ONTWIGS: A FOREST GROWTH AND YIELD PROJECTION SYSTEM ADAPTED FOR ONTARIO

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ABSTRACT

ONTWIGS is a first step in the adaptation of LSTWIGS for use in Ontario. LSTWIGS is a growth and yield projection model developed by the USDA Forest Service for major tree species in the Lake States. Since growing conditions in northern parts of the Lake States are quite similar to those in Ontario, the model may be modified to account for Ontario growing conditions. Such modification involves converting inputs and outputs to the metric system and substituting the codes for Ontario's tree species. In addition, the existing model parameters must be tested and, if necessary, replaced with parameters specifically developed for Ontario. Such a growth-projection model will be a useful tool for examining various management strategies in Ontario. It will allow its users to manipulate the stand in a variety of ways, including changes in tree size, density, species and size-class distribution.

RÉSUMÉ

ONTWIGS est la première adaptation du LSTWIGS à la situation de l'Ontario. Le LSTWIGS est un modèle prévisionnel de la croissance et du rendement des principales essences des États en bordure des Grands Lacs mis au point par le Service des forêts des États-Unis. Les conditions de croissance dans le nord de ces États étant très similaires à celles de l'Ontario, le modèle peut être adapté et modifié pour tenir compte des particularités de la province. Parmi ces modifications, mentionnons la conversion en unités métriques des données d'entrées et des résultats et le remplacement des codes d'essence par ceux de l'Ontario. De plus, les paramètres existants du modèle doivent être vérifiés et, au besoin, remplacés par d'autres spécifiquement élaborés pour l'Ontario. Ce modèle de prévision de la croissance sera un outil fort utile pour étudier les diverses stratégies d'aménagement de la province. Il permettra aux utilisateurs de faire varier de diverses façons les caractéristiques d'un peuplement, y compris modifier les dimensions des arbres, la densité, la composition du peuplement et la répartition des classes d'âge.

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INTRODUCTION

Over the past two decades, more than two dozen growth-simulation models have been developed for North American forests and tree species. Such models may be divided into two general categories: stand models and individual-tree models (Munro 1974).

Stand models simulate the growth and yield of a forest stand as a whole and use related stand variables and factors such as stand density, basal area, height, site productivity, etc. to project the forest's growth and yield. Individual-tree models simulate the growth of individual trees as this growth is affected by other trees competing for light, soil moisture and nutrients. Individual-tree models are further divided into two types: distance-dependent and distance-independent models.

Distance-dependent models are driven by the density and spatial pattern of trees. In general, spatial patterns vary from clustered (aggregated) to random or uniform patterns. Distance-dependent models may provide the most reliable growth and yield information because they are based on individual trees and their interactions with neighboring trees. However, such models are very expensive to develop, calibrate and apply.

In distance-independent models, the growth and development of individual trees are not affected by spatial patterns. Several models have been developed for single species and even-aged forest stands and a few models have been developed for multiple species and uneven-aged forest stands.

STEMS (Stand and Tree Evaluation and Modeling System) and TWIGS (i.e., "micro version of STEMS") have been developed at the USDA's North Central Forest Experiment Station (St. Paul, Minnesota). These models are suitable for growth and yield projection for uneven-aged and multiple-species forest stands. STEMS was developed for batch processing of inventory data on mainframe computers (Brand et al. 1988), whereas TWIGS (Miner et al. 1987) is the microcomputer version of STEMS. TWIGS is available in several versions for different computer systems or programming languages (e.g., FORTRAN and BASIC, for Apple II computers; FORTRAN and PASCAL, for IBM PC-compatible computers; and versions for Data General computers). The LSTWIGS (Lake States TWIGS) model is the version specifically developed and calibrated for the north-central states of Michigan, Wisconsin and Minnesota; other versions of the model have been developed for use in central states as well as the northeastern states. TWIGS can be easily adapted for application in Ontario because the growing conditions are fairly similar to those in the Lake States. As a result of interest shown by the Ontario Ministry of Natural Resources (OMNR) and the Ontario forest industry, it was decided to modify LSTWIGS and develop an Ontario version of the program, hereafter referred to as ONTWIGS. Conversion of the LSTWIGS model into a form that can be used in Ontario entails three main steps:

- Conversion of the input and output files into the metric system.
- Substitution of Ontario species codes for those used in the United States.
- Development of new submodels.

This report covers the first two steps and provides a brief description of ONTWIGS.

CONVERSION OF INPUTS AND OUTPUTS INTO THE METRIC SYSTEM

Conversion of inputs and outputs into the metric system involves conversion of the coefficients of equations from English units into metric units. Since Ontario's major commercial species are far fewer than those of the Lake States, we reduced the number of species groups from 31 for the Lake States to 8 for Ontario. The species group codes 1, 2, 3, 4, 5, 6, 25 and 26, respectively, are equivalent to the following Ontario species: jack pine (*Pinus banksiana* Lamb.), red pine (*Pinus resinosa* Ait.), white pine (*Pinus strobus* L.), white spruce (*Picea glauca* [Moench] Voss), balsam fir (*Abies balsamea* [L.] Mill.), black spruce (*Picea mariana* [Mill.] B.S.P.), aspen (*Populus* spp.) and white birch (*Betula papyrifera* Marsh.).

