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WestProPlus: A Stochastic Spreadsheet Program for the Management of All-Aged Douglas-Fir–Hemlock Forests in the Pacific Northwest

Jingjing Liang, Joseph Buongiorno, and Robert A. Monserud

Authors

Jingjing Liang is a post-doctoral researcher, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Forestry Sciences Laboratory, 800 E Beckwith Ave., Missoula, MT 59801; **Joseph Buongiorno** is the Class of 1933 Bascom Professor and John N. McGovern WARF Professor, Department of Forest Ecology and Management, University of Wisconsin-Madison, 1630 Linden Drive, Madison, WI 53706; **Robert A. Monserud** is a supervisory research forester, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 620 SW Main St., Suite 400, Portland, OR 97205.

Cover photograph by Tom Iraci.

Abstract

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WestProPlus is an add-in program developed to work with Microsoft Excel to simulate the growth and management of all-aged Douglas-fir–western hemlock (*Pseudotsuga menziesii* (Mirb.) Franco–*Tsuga heterophylla* (Raf.) Sarg.) stands in Oregon and Washington. Its built-in growth model was calibrated from 2,706 permanent plots in the Douglas-fir–western hemlock forest type in Oregon and Washington. Stands are described by the number of trees per acre in each of nineteen 2-in diameter classes in four species groups: Douglas-fir, other shade-intolerant species, western hemlock, and other shade-tolerant species.

WestProPlus allows managers to predict stand development by year and for many decades from a specific initial state. The simulations can be stochastic or deterministic. The stochastic simulations are based on bootstrapping of the observed errors in models of stand growth, timber prices, and interest rate. When used in stochastic simulations, this bootstrap technique simulates random variables by sampling randomly (with replacement) from actual observations of the variable, rather than from an assumed distribution. Users can choose cutting regimes by specifying the interval between harvests (cutting cycle) and a target distribution of trees remaining after harvest. A target distribution can be a reverse-J-shaped distribution or any other desired distribution. Diameter-limit cuts can also be simulated. Tabulated and graphic results show diameter distributions, basal area, volumes by log grade, income, net present value, and indices of stand diversity by species and size.

This manual documents the program installation and activation, provides suggestions for working with Excel, and gives background information on West-ProPlus's models. It offers a comprehensive tutorial in the form of two practical examples that explain how to start the program, enter simulation data, execute a simulation, compare simulations, and plot summary statistics.

Keywords: WestProPlus, simulation, growth model, Douglas-fir, western hemlock, management, economics, ecology, diversity, wood quality, risk, stochastic, deterministic.

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1. Introduction

WestProPlus is a program intended to help forest managers predict the effects of management, or lack thereof, on stand growth, productivity, income, wood quality, diversity of species, and diversity of tree size. The WestProPlus user's manual documents background, instruction, and additional suggestions for using the WestProPlus program. The next section explains how to install WestProPlus on your computer and provides a description of the input data, as well as instructions for loading and saving these data, running simulations, and saving the results. Examples of applications in simulating management regimes are given. If you are new to WestProPlus, it will be useful to run these examples while reading the manual. We included answers to some common questions. Appendixes cover the growth equations, volume equations, and log grade equations of WestProPlus, and the data used to calibrate these equations.

The WestProPlus software and all the sample spreadsheets can be downloaded from http://www.forest.wisc.edu/facstaff/buongiorno/.

What Is WestProPlus?

WestProPlus is a computer program to predict the development of all-aged Douglas-fir–western hemlock (*Pseudotsuga menziesii* (Mirb.) Franco–*Tsuga heterophylla* (Raf.) Sarg.) forests in the Pacific Northwest. With this program, various management regimes can be considered, and their outcomes can be quickly predicted. WestProPlus is a successor of WestPro (Ralston et al. 2003). WestProPlus has the following features compared to WestPro:

- Extensions of the database from 66 uneven-aged plots to 2,706 all-aged plots, covering most of the Douglas-fir–western hemlock type in Oregon and Washington (app. 1).
- Expansion of species groups from two (softwoods, hardwoods) to four (Douglas-fir, other shade-intolerant, western hemlock, other shade-tolerant).
- Calibration of an improved growth model, with particular attention to the effect of stand diversity on growth, mortality, and recruitment (Liang et al. 2005).
- Introduction of log grade equations to predict the effects of management on wood quality.
- Recognition of risk and uncertainty in stand growth, timber prices, and interest rates.

Three other deterministic relatives of WestProPlus (CalPro, NorthPro, and SouthPro) already exist for California mixed-conifer forests (Liang et al. 2004b), northern hardwoods in Wisconsin and Michigan (Liang et al. 2004a), and for loblolly pine (*Pinus taeda* L.) in the Southern United States (Schulte et al. 1998), respectively. We have used our experience with these programs to further simplify the data input and the program output to increase WestProPlus' usefulness for practitioners.

Why Simulate This Type of Stand?

Douglas-fir–western hemlock forests in the Pacific Northwest are very productive. They were harvested heavily during the late 1800s and early 1900s, at an unsustainable rate (Curtis and Carey 1996). Consequently, although they vary highly in composition and structure, Douglas-fir–western hemlock forests are mostly in early seral stages (Barbour and Billings 1988).

Douglas-fir wood is valued for its superior mechanical properties, making it most useful in building and construction (Barbour and Kellogg 1990). Western hemlock is another important commercial species. It is shade tolerant yet fast growing, deer and elk browse it, and hemlock trees are a part of the aesthetics of Western forests (Burns and Honkala 1990).

Even-age silviculture is prevalent in managed Douglas-fir forests. There has been little tendency to adopt uneven-age (selection) management (Emmingham 1998) despite its attractive features (Guldin 1996, Hansen et al. 1991). This seems to be due to a lack of experience with uneven-age management, and scarcity of data regarding its effects compared to even-age systems.

WestProPlus helps predict the development of Douglas-fir–western hemlock stands with various types of silviculture. Some of the examples in this manual suggest that effective uneven-age management of Douglas-fir–western hemlock forests can be profitable while maintaining stands with high diversity of tree species and size.

How Does WestProPlus Work?

WestProPlus predictions are based on a stochastic version of a multispecies, site- and density-dependent matrix growth model (Liang et al. 2005, app. 2) coupled with a log grade model (app. 3) and stochastic stumpage price and interest rate models (app. 4). To run WestProPlus, you specify an initial stand state and define a management policy by target stand state and cutting cycle. The program predicts economic and ecological effects of the policy. You may use a deterministic model of stand growth with fixed timber prices and interest rate, or stochastic models of stand growth, timber prices, and interest rate. The stochastic simulation reflects the random disturbances that were observed in developing each model.

If you do stochastic simulations, as you change policy, WestProPlus repeats the same sequence of random numbers to simulate stochastic stand growth, timber prices, and interest rates. Using the same string of random numbers facilitates comparison of management policies. A new string of random numbers may also be generated by quitting WestProPlus and loading it again (see section 2).

What Is in This Manual?

The next section explains how to install WestProPlus on your computer and provides a description of the input data, as well as instructions for loading and saving these data, running simulations, and saving the results. Examples of applications in simulating uneven-age management regimes are given. We included answers to some common questions. Appendixes cover the equations involved in WestProPlus, and the data used to calibrate these equations. The manual assumes that you are familiar with the basics of Microsoft Excel®.[1] All the spreadsheets shown in this manual are screenshots from the Excel 2002.

2. Getting Started

System Requirements

You need the following hardware and software to operate WestProPlus:

- A personal computer with at least 128 megabytes of random access memory (RAM)
- Microsoft Windows 98, 2000, Me, XP, or Windows NT™ 4
- Microsoft Excel 97 or above
- A free copy of the WestProPlus software downloaded from http://www.forest.wisc.edu/facstaff/buongiorno/, or from the authors through jbuongio@wisc.edu.

Loading WestProPlus

To install the program for the first time:

1. Insert the diskette containing WestProPlus.xla into your computer, or download it from the Web site to your local disk and go to step 3.
2. Select the **WestProPlus.xla** icon and copy it onto your hard disk. For your convenience, you may save it in a new folder named **WestProPlus**, e.g., C:\WestProPlus\WestProPlus.xla.

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

3. Open Microsoft Excel and **START A NEW WORKBOOK**.
4. Under the **Tools** menu, select **Add-ins**. In the add-ins dialogue box, select **Browse** and choose **WestProPlus.xla** from its location on your hard disk. Click **OK**.
5. Return to the **Tools** menu. WestProPlus is now the last item in the menu. Select **WestProPlus** and click **OK** in the title box.
6. The WestProPlus menu should now be in the Excel menu bar.

Until you uninstall it, WestProPlus will be a permanent option in the Tools menu of Excel. You can load the program by selecting **WestProPlus** in the **Tools** menu. This will add WestProPlus to the Excel menu, and the Input Data worksheet (fig. 1) will appear.

There are three sample workbooks at http://www.forest.wisc.edu/facstaff/buongiorno/ with the Input Data worksheets corresponding to the "Examples" section of this paper. By copying the data from these worksheets into your Input Data worksheet you will be able to run these examples with WestProPlus.

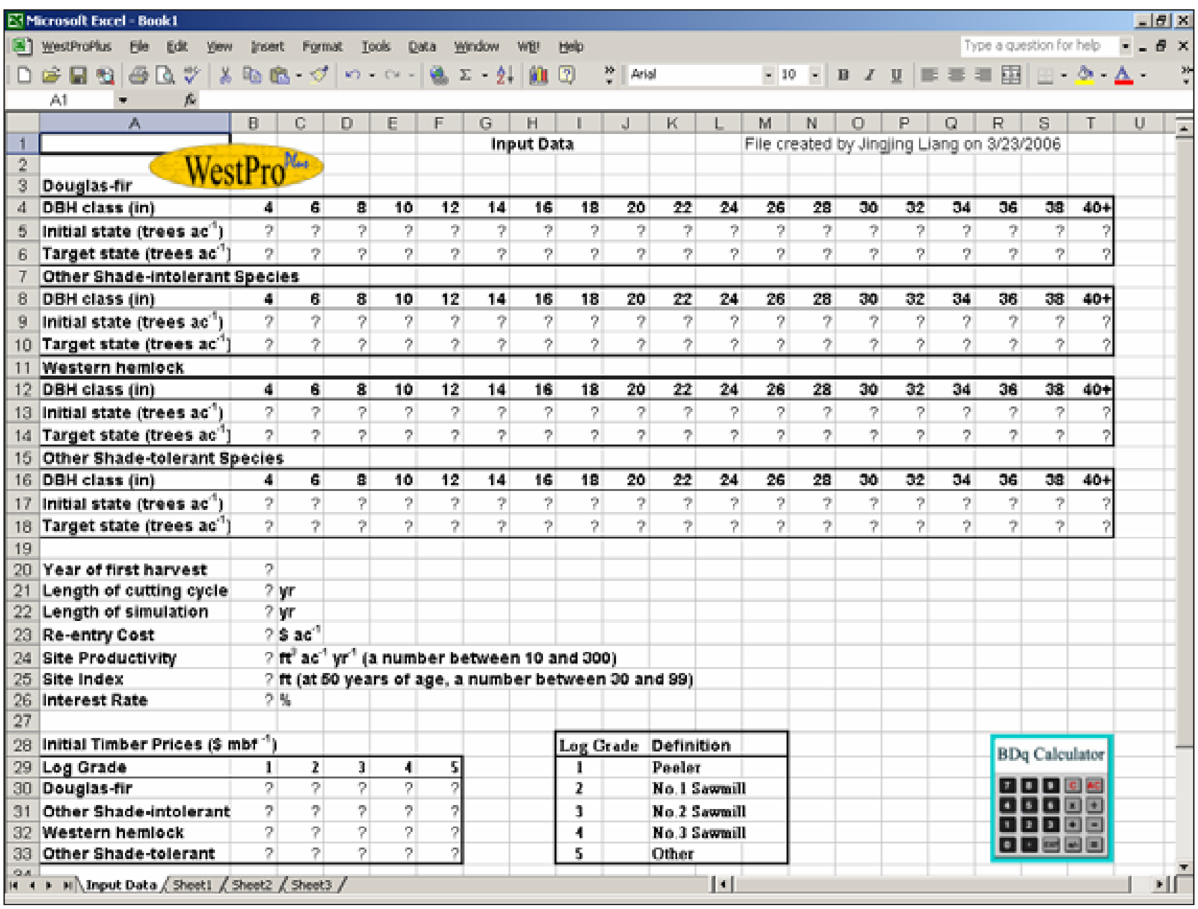


Figure 1—Input Data worksheet.

Unloading WestProPlus

To finish working with WestProPlus, choose the command **Quit** under the **WestProPlus** menu (fig. 2). The WestProPlus menu will disappear, but the current worksheets will stay in the Excel window until you close them.

