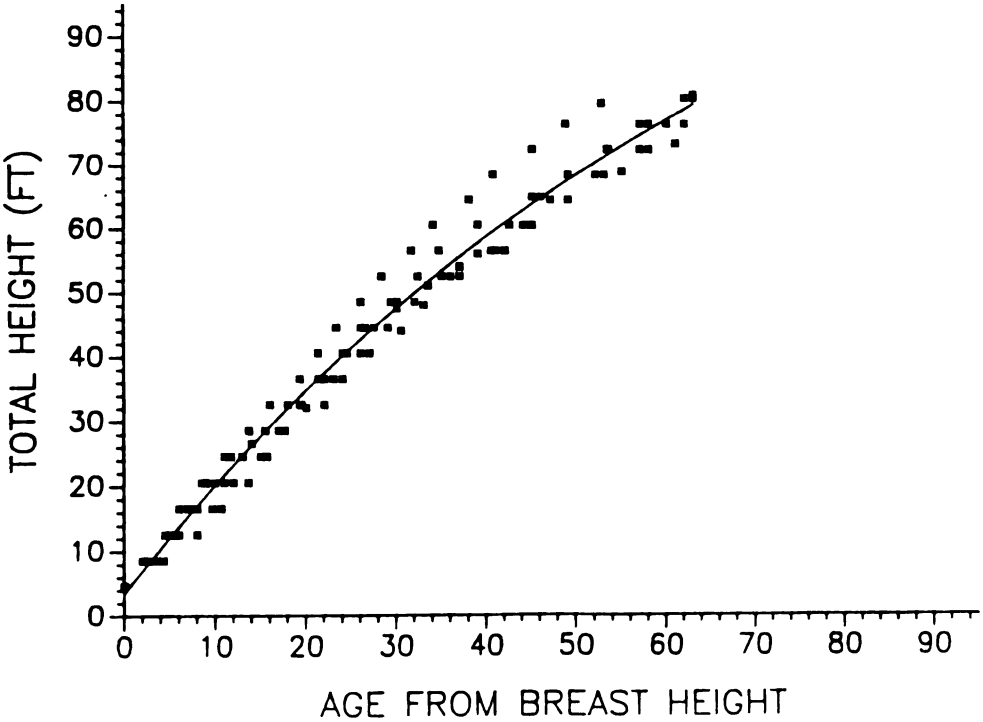
AGE FROM BREAST HEIGHT

Figure 35. Height growth of red oak growing on the SMM vegetation type.

Figure 36. Height growth of red oak growing on the RMOT vegetation type.



TOTAL HEIGHT (FT)
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AGE FROM BREAST HEIGHT

TOTAL HEIGHT (FT)
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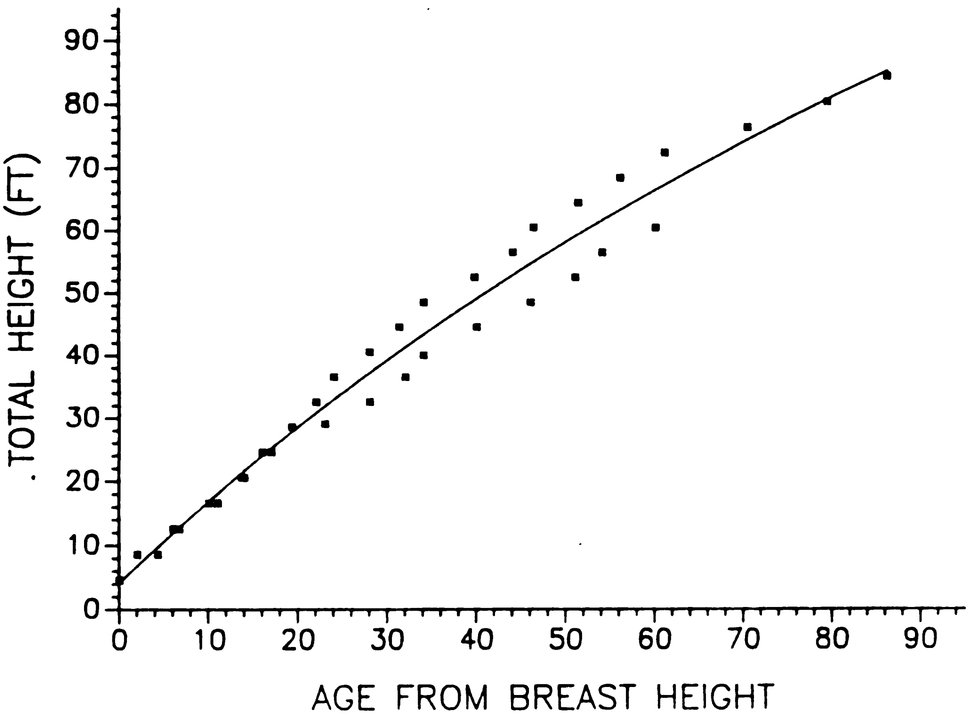
AGE FROM BREAST HEIGHT