Hardware and Software Requirements

In order to modify the TWIGS growth and yield projection system, the programmer must have the following items:

- an IBM PC or compatible microcomputer with at least 384K of memory
- DOS 2.1 operating system (or more recent version)
- one floppy disk drive and a hard drive
- the Microsoft FORTRAN compiler (version 4.1 or later) and the "No Limit FORTRAN library", FOR2LIB.MEF, from MEF Environment Inc. (Anon. 1984)
- the following FORTRAN source code (10,472 lines of code, including documentation): TWIGS1.FOR, TWIGS2.FOR, INIT.FOR, SETTL.FOR, VOL.FOR, STOCK.FOR, ECON.FOR and GROW.FOR.

However, the user only needs TWIGS.EXE, TWIGS.DAT and a tree-list data file for running the program. The user must provide his own tree-list data file. If an actual data set is not available, one can be generated with the program TREEGEN. The latter program generates a tree list based on normal or Weibull distributions, or for individual trees.

Growth and mortality equations for the LSTWIGS model were developed from data collected from 15,000 plots (80,000 trees) across the Lake States.

Conversion of Existing Equations into Metric Units

To demonstrate the metric conversion of sub-model coefficients, we have chosen the potential annual diameter growth equation as an example. In English units, this equation has the following form (Miner et al. 1987, Appendix B1):

$$(1) \quad PG = b_1 + b_2\ (D)^{b_3} + b_4(SI)CR(D)^{b_5}$$

where: PG = potential annual diameter growth (in./year); b_1, b_2, b_3, b_4 and b_5 are equation coefficients; D = current tree diameter (in.); SI = site index (height in feet at a base age of 50 years); and CR = tree crown-ratio code (0–10% = 1, 11–20% = 2, 21–30% = 3, ..., 71–80% = 8, > 80% = 9).

Now, let D' current diameter (cm); SI' = site index (height in metres at a base age of 50 years); CR' = tree crown-ratio code (0–10% = 1, 11–20% = 2, ..., 71–80% = 8, > 80% = 9); PG' = potential annual diameter growth (cm/year); $k = 1/2.54$ (the conversion factor from cm to in.); and $n = 1/0.3048$ (the conversion factor from metres to ft).

Then we have an equivalent equation of the form:

$$(2) \quad kPG' = b_1 + b_2\ k^{b_3}(D')^{b_3} + b_4nk^{b_5}(SI')CR'(D')^{b_5}$$

Divide both sides by k:

$$PG' = b_1/k + b_2\ k^{b_3-1}(D')^{b_3} + b_4nk^{b_5-1}(SI')CR'(D')^{b_5}$$

Now if $b_1' = b_1/k$; $b_2' = b_2\ k^{b_3-1}$; $b_4' = b_4nk^{b_5-1}$:

$$(3) \quad PG' = b_1' + b_2'\ (D')^{b_3} + b_4'\ (SI')CR'(D')^{b_5}$$

Equation (3) is the equivalent of equation (1), but in metric units. The species-specific equation coefficients b_1', b_2', b_3, b_4' and b_5 are given in Table 1.

Growth and Yield Equations

The model employs diameter growth and mortality equations to simulate growth of the stand and to project yield from one period to the next. The growth equation estimates annual diameter growth for each sample tree and updates the tree's crown-ratio value. Annual diameter growth is estimated as the product of potential annual diameter growth and a modifier that accounts for competition. The latter is a function of tree species, size and the distance of each tree from neighboring trees. The equations used to describe the various components of stand growth have been modified from those of Miner et al. (1987).

Potential annual diameter growth

This value is predicted for each tree as if the trees were "open grown" or were growing free of competition. It is a function of species, the tree's crown ratio, its outside-bark diameter at breast height (DBH) and site index. Tables 1 through 8 summarize the derivation of coefficients for various submodels by species and converted to metric units. Table 1 contains such coefficients for potential annual diameter growth.

Table 1. Coefficients of potential annual diameter growth equation, converted to metric units for use with Ontario species[a].

Species		Coefficient				
Code	Name	b_1'	b_2'	b_3	b_4'	b_5
1	Jack pine	0.40797	−0.0000008	3.6245	0.0001312	1.0000
2	Red pine	0.23993	−0.0000447	2.0596	0.0023271	0.2422
3	White pine	0.64868	−0.0004471	1.7263	0.0001312	1.0000
4	White spruce	0.43322	−0.0136499	1.0660	0.0033597	0.2730
5	Balsam fir	0.30988	−0.0003182	1.9890	0.0001968	1.0000
6	Black spruce	0.27211	−0.0004206	2.0017	0.0002138	0.9113
25	Aspen	0.54978	−0.0000204	1.6030	0.0001443	1.0000
26	White birch	0.27866	−0.0001232	2.0236	0.0023233	0.2129

[a] Original coefficients from Miner et al. (1987).

Competition modifier

This equation reduces the predicted potential growth to account for competition for light, moisture and nutrients. This makes the projection a more realistic simulation of trees growing in the forest. Within-stand competition is reflected in this factor, which is based on stand basal area and the size of each tree in relation to the tree of average diameter in that stand. The metric version of this equation is of the following form:

$$(4) \quad CM = 1 - e^{(-f(R)\, g(AD')\, [(BA'_{max} - BA')/BA']\, 0.5)}$$

where: CM = competition modifier, which varies between zero and one; BA'_{max} = maximum basal area (m^2/ha) expected for each species; BA' = current basal area (m^2/ha); R = relative DBH of the tree (ratio of the tree's DBH to that of the average stand diameter); AD' = average stand diameter (cm); $f(R)$ = a function characterizing the individual tree's relative diameter effect on $CM = b_1\ [1 - e^{b_2 R}]^{b_3} + b_4$; $g(AD')$ = a function characterizing the effect of average stand diameter on $CM = c_1'\ (AD' + 2.54)\ c_2$; and b_1, b_2, b_3, b_4, c_1' and c_2 are species-specific equation coefficients given in Table 2.