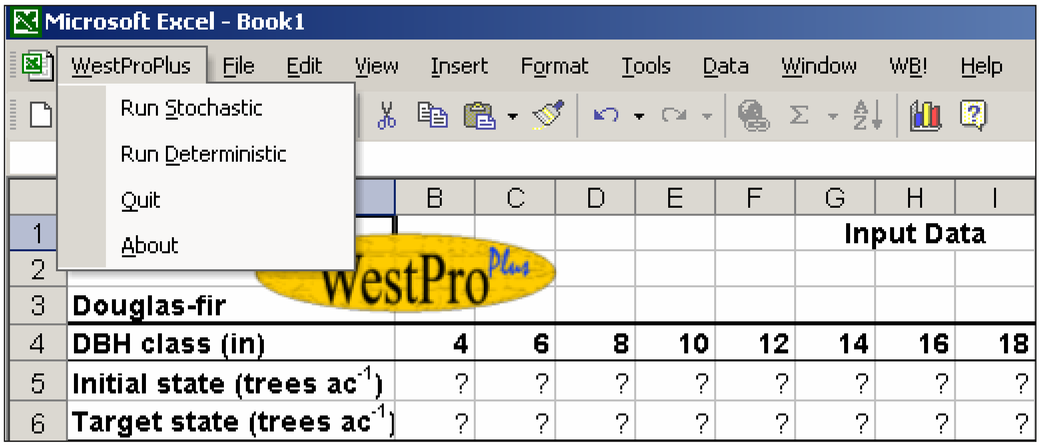


Figure 2—The WestProPlus menu.

To remove the WestProPlus menu and uninstall the program:

1. **Quit** WestProPlus.
2. Under the Tools menu, select **Add-ins**. Deselect **WestProPlus** to remove the title from the add-ins list.
3. Close the Excel window.

3. Using WestProPlus

WestProPlus Input

The Input Data worksheet (fig. 1) contains all the information needed by the program. Cells with question marks require numeric entries, except that initial timber prices are optional. WestProPlus rounds off numeric entries to one or two decimal places. Before running a simulation, WestProPlus checks all your entries and will prompt you to fix any improper input data.

In figure 1, the four rows labeled "**Initial state**" contain the initial number of trees per acre in the stand (at time zero), by species groups and by 2-in diameter classes. WestProPlus recognizes four species groups: Douglas-fir, other shade-intolerant species, western hemlock, and other shade-tolerant species (app. 1, table 3).

The four rows labeled "**Target state**" contain the number of trees per acre that should remain after harvest, by species group and diameter class. A target entry of zero instructs WestProPlus to harvest all trees in that category. When the number of trees in the stand exceeds the target value, the harvest is the difference between the available trees and the target; otherwise the harvest is zero. You can avoid harvesting in a particular species group and size class by entering a very high target, e.g., 10,000. You can enter the initial and target states by hand or with the BDq calculator described below.

WestProPlus measures time in years. All simulations start at time zero and last for the "Length of simulation." The "**Year of first harvest**" may be set at any nonnegative integer value. The "**Length of cutting cycle**," i.e., the interval between harvests, must be at least 1 year. To simulate stand growth without harvest, set the "**Year of first harvest**" to a value greater than the "**Length of simulation**."

The "**Re-entry Cost**" represents cost of doing a harvest, in dollars per acre, beyond the harvesting cost already reflected in the stumpage price. The cost of timber sale preparation and administration would be part of a typical re-entry cost.

The "**Site Productivity**" measured by mean annual increment, describes the wood-growing capacity of a site. It is defined as the increment in volume of a timber stand averaged over the period between age zero and the age at which mean annual increment reaches its maximum value (Hanson et al. 2002). **If you do not enter any value for Site Productivity, WestProPlus assumes that the site productivity is 150 $ft^3 \cdot ac^{-1} \cdot yr^{-1}$**, the average site productivity in the 2,706 permanent plots in Washington and Oregon used to calibrate the growth equations of WestProPlus. The site productivity should be between 10 to 300 $ft^3 \cdot ac^{-1} \cdot yr^{-1}$, the range of the data.

The "**Site Index**" was measured by the average total height of the dominant and codominant trees at 50 years of age (Hanson et al. 2002). WestProPlus uses site index to predict log grade. The site index should be between 30 and 99 ft, the range of the data.

The "**Interest Rate**" represents the initial interest rate. Starting from this initial value, WestProPlus generates a sequence of yearly stochastic interest rates. These interest rates are used to calculate the net present value (NPV) of each harvest, and the cumulative NPV.

The "**Initial Timber Prices**" are the initial stumpage prices in dollars per thousand board feet (mbf) by log grade and species group. These entries are optional. If you leave these cells blank, WestProPlus will generate random initial prices. Starting from these initial values, WestProPlus generates a sequence of stochastic prices (app. 4).

BDq Calculator

A BDq distribution is a tree distribution, by diameter class, defined by a stand basal area (B), a maximum and minimum tree diameter (D), and a q-ratio (q), the ratio of the number of trees in a given diameter class to the number of trees in the next larger class. You can use the BDq calculator (Schulte et al. 1998) to define the target state or the initial state with a BDq distribution.

To use the BDq calculator, click on the **BDq Calculator** icon in the Input Data worksheet. Use the arrow buttons to set the stand basal area ($ft^2 \cdot ac^{-1}$), the q-ratio, the minimum and the maximum diameters (in); click the **Calculate** button (fig. 3).

The example in figure 3 shows the number of trees by diameter class that would give a basal area of 120 $ft^2 \cdot ac^{-1}$ with trees of diameters from 3 to 33 in and a q-ratio of 1.3 for the Douglas-fir trees in the initial stand state. You can copy the resulting stand distribution to the Input Data worksheet as the initial distribution or as the target distribution for a species group by selecting the destination and clicking the **Copy** button on the BDq calculator (fig. 3).

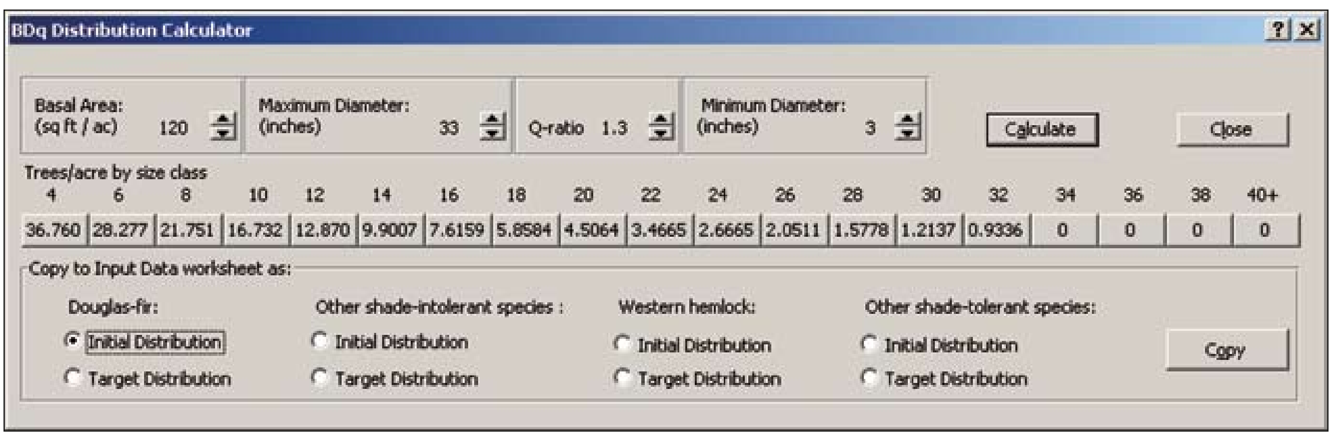


Figure 3—The BDq Distribution Calculator window.

Storing Data and Retrieving Stored Data

After entering data in the Input Data worksheet, you can save this worksheet for later use. You should save your work frequently to avoid losing data. It is advisable to save the work in a particular folder to facilitate locating the file in the future.

To run several simulations (e.g., to examine the effects of changing some of the parameters), you may find it efficient to work with previously saved input data. To retrieve the data, choose the **File → Open** command in Excel to open your saved file or double click on the file icon.

Running Simulations

After completing the Input Data worksheet or retrieving a previously saved one, you are ready to run a simulation. To run WestProPlus, make sure that the West-ProPlus menu is in the Excel menu bar. If not, click **WestProPlus** under the **Tools** menu to activate WestProPlus. You can then choose to run stochastic simulation or deterministic simulation by clicking **Run Stochastic** or **Run Deterministic** in the WestProPlus menu, respectively (fig. 2).

Each WestProPlus simulation generates the following worksheets and charts:

- **TreesPerAcre** worksheet: The number of trees by species and diameter class for each simulated year.
- **Basal Area** worksheet: The basal area by species and timber size, for each simulated year.
- **Volume** worksheet: The volume in stock by log grade, for each simulated year.
- **Products** worksheet: The physical output and the financial return from the harvests throughout the simulation.
- **Diversity** worksheet: Shannon's species diversity indices and size diversity indices for each year of the simulation.
- **Diversity** chart: A plot of Shannon's indices of species and size diversity over time.
- **Species BA** chart: A stacked area chart showing the development of stand basal area by species group over time.
- **Size BA** chart: A stacked area chart showing the development of stand basal area by timber size over time.
- **Volume** chart: A stacked area chart showing the development of volume in stock by log grade over time.

To compare various management regimes, **save** the output worksheets immediately after running a simulation. Otherwise WestProPlus will overwrite the previous results every time you run a new simulation.

All the data in the output worksheets are protected and you cannot change them. To see how results change with different input data, change the Input Data worksheet and rerun the simulation.

4. Example: Simulating BDq Management Regimes

In this example, we performed stochastic simulations of selection regimes based on the BDq principle. For a given initial state, we changed the q-ratio of the target stand state and interpreted the results in terms of effects on economic returns, productivity, tree diversity, wood quality, and stand structure. We concentrate on the q-ratio because it is the main effect in most uneven-age management criteria (Liang et al., in press).

Simulation Parameters

The simulations were for 200 years, with cutting cycles of 10 years. The initial stand state was the average distribution of the 2,706 permanent plots used in calibrating the growth equations of WestProPlus (fig. 4). Composition by number of trees was 34 percent Douglas-fir, 30 percent other shade-intolerant species, 20 percent western hemlock, and 16 percent other shade-tolerant species. The average site productivity was 150 $ft^3 \cdot ac^{-1} \cdot yr^{-1}$ and the average 50-year site index was 90 ft. The first harvest occurred at year 1. The fixed cost of re-entry was set at $254 $\cdot ac^{-1}$, the estimated cost of preparing and administering timber sales in the state of Washington (Ralston et al. 2003). The initial interest rate was set at 3.8 percent per year, the yield of AAA bonds net of inflation, from 1970 to 2004 (US GPO 2005). The stumpage prices were approximated as the average delivered log prices (pond value) over four quarters in 2005 (Oregon Department of Forestry (2005) minus an estimated average cost of $1.13 ft^{-3} for getting logs from the woods to the mill pond.

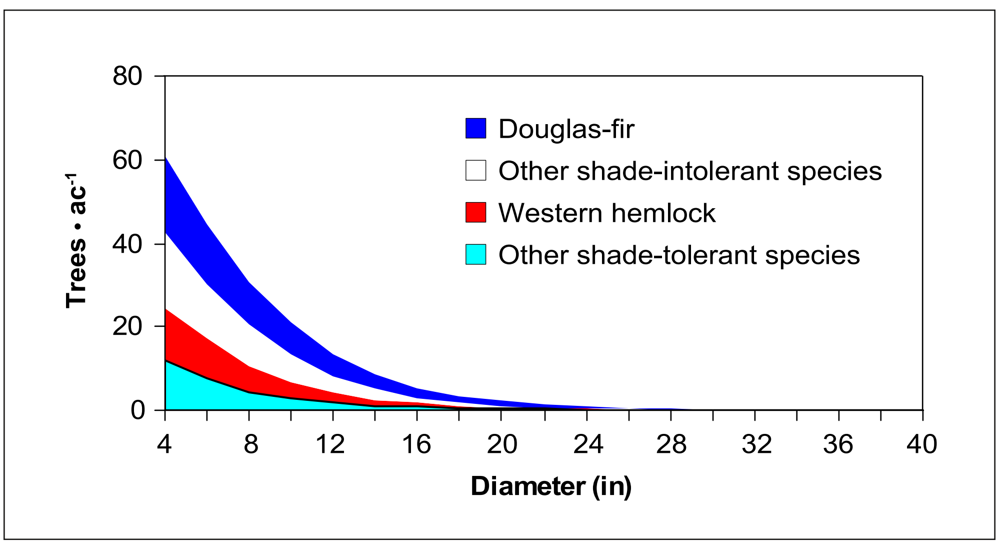


Figure 4—Initial stand state.

The three alternative target distributions are shown in figure 5. They all assumed a maximum diameter of 40 in for all species. The basal area was kept the same in the three alternatives, 87 $ft^2 \cdot ac^{-1}$ in total (Miller and Emmingham 2001), consisting of 30 $ft^2 \cdot ac^{-1}$ of Douglas-fir, 26 $ft^2 \cdot ac^{-1}$ of other shade-intolerant species, 17 $ft^2 \bullet ac^{-1}$ of western hemlock, and 14 $ft^2 \bullet ac^{-1}$ of other shade-tolerant species. The q-ratio was set at 1.2, 1.4, or 1.8. Higher q values kept more trees in the smaller diameter classes relative to the large (fig. 5).