Figure 37. Height growth of red oak growing on the RMOW vegetation type.

Figure 38. Height growth of red oak growing on the OPV vegetation type.



TOTAL HEIGHT (FT)
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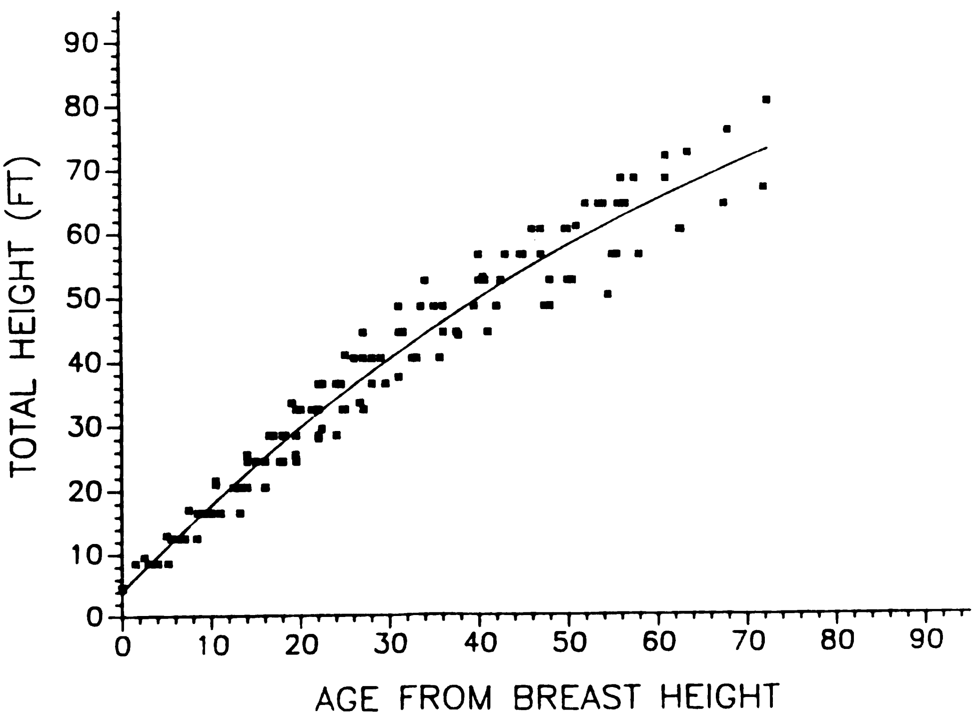
AGE FROM BREAST HEIGHT