Diameter adjustment factor

Each tree diameter is adjusted to make the projection more realistic (i.e., similar to real trees growing in a stand). The metric version of the regression equation is of the following form:

$$(5) \quad DAF' = a_1'\ D' + a_2'\ D'^2 + a_3'$$

where: DAF' = diameter-adjustment factor (cm); D' = current tree diameter (cm); and a_1', a_2' and a_3' are species-specific equation coefficients given in Table 3.

Crown ratio

This is the percentage of tree height occupied by live crown. Its mathematical equation is of the following form:

$$(6) \quad CR' = \frac{b_1'}{0.229568 + b_2(RBA')} + b_3(1 - e^{b_4' D'}) + CF$$

where: CR' = the crown-ratio code (0–10% = 1, 11–20% = 2, ..., 71–80% = 8, > 80% = 9) for an individual tree; RBA' = 10-year running-average stand basal area (m^2/ha) (i.e., the average for each year is used in that year); D' = current tree diameter (cm); CF = correction factor, computed as initial predicted crown ratio minus initial observed crown ratio; and b_1', b_2, b_3, and b_4' are the equation coefficients for specific species given in Table 4.

Table 3. Individual tree diameter-adjustment coefficients converted to metric units for use with Ontario species[a].

Species		Coefficient		
Code	Name	a_1'	a_2'	a_3'
1	Jack pine	−0.0069	0.000101	0.1753
2	Red pine	0.0000	−0.000026	0.0457
3	White pine	0.0017	0.000017	0.0737
4	White spruce	0.0000	0.000000	0.0000
5	Balsam fir	−0.0044	0.000062	0.0762
6	Black spruce	−0.0091	0.000251	0.0940
25	Aspen	1.0051	0.000122	0.0787
26	White birch	−0.0026	0.000059	0.0279

[a] Original coefficients from Miner et al. (1987).

Table 2. Coefficients for parameters in the competition modifier equation converted to metric units for use with Ontario species[a].

Species		Coefficient						
Code	Name	BA'_{max}	b_1	b_2	b_3	b_4	c_1'	c_2
1	Jack pine	52	1.780	−3.00	16.20	0.227	0.824	0.230
2	Red pine	69	0.179	−10.90	1688.00	0.357	7.172	−0.354
3	White pine	69	1.360	−2.64	11.50	0.386	0.122	0.755
4	White spruce	80	5.000	−1.01	3.64	0.000	6.215	−0.520
5	Balsam fir	75	1.760	−1.51	2.63	0.233	3.111	−0.299
6	Black spruce	69	3.800	−1.52	6.54	0.348	1.128	0.173
25	Aspen	57	1.080	−6.60	346.10	0.395	0.320	0.543
26	White birch	63	1.980	−1.75	3.67	0.232	0.148	0.678

[a] Original coefficients from Miner et al. (1987).

Tree mortality

This is calculated for the stand by estimating the probability of death for each tree in a given year. The metric version of the equation is of the following form:

$$(7) \quad Survival = b_1 - \frac{1}{1 + e^{(n'/2.54)}}$$

where: $Survival$ = a tree's annual probability of survival; $n' = b_2' + b_3' \, DGR'^{b_4} + b_5' \, [D' - 2.54]^{b_6} \, e^{-b_7'}(D' - 2.54)$; DGR' = predicted annual diameter growth (cm); D' = current tree diameter (cm); and b_1, b_2', b_3', b_4, b_5', b_6 and b_7' are the species-specific equation coefficients given in Table 5.

Volume

The height and volume equations used for the Lake States model are considerably different from those used in Ontario. The height and volume equations used for eastern Canadian species were substituted in ONTWIGS as described in Tables 6 through 8.

AN EXAMPLE OF RUNNING THE PROGRAM

In order to run ONTWIGS, the user must provide the input data file. Such a file may be the tree listing from an actual plot or may be generated entirely by the TREEGEN program. Figure 1 in Appendix C provides an example of the Ontario and the Great Lakes species codes that may be printed out at the beginning of the run. Figure 2 in Appendix C shows an example of a tree-list data file.

Initial stand conditions are reported in a table that appears at the beginning of the run. The table includes data on stand density (no. trees/ha), basal area, average diameter, and total and merchantable volumes for various species-group and size-class combinations (Figure 3 in Appendix C). Projections of stand condition after each growth cycle or management action are also tabulated (see Figures 4–6 in Appendix C). These tables also provide information on predicted harvest and mortality for various species-group and size-class combinations. Information on volume (total merchantable and residual) is also provided.

Table 4. Coefficients of crown ratio converted to metric units for use with Ontario species[a].

Species		Coefficient			
Code	Name	b_1'	b_2	b_3	b_4'
1	Jack pine	1.524	0.0135	3.200	−0.0204
2	Red pine	1.228	0.0053	1.528	−0.0130
3	White pine	1.559	0.0058	7.590	−0.0041
4	White spruce	1.800	0.0057	1.272	−0.0559
5	Balsam fir	1.292	0.0047	3.523	−0.0271
6	Black spruce	1.272	0.0072	4.200	−0.0209
25	Aspen	0.918	0.0024	−2.830	0.0083
26	White birch	1.148	0.0066	4.920	−0.0104

[a] Original coefficients from Miner et al. (1987).