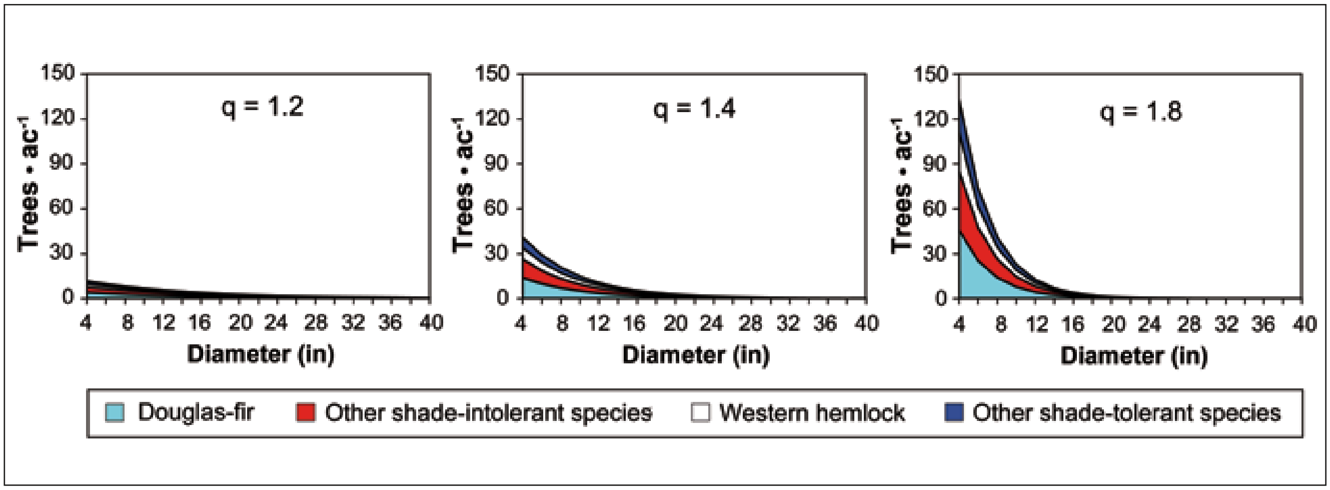


Figure 5—Target distribution of trees by species groups and diameter class for the BDq regime used here.

Figure 6 shows the BDq calculator set to produce the target state for Douglas-fir trees with basal area of 30 $ft^2 \bullet ac^{-1}$, maximum diameter of 40 in, and q-ratio of 1.2. Clicking on the **Calculate** button produces the number of trees by size class.

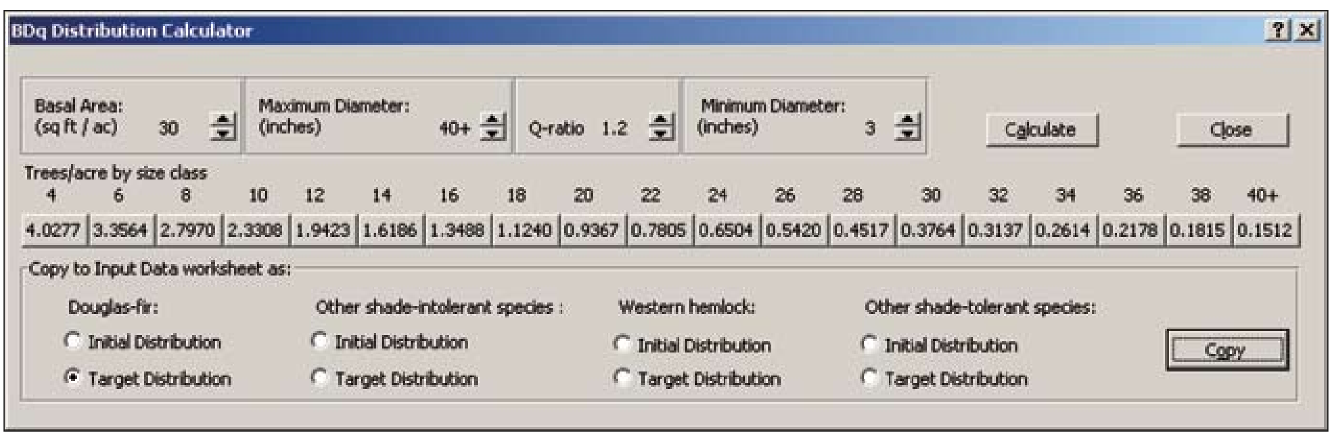
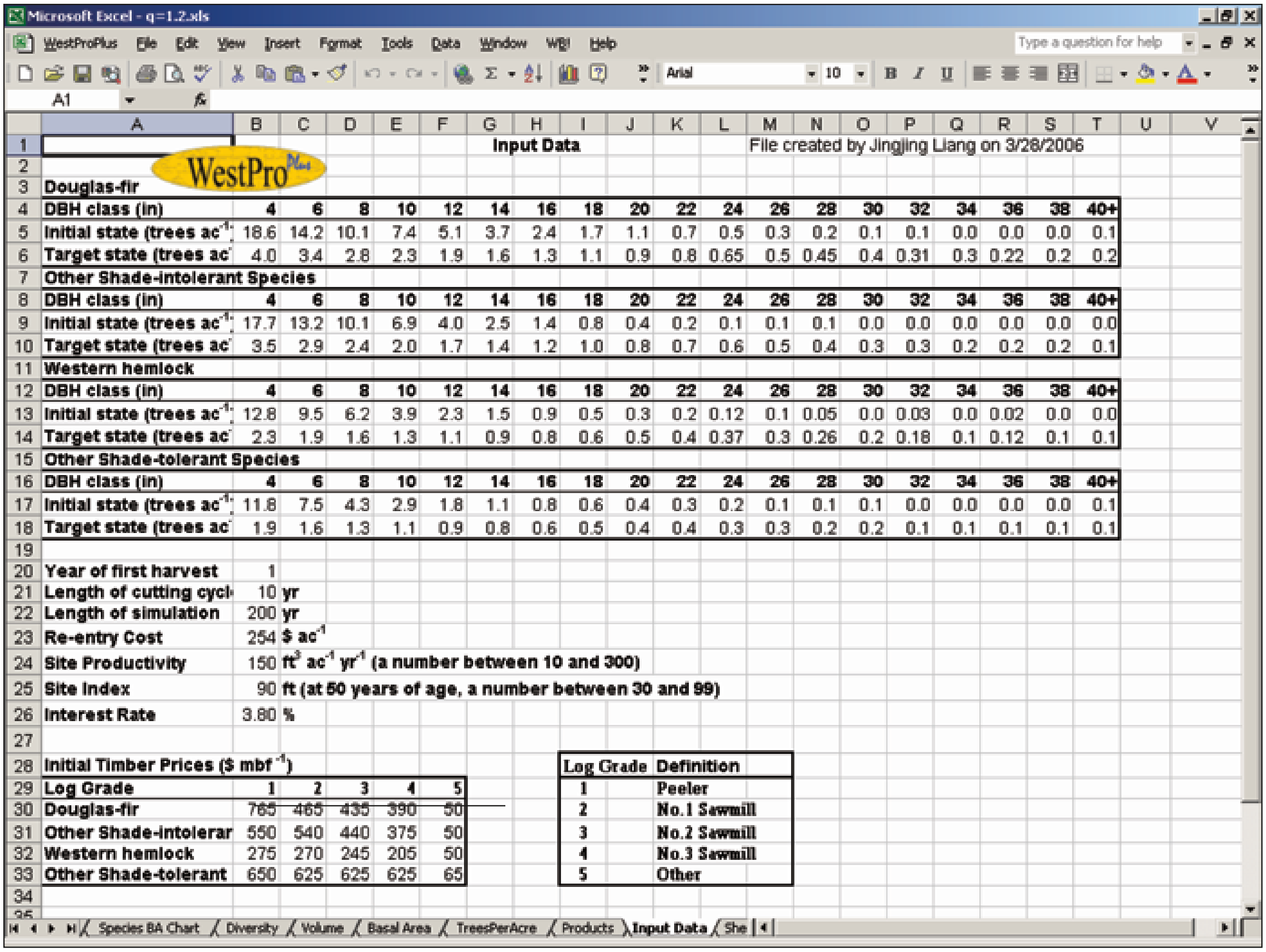


Figure 6—BDq Distribution Calculation dialog box.

To copy the distribution of Douglas-fir to the Input Data worksheet, select the option box corresponding to **Douglas-fir Target Distribution** and click on the **Copy** button. Figure 7 shows the Input Data worksheet for the above BDq selection regime with q = 1.2.



Microsoft Excel - q=1.2.xls

Input Data — File created by Jingjing Liang on 3/28/2006

Douglas-fir

DBH class (in)	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40+
Initial state (trees ac⁻¹)	18.6	14.2	10.1	7.4	5.1	3.7	2.4	1.7	1.1	0.7	0.5	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.1
Target state (trees ac	4.0	3.4	2.8	2.3	1.9	1.6	1.3	1.1	0.9	0.8	0.65	0.5	0.45	0.4	0.31	0.3	0.22	0.2	0.2

Other Shade-intolerant Species

DBH class (in)	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40+
Initial state (trees ac⁻¹)	17.7	13.2	10.1	6.9	4.0	2.5	1.4	0.8	0.4	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Target state (trees ac	3.5	2.9	2.4	2.0	1.7	1.4	1.2	1.0	0.8	0.7	0.6	0.5	0.4	0.3	0.3	0.2	0.2	0.2	0.1

Western hemlock

DBH class (in)	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40+
Initial state (trees ac⁻¹)	12.8	9.5	6.2	3.9	2.3	1.5	0.9	0.5	0.3	0.2	0.12	0.1	0.05	0.0	0.03	0.0	0.02	0.0	0.0
Target state (trees ac	2.3	1.9	1.6	1.3	1.1	0.9	0.8	0.6	0.5	0.4	0.37	0.3	0.26	0.2	0.18	0.1	0.12	0.1	0.1

Other Shade-tolerant Species

DBH class (in)	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40+
Initial state (trees ac⁻¹)	11.8	7.5	4.3	2.9	1.8	1.1	0.8	0.6	0.4	0.3	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1
Target state (trees ac	1.9	1.6	1.3	1.1	0.9	0.8	0.6	0.5	0.4	0.4	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1

Year of first harvest	1	
Length of cutting cycl	10	yr
Length of simulation	200	yr
Re-entry Cost	254	\$ ac⁻¹
Site Productivity	150	ft³ ac⁻¹ yr⁻¹ (a number between 10 and 300)
Site Index	90	ft (at 50 years of age, a number between 30 and 99)
Interest Rate	3.80	%

Initial Timber Prices (\$ mbf⁻¹)

Log Grade	1	2	3	4	5
Douglas-fir	765	465	435	390	50
Other Shade-intolerar	550	540	440	375	50
Western hemlock	275	270	245	205	50
Other Shade-tolerant	650	625	625	625	65

Log Grade	Definition
1	Peeler
2	No.1 Sawmill
3	No.2 Sawmill
4	No.3 Sawmill
5	Other

Figure 7—Input Data worksheet for the BDq selection regime with 87 ft^2 • ac^{-1} residual basal area, 40 in maximum diameter, q = 1.2, and 10 years cutting cycle.

Running Simulations

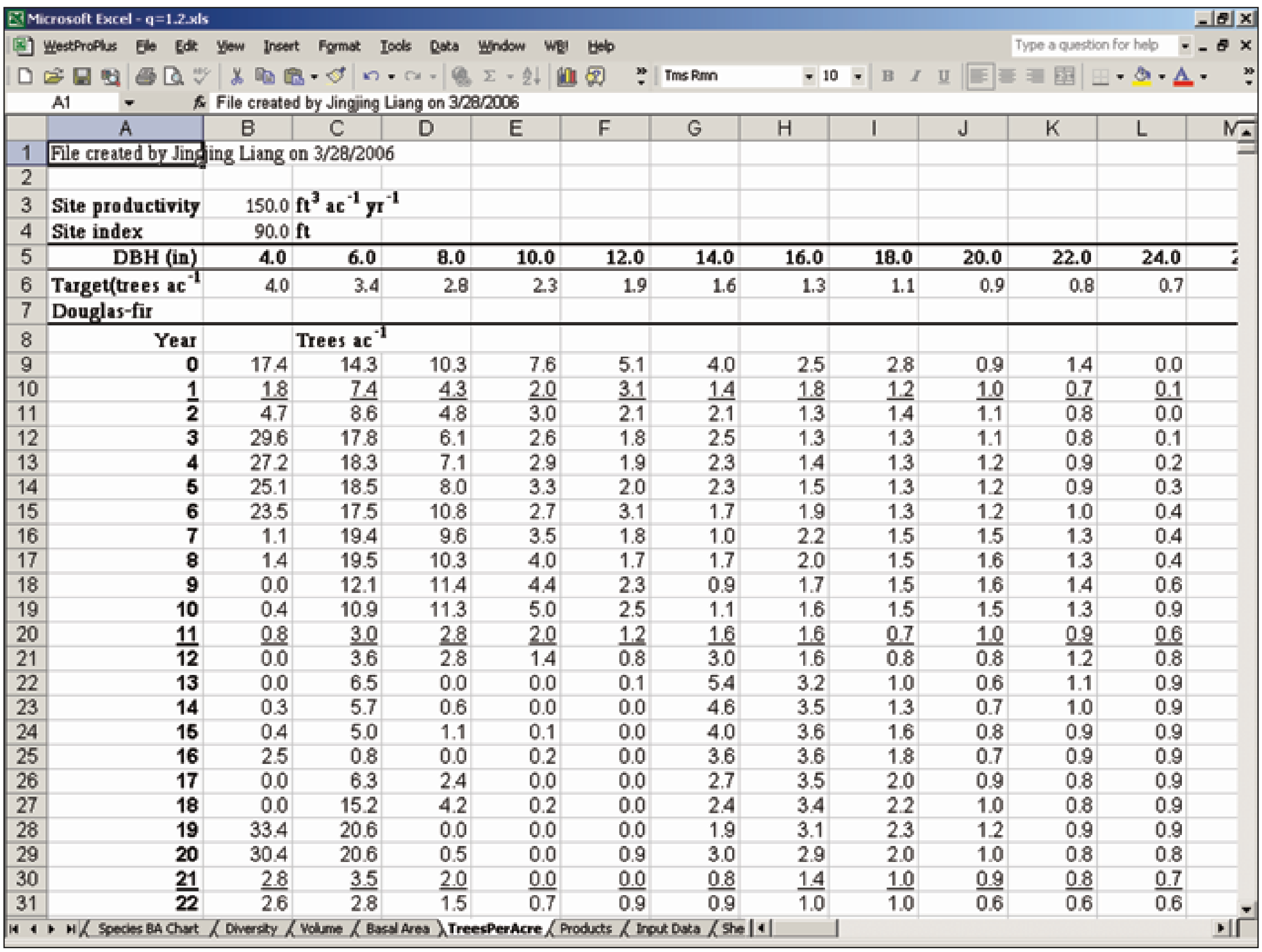
Upon running a simulation, WestProPlus will replace any old tables and charts with new ones. For this reason, you should save the workbook after each simulation. To run a series of simulations, load the input data for the first management regime, run the simulation, save your outcome, and proceed to load and run the second management regime. You can then compare the data on economic return, various ecological criteria, and wood quality for different regimes. To that end, comparative charts and tables can be built with Excel from the WestProPlus output worksheets.

