Section 7
Predicting Effects of Silvicultural Treatments

by Tim Williams

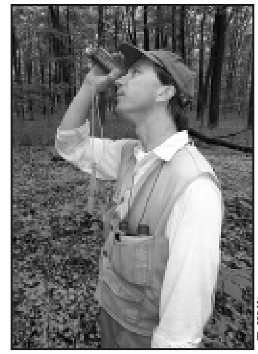
INTRODUCTION

Managing forest ecosystems for a variety of objectives requires a sound understanding of the spatial and temporal character of forest stands and the ability to assess stand responses to disturbance. It also requires some knowledge of how to predict short- and long-term ecosystem relationships and current and future values, as well as how to assess and maintain biological diversity. Focused research programs provide much of this information.

The primary goal of forest growth and yield research is to predict forest stand dynamics and the growth of stemwood biomass. In Ontario, growth and yield research is conducted using Permanent Sample Plots (PSPs). A network of PSPs, which are periodically re-measured, provides data about forest dynamics. Predictive models, ranging in complexity and scope, can then be constructed using data from these PSPs. A height curve predicting tree height based on observed diameter is an example of a simple model. This model can take the form of a simple graph depicted on a sheet of paper. Sophisticated computer growth models that predict the dynamics of entire forest stands are far more complex.

Discussion of forest growth and yield involves the use of specific terminology. The Glossary of Technical Terms provides definitions of commonly used growth and yield terms.

7.1 WHY TRY TO PREDICT EFFECTS OF SILVICULTURAL TREATMENTS?


T. Williams

In **Section 4.1**, factors contributing to the variability of forest productivity on different sites were briefly discussed. The interacting effects of latitude, elevation, climate, landform, bedrock geology, and soil texture and moisture determine the potential of a given site to grow trees of various species, sizes, and quality.

Due to the variable nature of forest productivity, silvicultural treatments might have quite different effects on one stand than they would have if the same treatments were applied to a similar stand occupying a different type of site. Similarly, silvicultural treatments applied to a different type of stand on the same site type could produce different results. Therefore, it is appropriate to customize silvicultural treatments to specific stands and sites. In order to do so properly, the forest manager must be able to predict the effects of a range of treatments in order to evaluate each one of them within the context of management objectives and to select the treatment that best applies to the existing scenario.

- For example, consider two hardwood stands – one on a highly productive site and another on a less productive site. Both stands are well suited to partial harvest using the selection system. The stand on the highly productive site might grow enough volume after the first cut to allow another cut to occur 17 years later. The less productive stand might require 22 years before a second cut is appropriate. In this example, the forest manager must know the rate at which these stands grow tree volume over time.

- Or, consider two different stands dominated by the same species. One stand might be located on an ideal site for that species; the other might be "off-site", where a different species could be more productive.

In order to determine management objectives for each stand, site index models can be of assistance. These models indicate tree species' relative productivity on various site types, and can help forest managers decide which silvicultural methods to apply to a stand.

7.2 WHAT INFORMATION AND TOOLS ARE USED TO PREDICT EFFECTS OF SILVICULTURE TREATMENTS?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The main factors that determine the growth and yield response of stands and individual trees can be grouped into three major divisions: site quality, individual tree characteristics, and stand level characteristics.

Site quality

As discussed in **Section 4.1**, many variables contribute to the ability of a site to support tree growth. Forest managers use two important measures of site productivity: site index and site class.

Site index

One of the most commonly used measures of site productivity for *even-aged* stands is site index (SI). Site index is a measure of tree height at a standard age (called the *index age*) and varies according to species. Site index is often represented by curves that depict the relationship between height and age of trees. Trees measured for site index must be those that have always been free from shading by neighboring trees. These trees reflect the potential (height) growth rate of an individual tree. Height growth is relatively unrelated to stand density, yet closely correlated to volume. Thus, two stands with the same initial density but different SI values will not produce equal volumes. The higher yield will occur in the stand with the greater SI value (Carmean *et al.* 1989). SI values in Ontario are usually described on a base age of 50 years. Measurements of stand age and stand top height are all that is required to determine SI. A stand with a height growth pattern intersecting 20 m at 50 years has a SI 20; another stand intersecting 22 m at 50 years has a SI 22.