Table 5. Tree survival coefficients converted to metric units for use with Ontario species[a].

Species		Coefficient						
Code	Name	b_1	b_2'	b_3'	b_4	b_5'	b_6	b_7'
1	Jack pine	0.9966	1.4991	23.57	0.711	0.0003	4.764	0.2690
2	Red pine	0.9997	5.0681	57.33	1.012	0.1477	1.626	0.0501
3	White pine	0.9989	4.1021	480.86	2.268	1.4793	0.432	0.0398
4	White spruce	0.9994	2.4699	133.90	1.915	0.2142	1.302	0.0662
5	Balsam fir	0.9984	4.8872	28.15	1.021	0.3773	3.640	0.6582
6	Black spruce	0.9946	4.3155	43.85	1.219	0.7088	0.959	0.0885
25	Aspen	0.9908	0.9581	31.80	1.089	0.0097	3.419	0.2104
26	White birch	0.9991	4.9629	14.68	0.398	0.4451	2.444	0.3513

[a] Original coefficients from Miner et al. (1987).

Table 6. Coefficients of the site index (height expressed as a function of site index and age) equations for Ontario's major timber species[a].

Species	Coefficient				
	b_1	b_2	b_3	b_4	b_5
Jack pine	1.8180	0.8830	−0.0381	6.7560	−0.4997
Red pine	1.5987	0.9682	−0.0275	2.3660	−0.2063
White pine	5.6095	0.6442	−0.0244	5.5377	−0.3386
White spruce	1.8041	0.9591	−0.0230	1.2841	0.0050
Balsam fir	1.2906	1.0096	−0.0401	2.0034	0.0182
Black spruce	6.1830	0.5150	−0.0211	5.9580	−0.5657
Aspen	2.5560	0.7940	−0.0335	9.2960	−0.6060
White birch	1.2150	1.0060	−0.0503	4.3290	−0.1823

[a] Source: Payandeh (1977).

Table 7. Coefficients of total-volume equations for Ontario's major timber species[a].

Species	Coefficient		
	c_1	c_2	c_3
Jack pine	0.151	0.897	348.530
Red pine	0.151	0.710	355.623
White pine	0.184	0.691	363.676
White spruce	0.176	1.440	342.175
Balsam fir	0.152	2.139	301.634
Black spruce	0.164	1.588	333.364
Aspen	0.127	−0.312	436.683
White birch	0.176	2.222	300.373

[a] Source: Honer et al. (1983).

Table 8. Coefficients of merchantable-volume equations for Ontario's major timber species[a].

Species	Coefficient			
	r_1	r_2	r_3	b_1
Jack pine	0.9635	−0.1500	−0.8081	0.151
Red pine	0.9672	−0.0393	−1.0523	0.151
White pine	0.9735	−0.2348	−0.7378	0.184
White spruce	0.9611	−0.2456	−0.6801	0.176
Balsam fir	0.9352	0.0395	−0.8147	0.152
Black spruce	0.9526	−0.1027	−0.8199	0.164
Aspen	0.9354	−0.0957	−1.1613	0.127
White birch	0.9087	−0.3049	−0.5107	0.176

[a] Source: Honer et al. (1983).

The management option comprises a flexible set of procedures that allow the user to impose practically any type of cutting regime on a single stand. The current stand conditions (before and after cut), the diameter of the trees cut, their basal area and the number of trees cut are shown in Figure 5 in Appendix C.

A summary of the entire simulation (management option and growth projection) is printed at the completion of the run; one example is presented in Figure 7 in Appendix C).

RECOMMENDATIONS

As mentioned earlier, this report describes the metric conversions for input and output values and the species-code conversion for LSTWIGS. In its present form, ONTWIGS may be used only if it can be assumed that growing conditions for the species group or forest type under consideration are the same in Ontario as in the Lake States. However, to have a true Ontario version of the model, its various sub-models and their species-specific coefficients must be tested under Ontario conditions and, where necessary, specific-species coefficients that are unique to Ontario must be developed. In other words, ONTWIGS must be calibrated extensively before it can be used as a reliable projection system for Ontario. This will require additional work and resources, but both should be easy to justify considering the valuable management tool that could be provided for Ontario forests.

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APPENDIX A: Miscellaneous information

Table A1. Imperial/metric conversion factors used in ONTWIGS (Source: Rennie 1975).

English unit		*Metric equivalent*
1 acre	=	0.404686 ha
1 ft^3	=	0.0283168 m^3
1 ft^2	=	0.092903 m^2
1 ft	=	0.3048 m
1 inch	=	2.54 cm
1 ft^3/ac	=	0.0699725 m^3/ha
1 ft^2/ac	=	0.229568 m^2/ha
1 ton (2000 lb)	=	0.907185 tonne (1000 kg = 1 tonne)
1 lb/ft^3	=	16.0185 kg/m^3

Table A2. Ontario and Great Lakes (STEMS) species-codes equivalents.