Simulation Output

The simulation outcomes of the preceding BDq selection are displayed in tables and charts. They are located in the same workbook as the Input Data worksheet. The following results are for the stochastic simulation with the initial condition and BDq management specified by the input data in figure 7.

TreesPerAcre worksheet—

This worksheet (fig. 8) shows the number of trees per acre, by species and diameter class, for each year of simulation. Scrolling to the right reveals the tree distribution for other species. The underlined numbers are the year of harvest, and the number of trees per acre after the harvest.



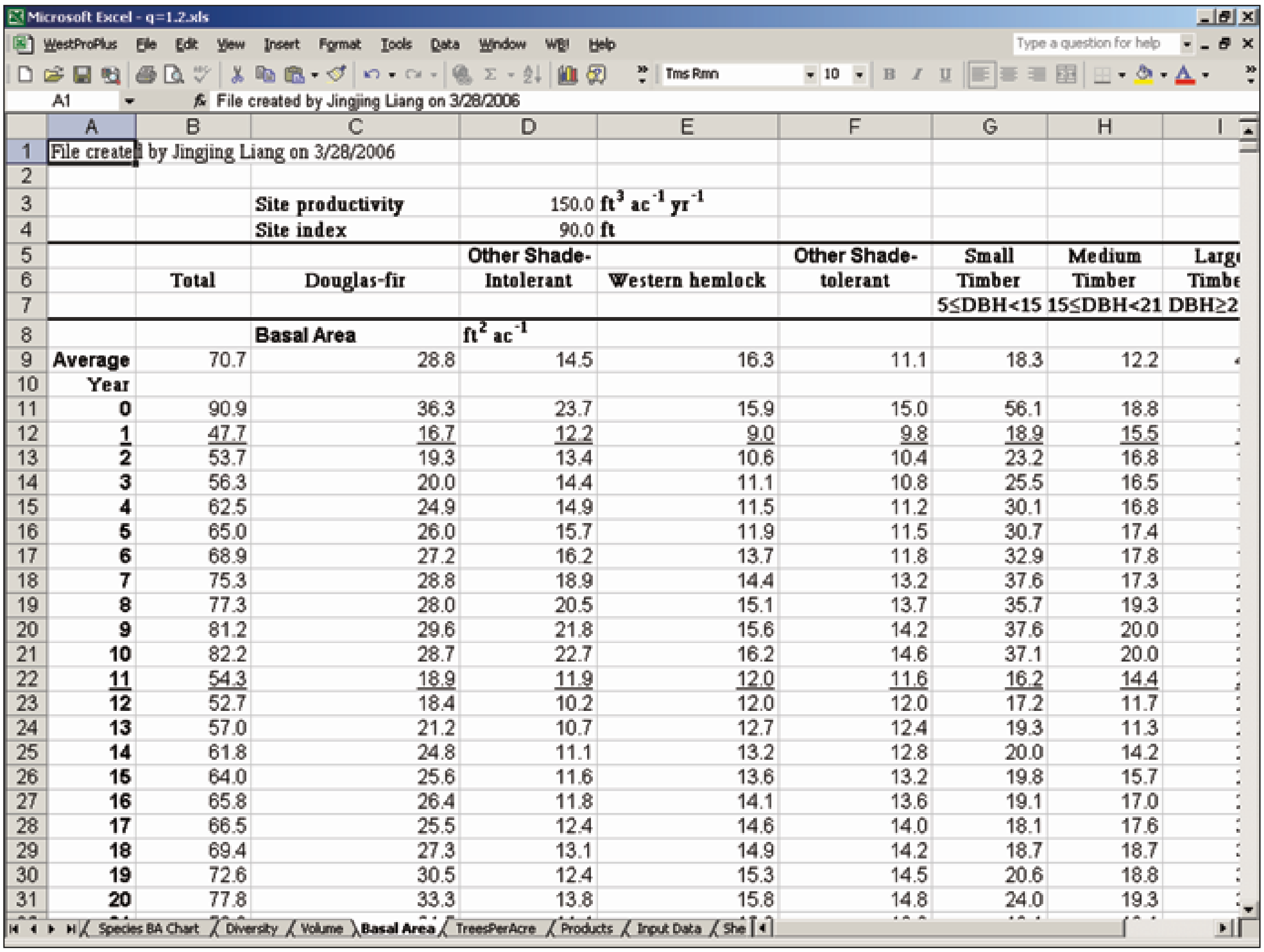
File created by Jingjing Liang on 3/28/2006

	A	B	C	D	E	F	G	H	I	J	K	L
1	File created by Jingjing Liang on 3/28/2006											
2												
3	Site productivity	150.0	$ft^3\ ac^{-1}\ yr^{-1}$									
4	Site index	90.0	ft									
5	DBH (in)	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0
6	Target(trees ac^{-1}	4.0	3.4	2.8	2.3	1.9	1.6	1.3	1.1	0.9	0.8	0.7
7	Douglas-fir											
8	Year		Trees ac^{-1}									
9	0	17.4	14.3	10.3	7.6	5.1	4.0	2.5	2.8	0.9	1.4	0.0
10	1	1.8	7.4	4.3	2.0	3.1	1.4	1.8	1.2	1.0	0.7	0.1
11	2	4.7	8.6	4.8	3.0	2.1	2.1	1.3	1.4	1.1	0.8	0.0
12	3	29.6	17.8	6.1	2.6	1.8	2.5	1.3	1.3	1.1	0.8	0.1
13	4	27.2	18.3	7.1	2.9	1.9	2.3	1.4	1.3	1.2	0.9	0.2
14	5	25.1	18.5	8.0	3.3	2.0	2.3	1.5	1.3	1.2	0.9	0.3
15	6	23.5	17.5	10.8	2.7	3.1	1.7	1.9	1.3	1.2	1.0	0.4
16	7	1.1	19.4	9.6	3.5	1.8	1.0	2.2	1.5	1.5	1.3	0.4
17	8	1.4	19.5	10.3	4.0	1.7	1.7	2.0	1.5	1.6	1.3	0.4
18	9	0.0	12.1	11.4	4.4	2.3	0.9	1.7	1.5	1.6	1.4	0.6
19	10	0.4	10.9	11.3	5.0	2.5	1.1	1.6	1.5	1.5	1.3	0.9
20	11	0.8	3.0	2.8	2.0	1.2	1.6	1.6	0.7	1.0	0.9	0.6
21	12	0.0	3.6	2.8	1.4	0.8	3.0	1.6	0.8	0.8	1.2	0.8
22	13	0.0	6.5	0.0	0.0	0.1	5.4	3.2	1.0	0.6	1.1	0.9
23	14	0.3	5.7	0.6	0.0	0.0	4.6	3.5	1.3	0.7	1.0	0.9
24	15	0.4	5.0	1.1	0.1	0.0	4.0	3.6	1.6	0.8	0.9	0.9
25	16	2.5	0.8	0.0	0.2	0.0	3.6	3.6	1.8	0.7	0.9	0.9
26	17	0.0	6.3	2.4	0.0	0.0	2.7	3.5	2.0	0.9	0.8	0.9
27	18	0.0	15.2	4.2	0.2	0.0	2.4	3.4	2.2	1.0	0.8	0.9
28	19	33.4	20.6	0.0	0.0	0.0	1.9	3.1	2.3	1.2	0.9	0.9
29	20	30.4	20.6	0.5	0.0	0.9	3.0	2.9	2.0	1.0	0.8	0.8
30	21	2.8	3.5	2.0	0.0	0.0	0.8	1.4	1.0	0.9	0.8	0.7
31	22	2.6	2.8	1.5	0.7	0.9	0.9	1.0	1.0	0.6	0.6	0.6

Figure 8—TreePerAcre worksheet for the BDq selection regime with 87 $ft^2 \cdot ac^{-1}$ residual basal area, 40 in maximum diameter, q = 1.2, and 10 years cutting cycle.

Basal Area worksheet—

This worksheet (fig. 9) shows, for each simulated year, the total stand basal area, the stand basal area by species group, and the stand basal area for three timber size categories: small timber (trees from 5 to 15 in diameter at breast height (d.b.h.), medium timber for trees from 15 to 21 in d.b.h., and large timber for trees 21 in d.b.h. and larger. Underlined numbers show the year of harvest and the basal areas just after harvest, and the first row represents the average basal area over the whole simulation period.