Site index is often required as an input value for many of the growth models that have been developed in the United States (e.g., Fiber 3.0 (Solomon *et al.* 1995**)**, SILVAH (Marquis and Ernst 1992) and NE-TWIGS (Belcher 1992)). These estimates of site productivity are often considered to be the "growth engines" of many growth models.

Site index curves for 12 species covered in this guide are included with the individual species fact sheets in **Appendix E**. **Appendix D** contains a guide to tree species suitability for site regions 6E and 7E (Taylor and Jones 1986). This appendix presents site index and site class information for several tree species, based on field recognizable soil properties. These tables are useful when resource managers are setting management objectives for a given site, as they provide estimates of which tree species are likely to be most productive. The tables may also explain why poor productivity is observed in some stands (i.e., species are not suited to site conditions).

Site class

Site class is a group of species-specific site indices. It is a more generalized form of site quality classification than site index. Ontario has a three-class system that is published in Plonski's (1960, 1981) normal yield tables.

Ranges of Site Indexes (SIs) were divided into poor (Site Class 3), good (Site Class 2), and better (Site Class 1) SI groupings. Plonski developed these classes empirically by hand-fitting a curve through individual height-age measurements for multiple plots per species. Using this first curve as a guide curve, curves of the same shape were drawn one standard deviation above and below to create the boundaries of the site classes. Plonski's curves are of similar shape for differing site classes or ranges of SIs. Today it is generally understood that such curves are less representative of stand height-age-site development patterns than curves with variable shape. Nevertheless, Plonski's Site Class curves still provide the basis for site productivity classification in Ontario.

Table 7.2.1: Input requirements for various types of volume tables.

TYPE OF VOLUME TABLES	REQUIRED INPUTS							
	Species	**DBH**	**Total Height**	**Merchantable Height**	**Stump Height**	**Top Diameter**	**Age**	**Cull %**
Local Volume Table	×	×						
Form-class Volume Table	×	×		×				
Standard Volume Table (GTV)	×	×	×					
Standard Volume Table (GMV)	×	×	×		×	×		
Standard Volume Table (NMV)	×	×	×		×	×	×	×

[1] Smalian's formula: V = L *(a1+a2)/2 where V = volume (m^3), L = log length (m), a1 = cross-sectional area at base of log (m^2), a2 = cross-sectional area at top of log (m^2).

Individual tree characteristics

Volume tables

Volume tables or equations provide estimates of individual tree volumes from previously established relationships among easily measured tree characteristics such as diameter, height, and tree form. *Form-class,* s*tandard*, and *local* volume tables are used in Ontario. A summary of the inputs required for each type of volume table is presented in **Table 7.2.1.**

Form-class volume tables have been used in Ontario for over 60 years (Anon. 1930, 1948). They were used to estimate total and merchantable yields of individual trees, or sections of trees, and were usually based on Smalian's formula[1]. In Ontario, Form-Class 65, 70, 75, and 79 volume tables have been used for a variety of species (Berry 1981; Staley 1991). The Form-Class 79 volume table has been tested throughout the tolerant hardwood forests of Ontario and it is the preferred volume table for estimating the volume of standing timber (**Appendix E**). Total fuelwood volume in the remaining tops is estimated by multiplying the form-class volume estimate by 0.8 (Staley 1991).

The calibration of form-class volume tables for local conditions requires measurements of stem diameter at some specified upper height, usually the top of the first log (e.g., 5.28 m). However, local form-class-diameter relationships were not easily constructed because of the difficulty in measuring upper stem diameter and dealing with variations in tree form. Often tree form was not measured and tables were arbitrarily assigned to each species (Honer *et al.* 1983). This led to the development of standard volume tables that express the volume-diameter-height relationship without the need for tree form.

Standard volume tables for Ontario (Honer 1967; Honer *et al.* 1983) provide an estimate of the total inside-bark volume for individual trees. This method requires DBH and total tree height to estimate volume. These tables are often well documented and provide information on sample size, data range, construction methodology, date of preparation, and measures of accuracy. Standard equations are developed by destructively sampling a large number of trees per species across the range of ecosites that the species occupies. Honer's (1967) sampling was done throughout Canada. Standard volume tables for 12 species covered in this guide are presented with their respective fact sheets in **Appendix E.**

Local volume tables are a modification of standard volume tables based on the species DBH-height relationship within a given area. Incorporation of the local DBH-height relationship eliminates the need to measure tree heights; volume is based solely on DBH. Local volume tables are commonly used during operational assessments of forest inventories. A common problem with the use of local volume tables occurs when resource managers use tables that have not been developed specifically for their site, species, and quality conditions. Therefore, managers should periodically calibrate their local volume tables by validating the diameter height relationship.