Species code			
STEMS	USFS	Ontario	Species name
1	105	3	Jack pine
2	125	2	Red pine
3	129	1	White pine
4	94	12	White spruce
5	12	20	Balsam fir
6	95	13	Black spruce
7	71	25	Tamarack
8	241	22	Cedar
9	261	19	Hemlock
10	1	–	Softwood
11	543	45	Black ash
12	742	71	Cottonwood
13	317	33	Silver maple
14	316	32	Red maple
15	792, 795	49	Elm
16	371	37	Yellow birch
17	951	51	Basswood
18	318	30	Sugar maple
19	541	46	White ash
20	802	40	White oak
21	833	41	Red oak
22	837, 809	43	Other oak
23	402, 403	53	Hickory
24	743	–	Largetooth aspen
25	741	73	Balsam poplar
26	375	74	Trembling aspen
30	300	38	White birch
31	999	99	Noncommercial

APPENDIX B: Programming hints

To compile, link and run ONTWIGS, one needs Microsoft FORTRAN Version 4.1 or later and the NOLIMIT FORTRAN library must be installed. An example of a batch file for compiling and linking ONTWIGS is given in the following file (COMPILE.BAT).

```
fl /c / FPc ontwigs1.for
fl /c / FPc ontwigs2.for
fl /c / FPc onecon.for
fl /c / FPc ongrow.for
fl /c / FPc onsettl.for
fl /c / FPc onstock.for
fl /c / FPc onvol.for
fl /c / FPc oninit.for
fl /c / FPc onstock.for
LINK /e ontwigs1+ontwigs2+onecon+ongrow+onsettl+onstock+onvol+oninit,twigs,,forlib2.mef;
```

The first eight lines compile ONTWIGS and its associated routines with the emulator math package option. If no error occurs, the object files are formed; each has the same file name, but with the extension "OBJ".

The "LINK" command loads and links the object modules ONTWIGS1.OBJ, ONTWIGS2.OBJ, ..., and ONINIT.OBJ and searches for unresolved subroutines in the library file "FORLIB2.MEF" and the default libraries (LLIBFORE.LIB and FORTRAN.LIB). The option "/e" packs the executable file "TWIGS.EXE", which is ready to run.

The program runs correctly even though an unresolved error, "FILDIR", in the "FORLIB2.MEF" library occurs after linking.

APPENDIX C: Sample output from ONTWIGS

```
èëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëë£
¤                                                                               ¤
¤  OOOO    N   N   TTTTT  W     W  III  GGGGG  SSSSS      Ontario adapted       ¤
¤ O    O  NN  N     T    W     W   I   G      S          Woodsman's            ¤
¤ O    O  N N N     T    W WW W    I   G  GG  SSSSS      Growth                ¤
¤ O    O  N  NN     T    WW   WW   I   G   G      S      projection System     ¤
¤  OOOO   N   N     T    W     W  III  GGGGG  SSSSS                            ¤
¤                                                                               ¤
¤ Ontario Region 1.0 (April 1989).                                              ¤
¤                                                                               ¤
¤ Microsoft FORTRAN for the IBM microcomputer                                   ¤
¤                                                                               ¤
¤ Written by:  Kevin K. Nimerfro and Monique L. Belli                           ¤
¤ With direction from:  Gary J. Brand, Nancy R. Walters,                        ¤
¤                       Charles R. Blinn, and Dietmar W. Rose                   ¤
¤ Ontario version modified by:  Luong Huynh, March 1989                         ¤
¤ With direction from:  Bijan Payandeh                                          ¤
¤ Forestry Canada, Ontario Region.  Sault Ste. Marie, Ontario                   ¤
¤                                                                               ¤
àëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëëV
```

```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                              ::
::         ONTARIO AND GREAT LAKES (STEMS) SPECIES CODES EQUIVALENTS            ::
::                                                                              ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

SPECIES CODES ARE:

STEMS	ONSP	NAME	STEMS	ONSP	NAME	STEMS	ONSP	NAME
1	3	JACK PINE*	10	299	OTHR SFTWD	19	46	WHITE ASH
1	4	SCTCH PINE	11	45	BLACK ASH	20	40	WHITE OAK
2	2	RED PINE*	11	47	GREEN ASH	21	41	RED OAK
3	1	WHITE PINE*	12	71	COTTONWOOD	22	43	OAK ALL
4	12	WHT SPRUCE*	13	33	SILV MAPLE	23	53	HICKORY
5	20	BALSAM FIR*	14	32	RED MAPLE	25	74	TREM ASPEN*
6	13	BLK SPRUCE*	15	49	ELM	25	73	BLSM POPLR
7	25	TAMARACK	16	37	YELO BIRCH*	26	38	WHT BIRCH*
8	22	N WHT CEDR	17	51	BASSWOOD	30	99	OTHR HRDWD*
9	19	HEMLOCK	18	30	SUGR MAPLE*	31	999	NONCOMMER

Figure 1. Ontario (ONSP) and Great Lakes (STEMS) species-code equivalents.