File created by Jingjing Liang on 3/28/2006

Site productivity 150.0 $ft^3\ ac^{-1}\ yr^{-1}$

Site index 90.0 ft

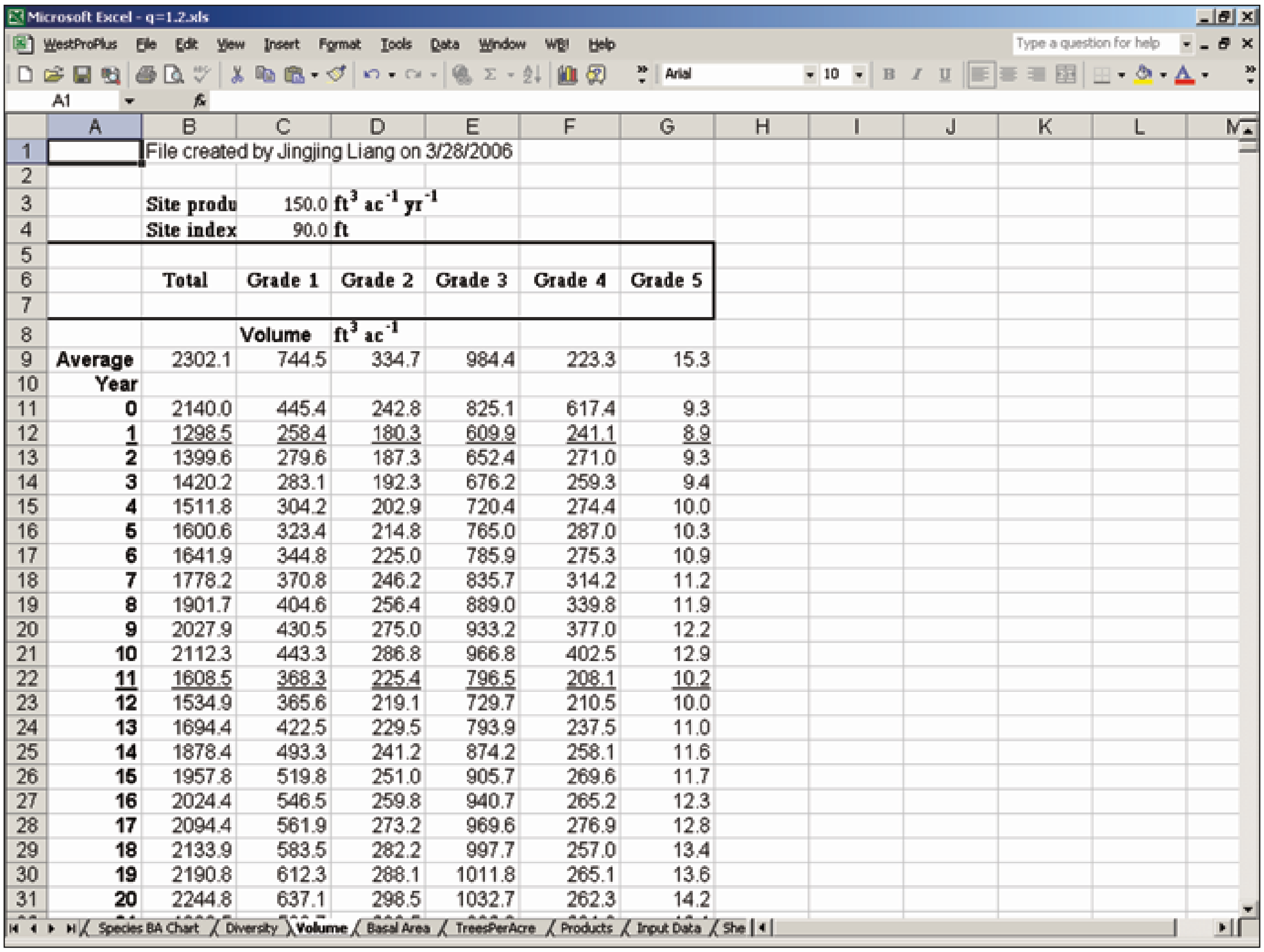
Basal Area $ft^2\ ac^{-1}$

Year	Total	Douglas-fir	Other Shade-Intolerant	Western hemlock	Other Shade-tolerant	Small Timber 5≤DBH<15	Medium Timber 15≤DBH<21	Large Timber DBH≥2[illegible]
Average	70.7	28.8	14.5	16.3	11.1	18.3	12.2	[illegible]
0	90.9	36.3	23.7	15.9	15.0	56.1	18.8	[illegible]
1	47.7	16.7	12.2	9.0	9.8	18.9	15.5	[illegible]
2	53.7	19.3	13.4	10.6	10.4	23.2	16.8	[illegible]
3	56.3	20.0	14.4	11.1	10.8	25.5	16.5	[illegible]
4	62.5	24.9	14.9	11.5	11.2	30.1	16.8	[illegible]
5	65.0	26.0	15.7	11.9	11.5	30.7	17.4	[illegible]
6	68.9	27.2	16.2	13.7	11.8	32.9	17.8	[illegible]
7	75.3	28.8	18.9	14.4	13.2	37.6	17.3	[illegible]
8	77.3	28.0	20.5	15.1	13.7	35.7	19.3	[illegible]
9	81.2	29.6	21.8	15.6	14.2	37.6	20.0	[illegible]
10	82.2	28.7	22.7	16.2	14.6	37.1	20.0	[illegible]
11	54.3	18.9	11.9	12.0	11.6	16.2	14.4	[illegible]
12	52.7	18.4	10.2	12.0	12.0	17.2	11.7	[illegible]
13	57.0	21.2	10.7	12.7	12.4	19.3	11.3	[illegible]
14	61.8	24.8	11.1	13.2	12.8	20.0	14.2	[illegible]
15	64.0	25.6	11.6	13.6	13.2	19.8	15.7	[illegible]
16	65.8	26.4	11.8	14.1	13.6	19.1	17.0	[illegible]
17	66.5	25.5	12.4	14.6	14.0	18.1	17.6	[illegible]
18	69.4	27.3	13.1	14.9	14.2	18.7	18.7	[illegible]
19	72.6	30.5	12.4	15.3	14.5	20.6	18.8	[illegible]
20	77.8	33.3	13.8	15.8	14.8	24.0	19.3	[illegible]

Figure 9—Basal Area worksheet for the BDq selection regime with 87 $ft^2 \bullet ac^{-1}$ residual basal area, 40 in maximum diameter, q = 1.2, and 10 years cutting cycle.

Volume worksheet—

This worksheet (fig. 10) shows the volume in stock by log grade. The log grade equations used by WestProPlus are described in appendix 3. The underlined numbers represent the year of harvest and the volume per acre just after the harvest, and the first row represents the average volume over the whole simulation period.

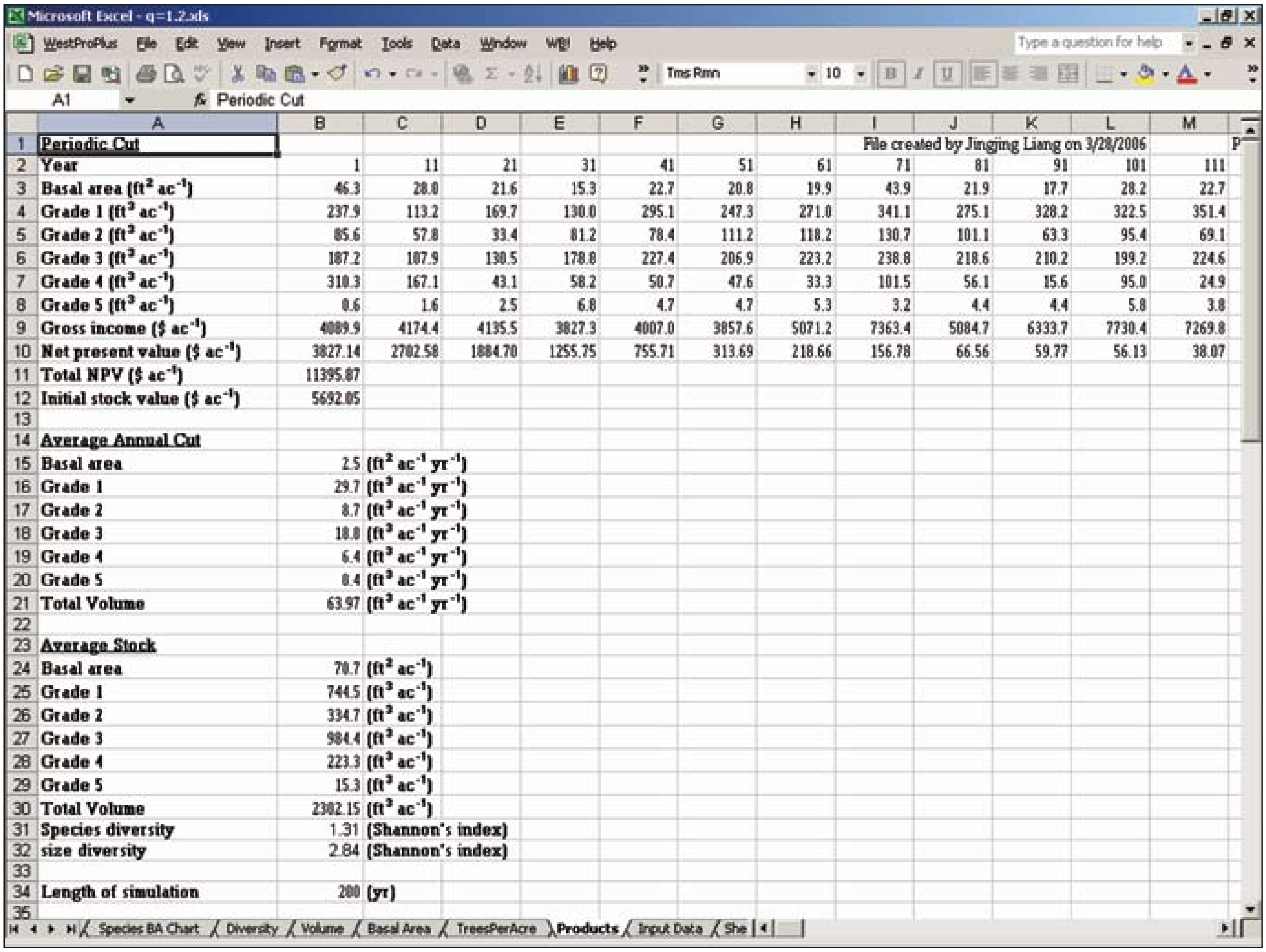


	A	B	C	D	E	F	G
1		File created by Jingjing Liang on 3/28/2006					
2							
3		Site produ	150.0	$ft^3\ ac^{-1}\ yr^{-1}$			
4		Site index	90.0	ft			
5							
6		Total	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
7							
8			Volume	$ft^3\ ac^{-1}$			
9	Average	2302.1	744.5	334.7	984.4	223.3	15.3
10	Year						
11	0	2140.0	445.4	242.8	825.1	617.4	9.3
12	1	1298.5	258.4	180.3	609.9	241.1	8.9
13	2	1399.6	279.6	187.3	652.4	271.0	9.3
14	3	1420.2	283.1	192.3	676.2	259.3	9.4
15	4	1511.8	304.2	202.9	720.4	274.4	10.0
16	5	1600.6	323.4	214.8	765.0	287.0	10.3
17	6	1641.9	344.8	225.0	785.9	275.3	10.9
18	7	1778.2	370.8	246.2	835.7	314.2	11.2
19	8	1901.7	404.6	256.4	889.0	339.8	11.9
20	9	2027.9	430.5	275.0	933.2	377.0	12.2
21	10	2112.3	443.3	286.8	966.8	402.5	12.9
22	11	1608.5	368.3	225.4	796.5	208.1	10.2
23	12	1534.9	365.6	219.1	729.7	210.5	10.0
24	13	1694.4	422.5	229.5	793.9	237.5	11.0
25	14	1878.4	493.3	241.2	874.2	258.1	11.6
26	15	1957.8	519.8	251.0	905.7	269.6	11.7
27	16	2024.4	546.5	259.8	940.7	265.2	12.3
28	17	2094.4	561.9	273.2	969.6	276.9	12.8
29	18	2133.9	583.5	282.2	997.7	257.0	13.4
30	19	2190.8	612.3	288.1	1011.8	265.1	13.6
31	20	2244.8	637.1	298.5	1032.7	262.3	14.2

Figure 10—Volume worksheet for the BDq selection regime with 87 $ft^2 \bullet ac^{-1}$ residual basal area, 40 in maximum diameter, q = 1.2, and 10 years cutting cycle.

Products worksheet—

The upper part of the products worksheet (fig. 11) shows data for each harvest: basal area cut, volume harvested by log grade, gross income, predicted NPV of the current harvest, the total (cumulative) NPV, and the initial stock value. The log grade equations, and the stochastic stumpage price model and interest rate model used by WestProPlus are described in appendixes 3 and 4.



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Periodic Cut								File created by Jingjing Liang on 3/28/2006				
2	Year	1	11	21	31	41	51	61	71	81	91	101	111
3	Basal area (ft² ac⁻¹)	46.3	28.0	21.6	15.3	22.7	20.8	19.9	43.9	21.9	17.7	28.2	22.7
4	Grade 1 (ft³ ac⁻¹)	237.9	113.2	169.7	130.0	295.1	247.3	271.0	341.1	275.1	328.2	322.5	351.4
5	Grade 2 (ft³ ac⁻¹)	85.6	57.8	33.4	81.2	78.4	111.2	118.2	130.7	101.1	63.3	95.4	69.1
6	Grade 3 (ft³ ac⁻¹)	187.2	107.9	130.5	178.8	227.4	206.9	223.2	238.8	218.6	210.2	199.2	224.6
7	Grade 4 (ft³ ac⁻¹)	310.3	167.1	43.1	58.2	50.7	47.6	33.3	101.5	56.1	15.6	95.0	24.9
8	Grade 5 (ft³ ac⁻¹)	0.6	1.6	2.5	6.8	4.7	4.7	5.3	3.2	4.4	4.4	5.8	3.8
9	Gross income ($ ac⁻¹)	4089.9	4174.4	4135.5	3827.3	4007.0	3857.6	5071.2	7363.4	5084.7	6333.7	7730.4	7269.8
10	Net present value ($ ac⁻¹)	3827.14	2702.58	1884.70	1255.75	755.71	313.69	218.66	156.78	66.56	59.77	56.13	38.07
11	Total NPV ($ ac⁻¹)	11395.87											
12	Initial stock value ($ ac⁻¹)	5692.05											
13													
14	Average Annual Cut												
15	Basal area	2.5	(ft² ac⁻¹ yr⁻¹)										
16	Grade 1	29.7	(ft³ ac⁻¹ yr⁻¹)										
17	Grade 2	8.7	(ft³ ac⁻¹ yr⁻¹)										
18	Grade 3	18.8	(ft³ ac⁻¹ yr⁻¹)										
19	Grade 4	6.4	(ft³ ac⁻¹ yr⁻¹)										
20	Grade 5	0.4	(ft³ ac⁻¹ yr⁻¹)										
21	Total Volume	63.97	(ft³ ac⁻¹ yr⁻¹)										
22													
23	Average Stock												
24	Basal area	70.7	(ft² ac⁻¹)										
25	Grade 1	744.5	(ft³ ac⁻¹)										
26	Grade 2	334.7	(ft³ ac⁻¹)										
27	Grade 3	984.4	(ft³ ac⁻¹)										
28	Grade 4	223.3	(ft³ ac⁻¹)										
29	Grade 5	15.3	(ft³ ac⁻¹)										
30	Total Volume	2302.15	(ft³ ac⁻¹)										
31	Species diversity	1.31	(Shannon's index)										
32	size diversity	2.84	(Shannon's index)										
33													
34	Length of simulation	200	(yr)										