Stand level characteristics

Growth and yield characteristics of groups of trees (i.e., forest stands) can be accounted for by using either yield tables or stand and stock tables.

Yield tables for *even-aged* stands are one of the oldest tools for estimating yields. Early yield tables only provided volume estimation, at different ages, for a given forest unit. Modern tables often include stand height, mean diameter, number of stems, stand basal area, and current and mean annual volume increments, in addition to accumulated volume estimates (i.e., yield). Yield tables are used to:

- predict growth and harvestable volume, and
- provide conceptual models of stand development.

Yield table estimates of growth and future harvest volume are good enough to plan both the timing and marketing of the harvest (Philip 1994).

The three most common classes of yield tables are: *normal*, *empirical*, and *variable density*.

Normal yield tables (e.g., Plonski 1960, 1981) provide estimates of expected yields tabulated by stand age and site index (or grouped into site classes) for ideal, fully stocked or "normal" forest stands (Vanclay 1994). They are usually derived by combining temporary sample plot data and stem analysis. The volume of an existing stand may be estimated with a normal yield table by adjusting the published yield values by a percentage of the expressed normality that is usually based on basal area. Normal yield tables provide reliable estimates of potential yields for even-aged stands that are like the stands used to develop the tables, but estimates may be poor in natural stands whose age varies considerably from those used in table construction (Vanclay 1994).

Table 7.2.2 provides yield estimates, for even-aged stands of four hardwood forest cover types in Site Region 6E and two hardwood forest cover types in Site Region 7E. Where data from enough PSPs was available, yield estimates were derived for both unmanaged and managed stands. For comparison purposes, yield estimates for the uneven-aged upland tolerant hardwood forest cover type in Site Regions 5E are presented in **Table 7.2.3.** Continued long-term monitoring of growth rates in PSPs is necessary to produce estimates exclusively for uneven-aged hardwood stands, both for unmanaged stands and those managed by the selection silvicultural system in both Site Regions 6E and 7E.

Empirical yield tables are similar to normal yield tables in their construction and use. The difference is that empirical tables are based on sample plots of average rather than full stocking. According to Husch *et al.* (1972), "the judgment necessary for selecting fully stocked stands is eliminated, simplifying the collection of field data." Yield tables developed in this manner display stand characteristics for the average stand density encountered in the collection of the field data.

Table 7.2.2: Yield estimates for even-aged hardwoods by forest cover type, Site Region, and residual BA class.

		Unmanaged		Managed**		Estimate Basis		
Forest Cover Type and Site Region	Residual BA Class*	BA Increment (m^2/ha/yr)	GMV Increment (m^3/ha/yr)	BA Increment (m^2/ha/yr)	GMV Increment (m^3/ha/yr)	# Obs. (control / managed)	# stands (control / managed)	# years (control / managed)
Early Successional Hardwoods - 6E	35	0.06	4.02	0.34	4.72	6 / 9	1 / 1	4-5 / 5
Lowland Hardwood or Swamp - 6E	30	0.31	5.00			3	1	5
Lowland Hardwood or Swamp - 6E	35	0.13	5.88			8	1	5-8
Upland Oaks - 6E	20	0.37	6.26			2	2	5
Upland Oaks - 6E	25	0.45	5.89			3	1	5
Upland Oaks - 7E	20			0.31	3.53	3	1	5
Upland Oaks - 7E	25	0.47	4.91			6	1	5
Upland Tolerant Hardwood - 6E	20	0.42		0.41	4.41	13 / 2	2 / 5	5-7 / 1-7
Upland Tolerant Hardwood - 6E	25	0.27	3.22	0.47	4.55	58 / 23	10 / 7	4-8 / 5-8
Upland Tolerant Hardwood - 6E	30	0.06	2.93	0.36	5.70	68 / 7	11 / 2	5-7 / 3-5
Upland Tolerant Hardwood - 6E	35	0.15	4.37			31	6	4-6
Upland Tolerant Hardwood - 7E	20			0.71	8.01	3	1	5
Upland Tolerant Hardwood - 7E	30	0.37	6.08			11	1	3-7
Upland Tolerant Hardwood - 7E	40	0.00	0.31	0.59	8.38	3 / 4	1 / 2	2 / 1-7