TOTAL HEIGHT (FT)
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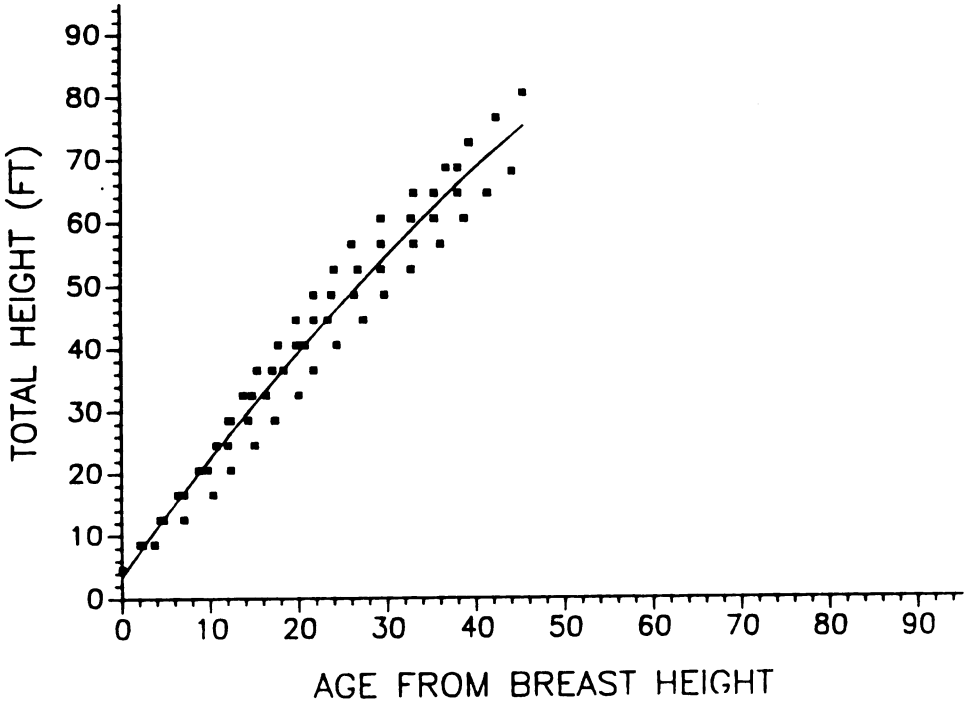
AGE FROM BREAST HEIGHT

Figure 39. Height growth of red pine growing on the SMO vegetation type.

Figure 40. Height growth of red pine growing on the SMM vegetation type.



TOTAL HEIGHT (FT)
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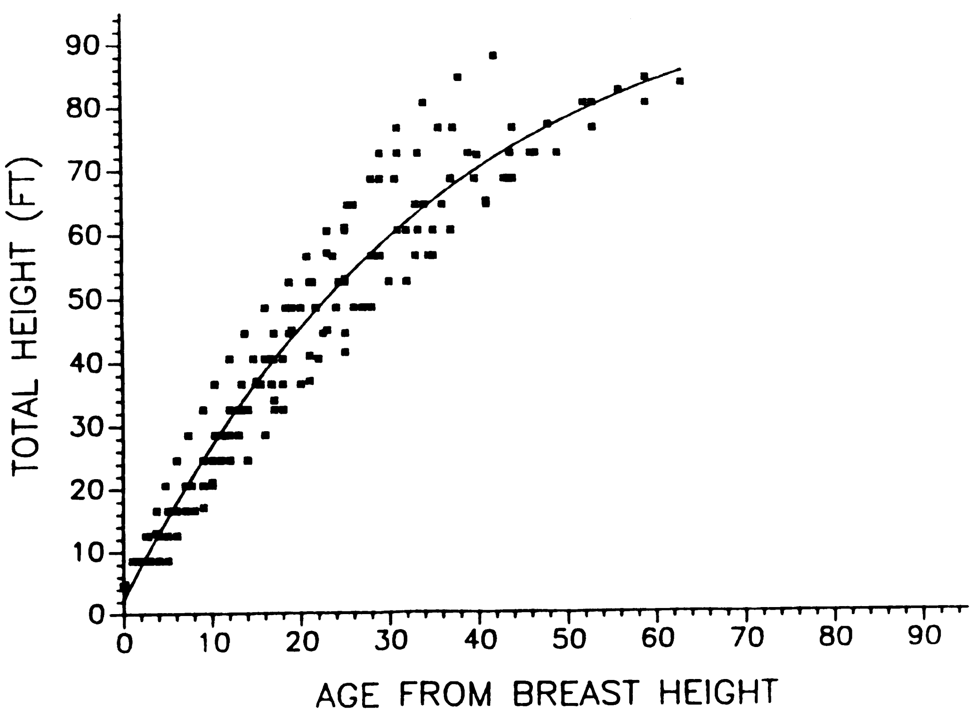
AGE FROM BREAST HEIGHT