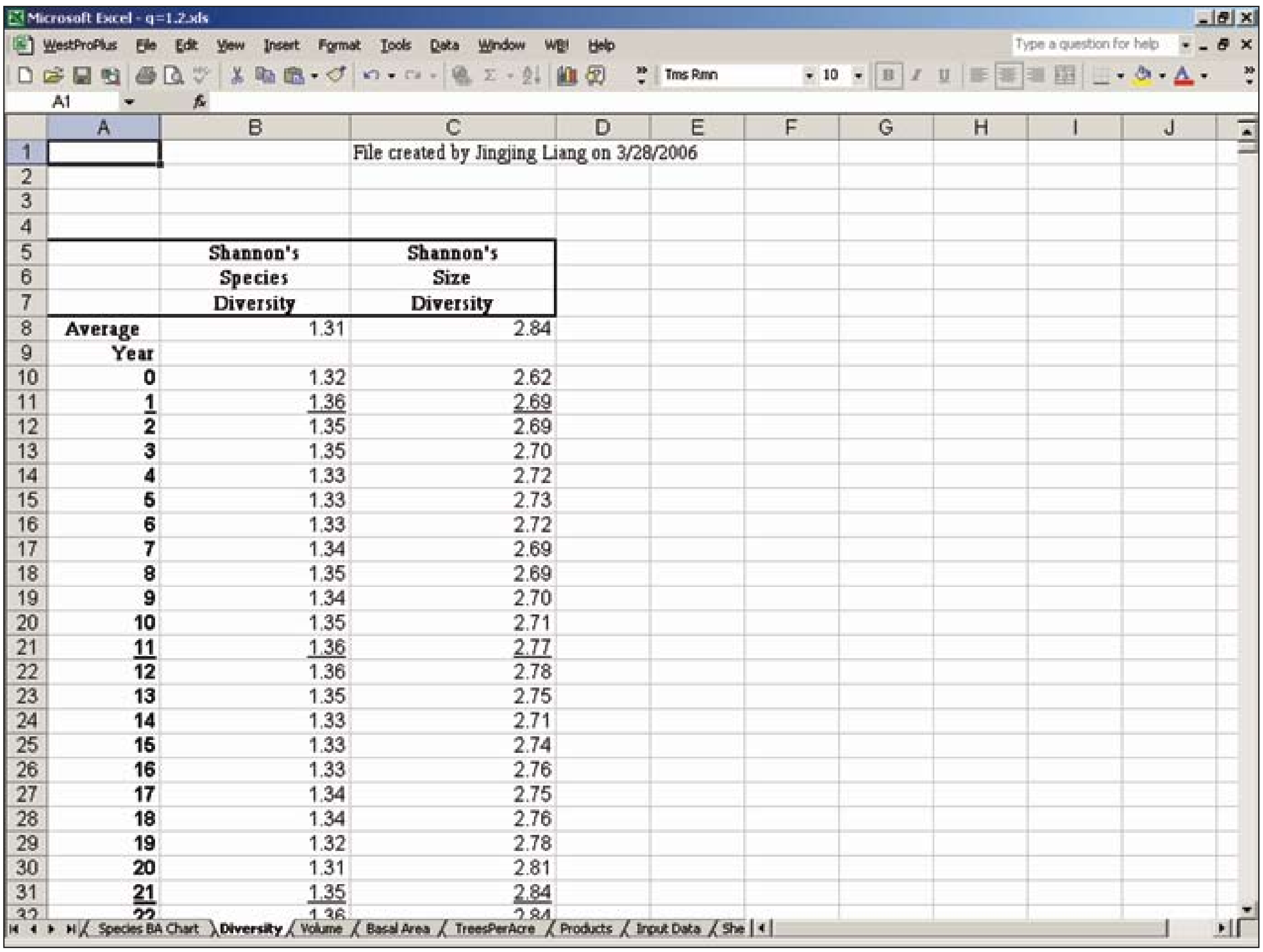
Figure 11—Products worksheet for the BDq selection regime with 87 $ft^2 \cdot ac^{-1}$ residual basal area, 40 in maximum diameter, q = 1.2, and 10 years cutting cycle.

The lower part of the products worksheet shows the average annual cut and the average stock in terms of basal area and volume by log grade. It also displays the average species diversity and size diversity over the whole simulation period.

The results show that with this particular BDq selection and a 10-year cutting cycle, the average yield over 200 years would be 63.97 $ft^3 \cdot ac^{-1} \cdot yr^{-1}$, for a NPV of \$11,395.87 $\cdot ac^{-1}$. This is the value of the land and initial trees, under this management. It suggests that this regime would be economically efficient. Because the value of the initial trees was \$5,692.05 $\cdot ac^{-1}$, the present value of the return from land and initial trees would exceed the initial investment in trees.

Diversity worksheet—

The diversity worksheet (fig. 12) shows Shannon's indices of species group diversity and tree size diversity for each simulated year (see app. 5 for the definitions of Shannon's diversity). The underlined data show the year of harvest and the values of the diversity indices just after harvest. The average of the diversity indices over all years is displayed above the annual values.



File created by Jingjing Liang on 3/28/2006

	Shannon's Species Diversity	Shannon's Size Diversity
Average	1.31	2.84
Year		
0	1.32	2.62
1	1.36	2.69
2	1.35	2.69
3	1.35	2.70
4	1.33	2.72
5	1.33	2.73
6	1.33	2.72
7	1.34	2.69
8	1.35	2.69
9	1.34	2.70
10	1.35	2.71
11	1.36	2.77
12	1.36	2.78
13	1.35	2.75
14	1.33	2.71
15	1.33	2.74
16	1.33	2.76
17	1.34	2.75
18	1.34	2.76
19	1.32	2.78
20	1.31	2.81
21	1.35	2.84
22	1.36	2.84

Figure 12—Diversity worksheet for the BDq selection regime with 87 $ft^2 \cdot ac^{-1}$ residual basal area, 40 in maximum diameter, q = 1.2, and 10 years cutting cycle.

Diversity chart—

The Diversity chart (fig. 13) displays the evolution of Shannon's indices over time. The results show that the effect of stochasticity in forest growth is greater than the effect of harvests on the species and size diversity.

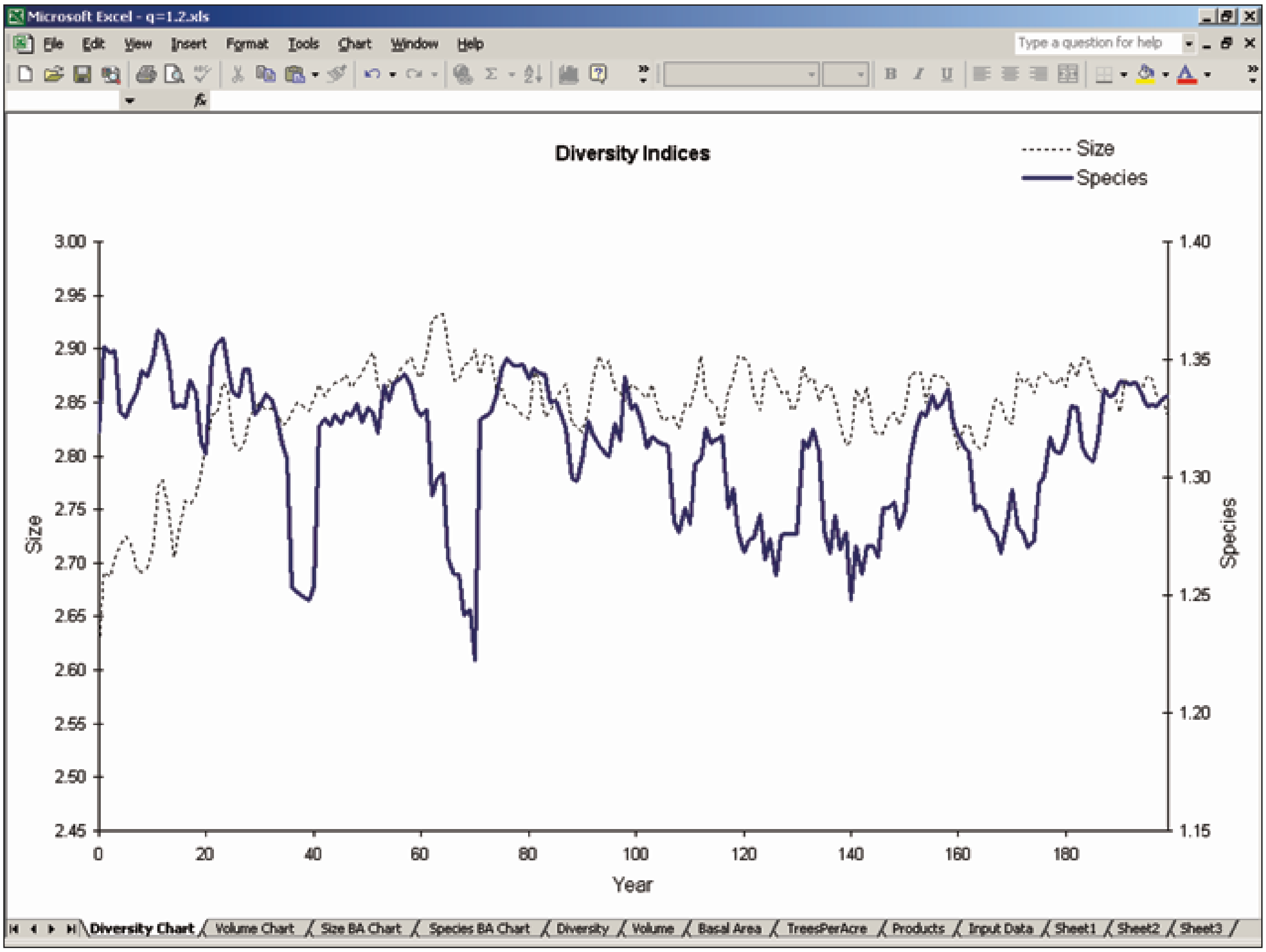


Figure 13—Diversity chart for the BDq selection regime with 87 $ft^2 \bullet ac^{-1}$ residual basal area, 40 in maximum diameter, q = 1.2, and 10 years cutting cycle.

Species BA chart—

This chart (fig. 14) shows the development of basal area by species throughout the simulation period. The chart shows the sharp decrease of total basal area is due to the periodic harvests. It also suggests that in the long run, this management would sustain all four species groups in the stand.

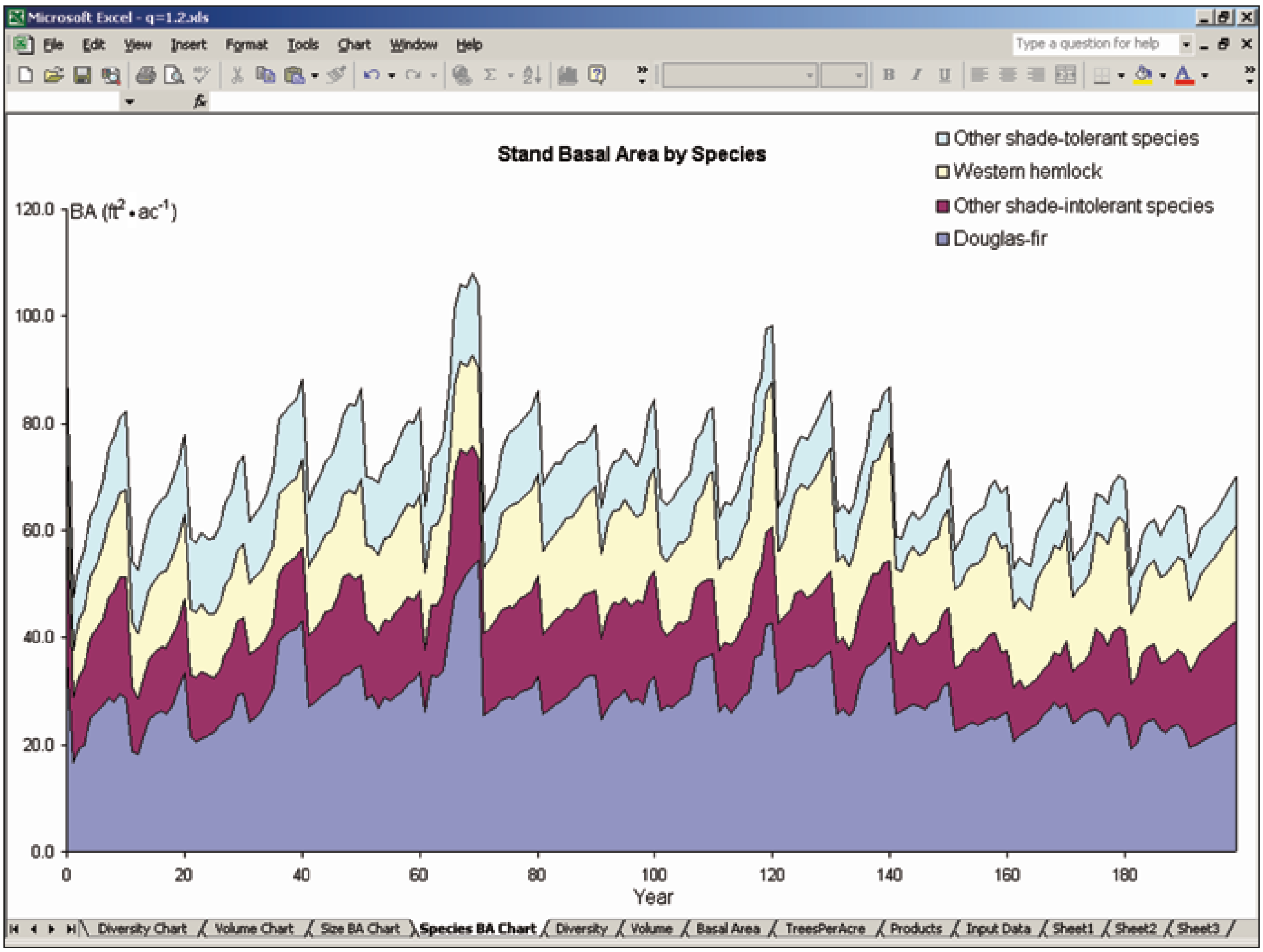


Figure 14—Species basal area by species chart for the BDq selection regime with 87 $ft^2 \cdot ac^{-1}$ residual basal area, 40 in maximum diameter, q = 1.2, and 10 years cutting cycle.