```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                      ::
::  TREE LIST FILE IS test1.dat                                         ::
::                                                                      ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

16 Trees will be read for property "CLOQUET ", STAND "COMP 284"
YEAR= 1987, AGE= 56, SITE INDEX FOR RED PINE = 16.8

SEQ NUM	STEMS CODE	ONSP CODE	STEMS GRP NAME	DBH	CROWN RATIO	TREES/HA	TREE STATUS	TREE CLASS
1	2	2	RED PINE	12.7	.0	69.2	1	20
2	2	2	RED PINE	15.2	.0	51.9	1	20
3	2	2	RED PINE	17.8	.0	69.2	1	20
4	2	2	RED PINE	20.3	.0	103.8	1	20
5	2	2	RED PINE	22.9	.0	69.2	1	20
6	2	2	RED PINE	25.4	.0	34.6	1	20
7	2	2	RED PINE	27.9	.0	121.1	1	20
8	2	2	RED PINE	30.5	.0	34.6	1	20
9	2	2	RED PINE	33.0	.0	34.6	1	20
10	1	3	JACK PINE	15.2	.0	17.3	1	20
11	1	3	JACK PINE	25.4	.0	51.8	1	20
12	1	3	JACK PINE	27.9	.0	17.3	1	20
13	26	38	WHT. BIRCH	12.7	.0	17.3	1	20
14	26	38	WHT. BIRCH	15.2	.0	17.3	1	20
15	26	38	WHT. BIRCH	17.8	.0	17.3	1	20
16	26	38	WHT. BIRCH	20.3	.0	17.3	1	20

TREE LIST HAS 16 TREES, TPH= 743.8, BATOT= 29.9, $\overline{\text{DBH}}$= 21.8

Figure 2. Sample tree-list input file.

```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::
::          S T A N D    C O N D I T I O N S    F O R    1987               ::
::                                                                          ::
::                          INITIAL CONDITIONS                              ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

REPORT FOR STAND "COMP 284". YEAR= 1987. INITIAL CONDITIONS
AGE= 56, CYCLE= 0, SITE INDEX FOR RED PINE = 16.8

SPECIES GR.	LIVE TREE/HA	BA/ HA	AVG DBH	AVG CAI	CUT TREE/HA	CUT BA/HA	MORTALITY TREE/HA	MORTALITY BA/HA	GROUP SI
JACK PINE									
.0- 7.5	0	.0	.0	.00	0	.0	0	.0	17.2
7.6-12.5	0	.0	.0	.00	0	.0	0	.0	
12.6-28.0	86	4.0	23.9	.00	0	.0	0	.0	
28.1-43.0	0	.0	.0	.00	0	.0	0	.0	
43.0+	0	.0	.0	.00	0	.0	0	.0	
GROUP TOTALS	86	4.0	23.9	.00	0	.0	0	.0	
RED PINE									
.0- 7.5	0	.0	.0	.00	0	.0	0	.0	16.8
7.6-12.5	0	.0	.0	.00	0	.0	0	.0	
12.6-28.0	519	18.9	20.9	.00	0	.0	0	.0	
28.1-43.0	69	5.5	31.8	.00	0	.0	0	.0	
43.0+	0	.0	.0	.00	0	.0	0	.0	
GROUP TOTALS	588	24.4	22.2	.00	0	.0	0	.0	
WHT. BIRCH									
.0- 7.5	0	.0	.0	.00	0	.0	0	.0	16.6
7.6-12.5	0	.0	.0	.00	0	.0	0	.0	
12.6-28.0	69	1.5	16.5	.00	0	.0	0	.0	
28.1-43.0	0	.0	.0	.00	0	.0	0	.0	
43.0+	0	.0	.0	.00	0	.0	0	.0	
GROUP TOTALS	69	1.5	16.5	.00	0	.0	0	.0	
ALL SPECIES									
.0- 7.5	0	.0	.0	.00	0	.0	0	.0	
7.6-12.5	0	.0	.0	.00	0	.0	0	.0	
12.6-28.0	675	24.4	20.8	.00	0	.0	0	.0	
28.1-43.0	69	5.5	31.8	.00	0	.0	0	.0	
43.0+	0	.0	.0	.00	0	.0	0	.0	
STAND TOTALS	744	29.9	21.8	.00	0	.0	0	.0	

CAI = CURRENT ANNUAL DIAMETER INCREMENT.

S T A N D   V O L U M E

SPECIES GR.	TOTAL CU.M	MERCHANTABLE CU.M	RESIDUE CU.M	RESIDUE TONNES
JACK PINE	32.8	28.7	18.1	13.1
RED PINE	197.9	136.2	103.3	69.3
WHT. BIRCH	11.3	.0	5.8	4.6
STAND TOTALS	242.0	164.9	127.3	87.0

MEAN ANNUAL INCREMENT = 2.9 CU.M/YEAR.

Figure 3. Table of initial stand conditions.

S T A N D   C O N D I T I O N S   F O R   1997

AFTER PROJECTION CYCLE

REPORT FOR STAND "COMP 284". YEAR= 1997. AFTER PROJECTION CYCLE
AGE= 66, CYCLE= 1, SITE INDEX FOR RED PINE = 16.8

SPECIES GR.	LIVE TREE/HA	BA/HA	AVG DBH	AVG CAI	CUT TREE/HA	CUT BA/HA	MORTALITY TREE/HA	MORTALITY BA/HA	GROUP SI
JACK PINE									17.2
.0- 7.5	0	.0	.0	.00	0	.0	0	.0	
7.6-12.5	0	.0	.0	.00	0	.0	0	.0	
12.6-28.0	48	2.4	25.0	.11	0	.0	21	.8	
28.1-43.0	13	.9	29.5	.13	0	.0	4	.2	
43.0+	0	.0	.0	.00	0	.0	0	.0	
GROUP TOTALS	62	3.4	26.0	.12	0	.0	25	1.1	
RED PINE									16.8
.0- 7.5	0	.0	.0	.00	0	.0	0	.0	
7.6-12.5	0	.0	.0	.00	0	.0	0	.0	
12.6-28.0	362	13.0	21.0	.27	0	.0	1	.0	
28.1-43.0	224	18.2	32.0	.31	0	.0	1	.0	
43.0+	0	.0	.0	.00	0	.0	0	.0	
GROUP TOTALS	586	31.2	25.2	.29	0	.0	2	.1	
WHT. BIRCH									16.6
.0- 7.5	0	.0	.0	.00	0	.0	0	.0	
7.6-12.5	0	.0	.0	.00	0	.0	0	.0	
12.6-28.0	65	1.6	17.6	.10	0	.0	5	.1	
28.1-43.0	0	.0	.0	.00	0	.0	0	.0	
43.0+	0	.0	.0	.00	0	.0	0	.0	
GROUP TOTALS	65	1.6	17.6	.10	0	.0	5	.1	
ALL SPECIES									
.0- 7.5	0	.0	.0	.00	0	.0	0	.0	
7.6-12.5	0	.0	.0	.00	0	.0	0	.0	
12.6-28.0	475	17.1	21.0	.23	0	.0	27	1.0	
28.1-43.0	237	19.1	31.9	.30	0	.0	4	.3	
43.0+	0	.0	.0	.00	0	.0	0	.0	
STAND TOTALS	712	36.2	24.6	.26	0	.0	32	1.3	

CAI = CURRENT ANNUAL DIAMETER INCREMENT.
NOTE: MORTALITY VALUES ARE FOR 1987 TO 1997

S T A N D   V O L U M E

SPECIES GR.	TOTAL CU.M	MERCHANTABLE CU.M	RESIDUE CU.M	RESIDUE TONNES
JACK PINE	29.2	26.4	16.1	11.7
RED PINE	273.0	221.9	142.9	95.5
WHT. BIRCH	12.4	.0	6.4	5.1
STAND TOTALS	314.6	248.4	165.4	112.2

MEAN ANNUAL INCREMENT = 3.8 CU.M/YEAR.

Figure 4. Table of stand conditions at the end of the projection cycle.