TOTAL HEIGHT (FT)
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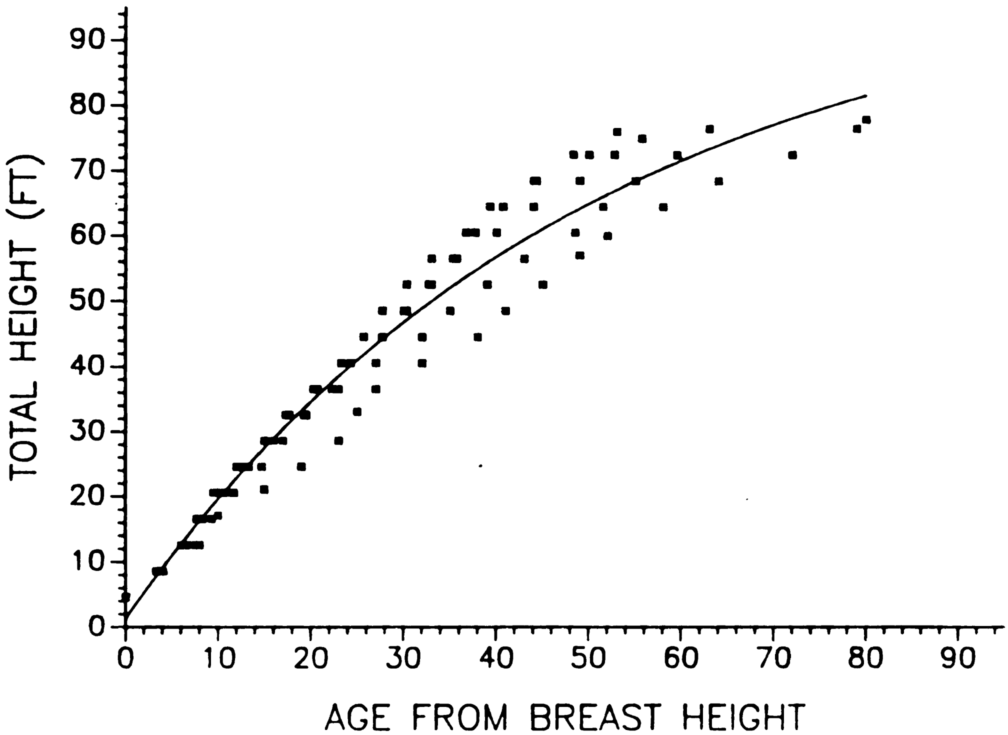
AGE FROM BREAST HEIGHT

Figure 41. Height growth of red pine growing on the RMOT vegetation type.

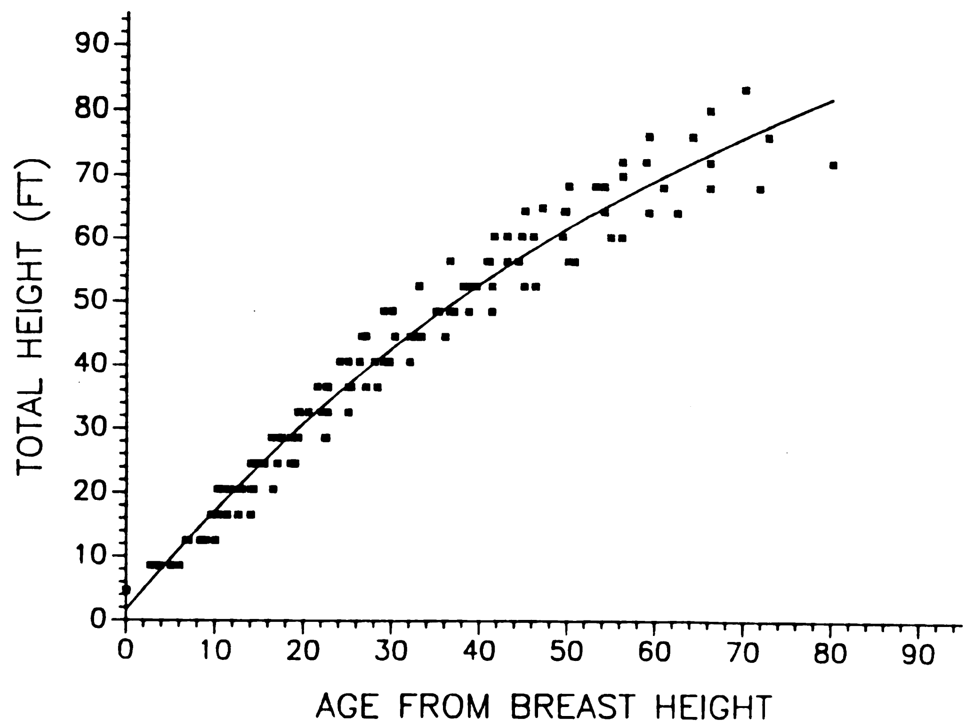
Figure 42. Height growth of red pine growing on the RMOW vegetation type.