Timber Size BA chart—

This chart (fig. 15) shows the development of basal area by timber size throughout the simulation. It excludes the basal area of trees less than 5 in d.b.h. The results suggest that all three size groups would remain present in the stand for 200 years. The basal area of the largest trees would tend to increase over time with this management.

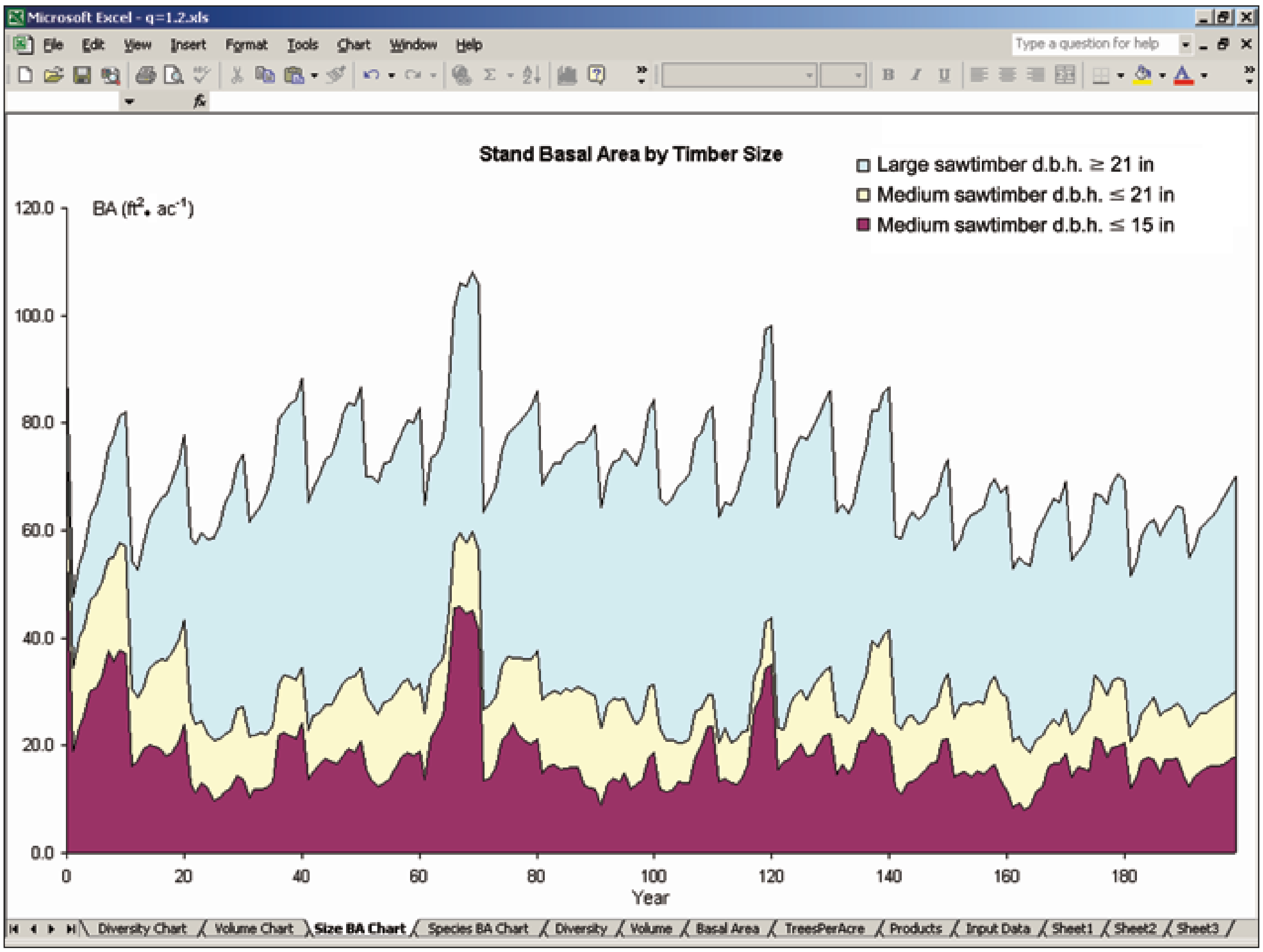


Figure 15—Timber Size BA chart for the BDq selection regime with 87 $ft^2 \bullet ac^{-1}$ residual basal area, 40 in maximum diameter, q = 1.2, and 10 years cutting cycle.

Volume chart—

This chart (fig. 16) shows the development of volume in stock by log grade throughout the simulation period. The chart suggests that all log grades would continue to be present in the stand. The stock of peeler, and No. 1 Sawmill logs tended to increase slightly over time under this management.

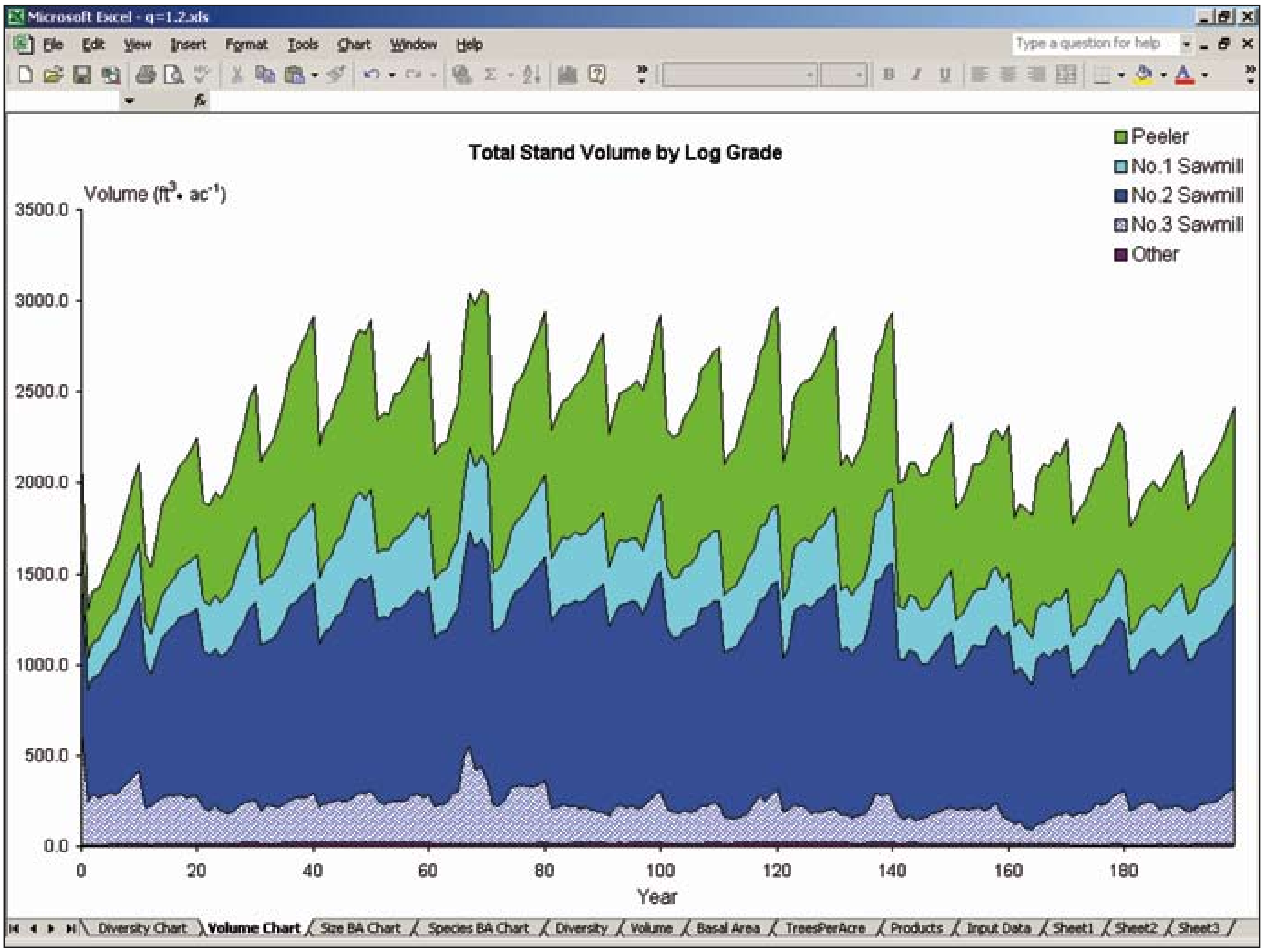


Figure 16—Volume chart for the BDq selection regime with 87 $ft^2 \cdot ac^{-1}$ residual basal area, 40 in maximum diameter, q = 1.2, and 10 years cutting cycle.

Comparison of BDq Selection Regimes Under a Stochastic Environment

As an example of how WestProPlus can be used to compare management under a stochastic environment, follow the steps below to compare BDq selection regimes with a 10-year cutting cycle, 87 $ft^2 \cdot ac^{-1}$ residual basal area, 40 in maximum diameter, and a q-ratio of 1.2, 1.4, or 1.8:

- Load **WestProPlus**, fill in, and save three **Input Data** worksheets corresponding to the three q-ratios.
- Run a stochastic simulation for each Input Data worksheet and record the total NPV ($\$ \cdot ac^{-1}$), productivity ($ft^3 \cdot ac^{-1} \cdot yr^{-1}$), average stand diversity of tree species and size, average basal area, and average percentage of peeler logs from the products worksheet (fig. 11).
- Keep the three **Input Data** worksheets active on the desktop and **Quit** WestProPlus (see section 2).
- Reload **WestProPlus** (see section 2) and go to step 2 to start a new replication.

WestProPlus simulations are run three times in step 2 (once for each regime) with the same string of random numbers to compare the regimes efficiently, while steps 3 and 4 generate a new string of random numbers for another replication.

An example of 10 replications is in table 1. There was a strong positive effect of q-ratio on the productivity (fig. 17), because more large trees were cut with higher q-ratios. As smaller trees were left on the stand, higher q-ratio led to significantly lower percentage of peelers, and lower tree size diversity (fig. 17). Here, we have detected little or no effect of q-ratio on the other criteria with only 10 replications. More replications with more initial states suggest that as the q-ratio increases, NPV increases, species diversity decreases, and basal area increases (Liang et al., in press).

Table 1—Simulation results of the three BDq selection regimes with different q-ratios

Replication	NPV q = 1.2	NPV q = 1.4	NPV q = 1.8	Productivity q = 1.2	Productivity q = 1.4	Productivity q = 1.8
		$ • ac⁻¹			*ft³ • ac⁻¹ • yr⁻¹*	
1	11,396	16,239	13,312	63.97	68.56	99.99
2	17,078	9,414	9,360	59.46	64.21	95.85
3	12,136	6,104	13,744	59.69	72.42	98.97
4	7,558	13,222	11,978	55.79	72.90	112.46
5	7,618	8,250	10,666	47.92	64.91	116.16
6	12,574	11,496	10,425	55.93	64.31	98.00
7	8,298	17,314	14,390	61.82	85.62	126.88
8	14,790	5,022	22,120	57.26	75.92	108.32
9	7,366	12,456	11,038	53.14	68.75	111.96
10	15,062	11,316	8,054	49.35	70.98	99.25

	Species diversity q = 1.2	Species diversity q = 1.4	Species diversity q = 1.8	Size diversity q = 1.2	Size diversity q = 1.4	Size diversity q = 1.8
1	1.31	1.33	1.31	2.84	2.78	2.38
2	1.31	1.32	1.33	2.85	2.79	2.38
3	1.32	1.32	1.28	2.83	2.78	2.39
4	1.32	1.33	1.34	2.85	2.79	2.41
5	1.30	1.31	1.30	2.83	2.78	2.36
6	1.32	1.34	1.31	2.85	2.78	2.38
7	1.33	1.33	1.32	2.85	2.77	2.37
8	1.33	1.34	1.33	2.85	2.77	2.38
9	1.34	1.34	1.32	2.86	2.79	2.38
10	1.31	1.31	1.34	2.85	2.79	2.42

	Percentage of peeler q = 1.2	Percentage of peeler q = 1.4	Percentage of peeler q = 1.8	Average basal area q = 1.2	Average basal area q = 1.4	Average basal area q = 1.8
		Percent			*ft² • ac⁻¹*	
1	0.31	0.23	0.17	70.7	81.8	76.9
2	0.30	0.22	0.17	73.8	72.7	73.6
3	0.30	0.22	0.16	70.6	83.4	77.5
4	0.31	0.22	0.16	73.5	82.5	80.8
5	0.29	0.22	0.16	65.2	74.7	86.1
6	0.32	0.23	0.16	73.7	77.5	78.2
7	0.29	0.22	0.16	76.5	88.0	89.1
8	0.31	0.22	0.17	71.5	85.9	75.5
9	0.29	0.22	0.16	71.7	80.0	81.1
10	0.30	0.22	0.16	68.4	81.7	74.0

Note: Except for net present value (NPV), all data are averages over 200 years.