```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                          ::
::                 M A N A G E M E N T   I N   1997                         ::
::                                                                          ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

******************************************************************************
CURRENT STAND STATISTICS: 1997, CYCLE  1 FOR STAND "COMP 284".
******************************************************************************

                                                         ____  _________  TOTAL VOLUME
        TREES/HA  BATOT  BASAW  BAPOLE  BASAP     DBH  DBH>12.5     CU.M
LIVE:       712    36.2   29.6     6.6     .0     24.6    24.6      314.6
CUT :         0      .0     .0      .0     .0                          .0

***  Management Action:  Row thin.

========== Row thinning.
33.3 percent of the stand will be cut regardless of species.

TREE 17,  RED PINE     , DBH= 14.6   CUT VALUES: TREES/HA=  22.9, BA/HA=   .38
TREE 18,  RED PINE     , DBH= 17.8   CUT VALUES: TREES/HA=  17.2, BA/HA=   .43
TREE 19,  RED PINE     , DBH= 20.9   CUT VALUES: TREES/HA=  23.0, BA/HA=   .79
TREE 20,  RED PINE     , DBH= 23.6   CUT VALUES: TREES/HA=  34.5, BA/HA=  1.50
TREE 21,  RED PINE     , DBH= 26.2   CUT VALUES: TREES/HA=  23.0, BA/HA=  1.24
TREE 22,  RED PINE     , DBH= 28.7   CUT VALUES: TREES/HA=  11.5, BA/HA=   .75
TREE 23,  RED PINE     , DBH= 31.2   CUT VALUES: TREES/HA=  40.2, BA/HA=  3.09
TREE 24,  RED PINE     , DBH= 33.8   CUT VALUES: TREES/HA=  11.5, BA/HA=  1.03
TREE 25,  RED PINE     , DBH= 36.3   CUT VALUES: TREES/HA=  11.5, BA/HA=  1.19
TREE 26,  JACK PINE    , DBH= 15.8   CUT VALUES: TREES/HA=   2.7, BA/HA=   .05
TREE 27,  JACK PINE    , DBH= 26.9   CUT VALUES: TREES/HA=  13.4, BA/HA=   .76
TREE 28,  JACK PINE    , DBH= 29.5   CUT VALUES: TREES/HA=   4.4, BA/HA=   .30
TREE 29,  WHT. BIRCH   , DBH= 13.5   CUT VALUES: TREES/HA=   5.5, BA/HA=   .08
TREE 30,  WHT. BIRCH   , DBH= 16.2   CUT VALUES: TREES/HA=   5.4, BA/HA=   .11
TREE 31,  WHT. BIRCH   , DBH= 19.0   CUT VALUES: TREES/HA=   5.3, BA/HA=   .15
TREE 32,  WHT. BIRCH   , DBH= 21.7   CUT VALUES: TREES/HA=   5.3, BA/HA=   .20

******************************************************************************
CURRENT STAND STATISTICS: 1997, CYCLE  1 FOR STAND "COMP 284".
******************************************************************************

                                                         ____  _________  TOTAL VOLUME
        TREES/HA  BATOT  BASAW  BAPOLE  BASAP     DBH  DBH>12.5     CU.M
LIVE:       475    24.1   19.7     4.4     .0     24.6    24.6      209.8
CUT :       237    12.1    9.9     2.2     .0                       104.9