(based on data collected from trees 10 cm in DBH and greater)

* BA Class represents midpoint:

20	17.5-22.4 m^2/ha
25	22.5-27.4 m^2/ha
30	27.5-32.4 m^2/ha
35	32.5-37.4 m^2/ha
40	37.5-42.4 m^2/ha

Management of some of the stands presented ranges from random tree removal to application of recognized silvicultural practices. Potential higher increments may be realized with proper and careful management. **Failure to implement careful logging practices will result in smaller growth increments.

Table 7.2.3: Yield estimates for uneven-aged upland tolerant hardwoods in Site Region 5E, by residual BA class (from Woods *et al.* 1998).

		Unmanaged		Managed**		Estimate Basis		
Forest Cover Type and Site Region	Residual BA Class*	BA Increment (m^2/ha/yr)	GMV Increment (m^3/ha/yr)	BA Increment (m^2/ha/yr)	GMV Increment (m^3/ha/yr)	# Obs. (control / managed)	# stands (control / managed)	# years (control / managed)
Upland Tolerant Hardwood - 5E	10			0.46		18	1	3-4
Upland Tolerant Hardwood - 5E	15			0.38		18	1	3-4
Upland Tolerant Hardwood - 5E	20			0.49		107	3	3-5
Upland Tolerant Hardwood - 5E	25	0.49		0.32		23 / 107	2 / 3	6-7 / 4-10
Upland Tolerant Hardwood - 5E	30	-0.57				6	1	6

(based on data collected from trees 10 cm in DBH and greater)

* BA Class represents midpoint:

10 7.5-12.4 m^2/ha
15 12.5-17.4 m^2/ha
20 17.5-22.4 m^2/ha
25 22.5-27.4 m^2/ha
30 27.5-32.4 m^2/ha

**Managed and Unmanaged stand estimates are based mainly on controlled research trials. Limited operational trial data is presented.

Variable density yield tables include the additional variable of density that permits data from partially stocked stands to be used in their development. This addition also means that variable density yield tables can be applied to stands regardless of their stocking. Recently published variable density yield tables in the boreal forest (Bell *et al.* 1990) use a combination of stand density, stand age, and SI in their presentation of yield information. Variable density yield tables do not exist for tolerant hardwood stands in Ontario.

Stand and stock tables are quantitative descriptions of individual or groups of forest stands for forest inventory purposes. They are used to estimate the amount of useable wood for a variety of products, including pulpwood, fuelwood, or sawtimber. Stand and stock tables are also used to analyze stand structure in the development of intermediate thinning or final harvest prescriptions. The most common stand parameters measured include frequencies of species by diameter and quality class.

A *stand table* is used to present the number of trees by species for a forest, with data often expressed as basal area by diameter, quality, or height classes. Stand tables can be expressed as a unit area (e.g., hectare) or as total forest or stand area. A stand table is useful for showing the structure of the stand (Husch *et al.* 1972).

Once harvest or thinning prescriptions have been developed, current stand yield by product class can be determined. Future stand growth can also be predicted within each diameter or size class, which provides more accurate assessments of future stand structure. Many growth models (e.g., Raymond and McLean 1984) use this method of stand growth projection.

7.3 GROWTH AND YIELD SAMPLING IN SOUTHERN ONTARIO


K. Elliott

A network of 398 Beckwith PSPs (named for the project leader, Alan Beckwith) was established in southern Ontario during the 1960s to 1980s. These plots are located primarily in hard maple stands and conifer plantations. Re-measurements continue to be carried out by the OMNR, and some plots have data from as many as nine observation periods.

To address data needs not met by the Beckwith PSP network, the current OMNR Growth and Yield program began installing enhanced PSPs from 1991 to 1995. These PSPs expanded the type of data collected to include data on downed woody debris, shrubs and vegetation, wildlife evidence and habitat, soils, and forest regeneration.

Re-measurement and expansion of this plot network is ongoing. A complete set of growth and yield tools derived from research in southern Ontario is unavailable for all species discussed in this silvicultural guide. However, growth and yield models from nearby provinces and states are presented in **Appendix E** for species that lack Ontario models. Research will continue in both the development and standardization of these tools for Ontario.