TOTAL HEIGHT (FT)
AGE FROM BREAST HEIGHT

TOTAL HEIGHT (FT)
AGE FROM BREAST HEIGHT

Figure 43. Height growth of red pine growing on the OPV vegetation type.


TOTAL HEIGHT (FT)
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AGE FROM BREAST HEIGHT

APPENDIX C

<u>Levels of significance for each site index comparison.</u>

Table 7. Levels of significance for each of the species/soil type comparisons.

		EMMET	ROSELAWN
	Red pine	.010	
ROSELAWN	Bigtooth aspen	.009	
	Red oak	.071	
	Red pine	.0002	.019
RUBICON	Bigtooth aspen	9.7×10^{-7}	.004
	Red oak	.0014	.021

Table 8. Levels of significance for each of the species vegetation/type comparisons.

		RED PINE		
	SMM	RMOT	RMOW	OPV
SMO	.142	.004	.002	$3.4X10^{-5}$
SMM	---	.009	.003	$6.9X10^{-5}$
RMOT	---	---	.172	.091
RMOW	---	---	---	.472
		BIGTOOTH ASPEN		
	SMM	RMOT	RMOW	OPV
SMO	.341	.007	.006	$3.5X10^{-5}$
SMM	---	.011	.009	$5.8X10^{-5}$
RMOT	---	---	.315	.240
RMOW	---	---	---	.068
		RED OAK		
	SMM	RMOT	RMOW	OPV
SMO	---	---	---	---
SMM	---	.092	---	.003
RMOT	---	---	---	.014

BASSWOOD	SMO VS SMM	.323
SUGAR MAPLE	SMO VS SMM	.477
WHITE ASH	SMO VS SMM	.190

APPENDIX D

Regression parameters for each of the species/soil type and species vegetation type combinations.

Table 9. Regression parameters for each of the species/soil type combinations.

		SOIL TYPE		
		EMMET	ROSELAWN	RUBICON
	Species	Regression Parameters		
	Bigtooth aspen	98.15	150.7	119.9
B(1)	Red pine	156.2	103.8	105.3
	Red oak	124.7	129.8	131.5
	Bigtooth aspen	.9632	.9662	.9541
B(2)	Red pine	.9816	.9905	.9757
	Red oak	.9658	.9860	.9678
	Bigtooth aspen	.0340	.0125	.0137
B(3)	Red pine	.0137	.0207	.0169
	Red oak	.0152	.0135	.0110

Parameters to be used with the following model:

$$H = B(1) * (1.0 - B(2) * EXP(-B(3) * A))$$

Table 10. Regression parameters for each of the species/vegetation type combinations.

		VEGETATION TYPE				
		SMO	SMM	RMOT	RMOW	OPV
	Species	Regression Parameters				
B(1)	Bigtooth aspen	106.4	102.8	146.3	119.2	122.0
	Red pine	193.0	146.5	101.7	121.7	121.7
	Red oak	---	137.3	129.8	162.3	118.3
	Sugar maple	116.1	117.3	---	---	---
	Basswood	163.3	153.1	---	---	---
	White ash	127.7	180.2	---	---	---
B(2)	Bigtooth aspen	.9837	.9767	.9616	.9841	.9697
	Red pine	.9819	.9802	.9873	.9808	.9866
	Red oak	---	.9751	.9860	.9744	.9661
	Sugar maple	.9794	.9703	---	---	---
	Basswood	.9772	.9785	---	---	---
	White ash	.9898	.9972	---	---	---
B(3)	Bigtooth aspen	.0276	.0281	.0114	.0180	.0151
	Red pine	.0105	.0142	.0201	.0137	.0139
	Red oak	---	.0133	.0135	.0084	.0128
	Sugar maple	.0159	.0151	---	---	---
	Basswood	.0110	.0117	---	---	---
	White ash	.0181	.0117	---	---	---

Parameters to be used with the following model:

$$H = B(1) * (1.0 - B(2) * EXP(-B(3) * A))$$

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LITERATURE CITED

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