*****        Management Action:  Value After Management.        *****

*** Income from sale of cut trees in 1997 is $    408.13 per hectare.

             VOLUME                                   VALUE
  -------------------------------      -------------------------------
   TOTAL   MERCHANTABLE   RESIDUE        TOTAL   MERCHANTABLE   RESIDUE
  CU.M/HA    CU.M/HA      CU.M/HA        $/HA        $/HA        $/HA
  --------------------------------------------------------------------

   104.9       82.8         55.1        475.16     408.13         .00

*** Value of residual stand (all live trees) is $    816.26 per hectare.

             VOLUME                                   VALUE
  -------------------------------      -------------------------------
   TOTAL   MERCHANTABLE   RESIDUE        TOTAL   MERCHANTABLE   RESIDUE
  CU.M/HA    CU.M/HA      CU.M/HA        $/HA        $/HA        $/HA
  --------------------------------------------------------------------

   209.8      165.6        110.3        950.33     816.26         .00

Management complete for year 1997
```

Figure 5. An example of a stand management option (row thinning).

STAND CONDITIONS FOR 1997

AFTER MANAGEMENT

REPORT FOR STAND "COMP 284". YEAR= 1997. AFTER MANAGEMENT
AGE= 66, CYCLE= 1, SITE INDEX FOR RED PINE = 16.8

SPECIES GR.	LIVE TREE/HA	BA/HA	AVG DBH	AVG CAI	CUT TREE/HA	CUT BA/HA	MORTALITY TREE/HA	MORTALITY BA/HA	GROUP SI
JACK PINE									17.2
.0- 7.5	0	.0	.0	.00	0	.0	0	.0	
7.6-12.5	0	.0	.0	.00	0	.0	0	.0	
12.6-28.0	32	1.6	25.0	.11	16	.8	21	.8	
28.1-43.0	9	.6	29.5	.13	4	.3	4	.2	
43.0+	0	.0	.0	.00	0	.0	0	.0	
GROUP TOTALS	41	2.2	26.0	.12	21	1.1	25	1.1	
RED PINE									16.8
.0- 7.5	0	.0	.0	.00	0	.0	0	.0	
7.6-12.5	0	.0	.0	.00	0	.0	0	.0	
12.6-28.0	241	8.7	21.0	.27	121	4.3	1	.0	
28.1-43.0	149	12.1	32.0	.31	75	6.1	1	.0	
43.0+	0	.0	.0	.00	0	.0	0	.0	
GROUP TOTALS	391	20.8	25.2	.29	195	10.4	2	.1	
WHT. BIRCH									16.6
.0- 7.5	0	.0	.0	.00	0	.0	0	.0	
7.6-12.5	0	.0	.0	.00	0	.0	0	.0	
12.6-28.0	43	1.1	17.6	.10	22	.5	5	.1	
28.1-43.0	0	.0	.0	.00	0	.0	0	.0	
43.0+	0	.0	.0	.00	0	.0	0	.0	
GROUP TOTALS	43	1.1	17.6	.10	22	.5	5	.1	
ALL SPECIES									
.0- 7.5	0	.0	.0	.00	0	.0	0	.0	
7.6-12.5	0	.0	.0	.00	0	.0	0	.0	
12.6-28.0	317	11.4	21.0	.23	158	5.7	27	1.0	
28.1-43.0	158	12.7	31.9	.30	79	6.4	4	.3	
43.0+	0	.0	.0	.00	0	.0	0	.0	
STAND TOTALS	475	24.1	24.6	.26	237	12.1	32	1.3	

CAI = CURRENT ANNUAL DIAMETER INCREMENT.
NOTE: MORTALITY VALUES ARE FOR 1987 TO 1997
CUT VALUES ARE FOR YEAR 1997 ONLY.

STAND VOLUME

SPECIES GR.	TOTAL CU.M	MERCHANTABLE CU.M	RESIDUE CU.M	RESIDUE TONNES
JACK PINE	19.5	17.6	10.7	7.8
RED PINE	182.0	148.0	95.2	63.7
WHT. BIRCH	8.3	.0	4.3	3.4
STAND TOTALS	209.8	165.6	110.3	74.8

MEAN ANNUAL INCREMENT = 4.1 CU.M/YEAR.

Figure 6. An example of stand conditions after management.

```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                      ::
::          SUMMARY OF MANAGEMENT AND GROWTH PROJECTION                 ::
::                                                                      ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

Stand Description:

Stand Name: COMP 284
Initial Year of Projection: 1987
Initial Age: 56
Site Index Species: RED PINE   Site Index: 16.8

Management Applied:

Remove 33.3 percent of the stand in 1997

YEAR	AGE	MGMT STATUS	TREES/HA LIVE	TREES/HA DIED	BA/ HA	AVE DBH	VOLUME TOTAL CU.M	VOLUME MERCHANTABLE CU.M	VOLUME RESIDUAL CU.M	VOLUME RESIDUAL TONNES
1987	56	BEFORE	744	0	29.9	21.8	242.0	164.9	127.3	87.0
1997	66	BEFORE	712	32	36.2	24.6	314.6	248.4	165.4	112.2
1997	66	CUT	237	0	12.1	.0	104.9	82.8	55.1	37.4
1997	66	AFTER	475	32	24.1	24.6	209.8	165.6	110.3	74.8

Figure 7. An example of summary output for a particular type of management option and the resulting growth projection.