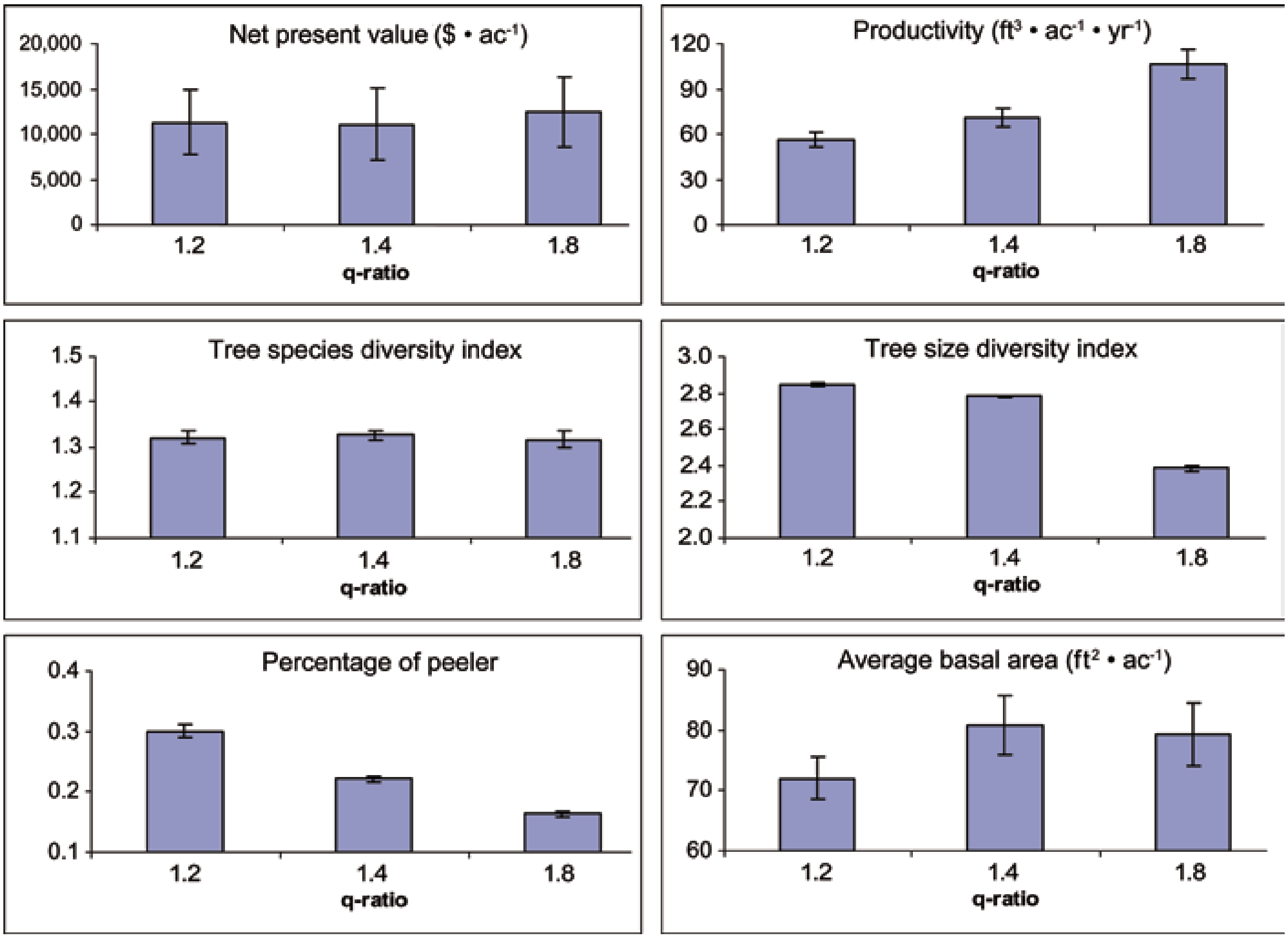


Figure 17—Mean and standard error of the management criteria over 10 replications for different q-ratios, other things being held constant.

Troubleshooting WestProPlus

Why can't I open WestProPlus?

First, make sure you have the latest version of WestProPlus (2005). Check our Web site: http://www.forest.wisc.edu/facstaff/buongiorno/ for updates.

Set your Excel macro security level to **Medium**. You can change the level at **Tools → Macro → Security**. After setting the macro security level to **Medium**, each time you load WestProPlus, a security warning message window will pop up, and you should select **Enable Macros** (fig. 18).

Figure 18—Microsoft Excel Security Warning Window against Macro viruses.

WestProPlus does not insert a new Input Data worksheet. What can I do?
Before inserting a new Input Data worksheet, WestProPlus checks to see if there is a worksheet named Input Data already open. If there is one, WestProPlus will not generate a new Input Data worksheet. To get a new Input Data worksheet, close all Excel windows and reopen WestProPlus.

Why is there no BDq calculator in the example worksheets?
The example workbooks contain only the input data. After you have installed WestProPlus, the BDq calculator icon will appear in the new Input Data worksheet. At that point, you can copy data from the example workbooks into the Input Data worksheet.

Why is the BDq calculator not working?
WestProPlus must be open to use the BDq calculator. To use the BDq calculator on a previously saved Input Data worksheet, WestProPlus must be in the Excel menu bar.

Why can't I copy all the content from the example worksheet to the Input Data worksheet?
All the cells of the Input Data worksheet are protected except those that need entries (marked with ? marks). Copy only the data from the example worksheet and paste them to the corresponding locations in the Input Data worksheet.

For further assistance, or to send us your comments, please contact us through jbuongio@wisc.edu.

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters
Feet (ft)	.3048	Meters
Square feet (ft^2)	.0929	Square meters
Square feet per acre ($ft^2 \cdot ac^{-1}$)	.229	Square meters per hectare
Cubic feet (ft^3)	.0283	Cubic meters
Cubic feet per acre ($ft^3 \cdot ac^{-1}$)	.070	Cubic meters per hectare

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Appendix 1—WestProPlus Plot Data

The data to calibrate the stand growth model used by WestProPlus came from the PNW-FIA Integrated Database (Version 1.3) (Hiserote and Waddell 2003), specifically, the part of the database that combines information from four forest inventories (eastern Oregon, western Oregon, eastern Washington, and western Washington) conducted by the USDA Forest Service between 1988 and 2000.

The 2,706 plots used in calibrating WestProPlus had all been classified in the Douglas-fir–western hemlock forest type, they had been measured at two successive inventories, and they were located in Oregon and Washington west of 120° in longitude (fig. 19). This area includes the Coast Range and the Cascade Range of western Washington and Oregon, as well as the Klamath region of southwestern Oregon. About 80 percent of the plots were on private land, and most of the remaining 20 percent were on lands belonging to the states of Oregon or Washington (table 2). United States federal lands (e.g., national forests, national parks, and Bureau of Land Management land) comprise only 2.4 percent of the land in this database.

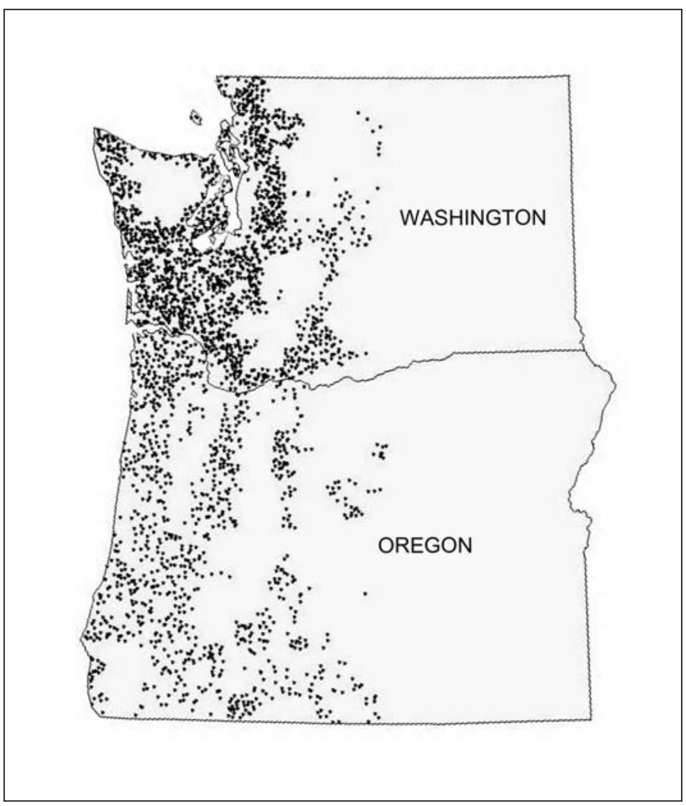

Figure 19—Geographic distribution of the Forest Inventory and Analysis plots used to calibrate the growth and yield model.

Table 2—Distribution of plots by ownership

Ownership	Number of plots	Percent
Private	2,136	78.9
Public		
State	438	16.2
Local government	67	2.5
Bureau of Land Management	20	0.7
National Park Service	16	0.6
Other federal owner	29	1.1
Total	2,706	100.0

The trees were categorized into four species classes (table 3): Douglas-fir, other shade-intolerant species, western hemlock, and other shade-tolerant species (Barbour and Billings 1988). Red alder (*Alnus rubra* Bong.) and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) were the most abundant shade-intolerant species other than Douglas-fir. Western redcedar (*Thuja plicata* Donn ex D. Don) and bigleaf maple (*Acer macrophyllum* Pursh) were the most abundant shade-tolerant species other than western hemlock (table 3). Within each species, trees were grouped into nineteen 2-in diameter classes, from 3 to 5 in up to 40 in and above.

The plot characteristics are summarized in table 4. The theoretical maximum species diversity is $ln(4) = 1.39$, and the maximum size diversity is $ln(19) = 2.94$, occurring when all the basal area is equally distributed in all 4 species classes and 19 size classes, respectively. There was a 0.90 correlation between the diversity by species group, used here, and the diversity by individual species. The average recruitment was highest for Douglas-fir and other shade-intolerant trees (table 4).

The individual tree data (table 5) show that, on average, Douglas-fir trees had the highest diameter growth rate, and lowest mortality rate. Other shade-tolerant species had the highest single tree gross volume. Although the time between measurements was short, averaging a decade, there was much difference in trees and stand conditions between plots. It is this cross-sectional variation that allows inferring how stands would grow in very different conditions that might arise in space and over long periods.

Table 3—Frequency of tree species in all sample plots, for each of our four species groups

Common name	Scientific name	Percentage of plots
Douglas-fir	*Pseudotsuga menzeisii* (Mirb.) Franco	41.27
Other shade-intolerant species		24.07
Red alder	*Alnus rubra* Bong.	10.85
Ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.	7.10
Lodgepole pine	*Pinus contorta* Dougl. ex Loud.	1.94
Western larch	*Larix occidentalis* Nutt.	0.92
Black cottonwood	*Populus trichocarpa* (Torr. & Gray)	0.72
Pacific madrone	*Arbutus menziesii* Pursh	0.63
Incense-cedar	*Calocedrus decurrens* Torr.	0.44
Oregon white oak	*Quercus garryana* Dougl. ex Hook	0.42
Western juniper	*Juniperus occidentalis* Hook.	0.26
Oregon ash	*Fraxinus latifolia* Benth.	0.25
Noble fir	*Abies procera* Rehd.	0.18
Quaking aspen	*Populus tremuloides* Michx.	0.15
Western white pine	*Pinus monticola* Dougl. ex D. Don	0.14
Sugar pine	*Pinus lambertiana* Dougl.	0.05
Jeffrey pine	*Pinus jeffreyi* Grev. & Balf.	0.01
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.)	18.80
Other shade-tolerant species		15.86
Western redcedar	*Thuja plicata* Donn ex D. Don	5.88
Bigleaf maple	*Acer macrophyllum* Pursh	3.09
Grand fir	*Abies grandis* (Dougl. ex D. Don) Lindl.	2.09
Sitka spruce	*Picea sitchensis* (Bong.) Carr.	1.44
Pacific silver fir	*Abies amabilis* Dougl. ex Forbes	1.32
White fir	*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.	0.94
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.	0.42
Engelmann spruce	*Picea engelmannii* Parry ex Engelm.	0.34
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt.	0.17
Port-Orford-cedar	*Chamaecyparis lawsoniana* (A Murr.) Parl.	0.12
Pacific yew	*Taxus brevifolia* Nutt.	0.03
Alaska yellowcedar	*Chamaecyparis nootkatensis* (D. Don) Spach	0.02
Redwood	*Sequoia sempervirens* (D. Don) Endl.	0.01
All the species		100.00

Table 4—Summary statistics for plot data (2,706 plots)

	First inventory						
	Douglas-fir	Other shade intolerants	Western hemlock	Other shade tolerants	Site productivity	Inter-inventory period	Basal area
	Trees • ac⁻¹				$Ft^3 \cdot ac^{-1} \cdot yr^{-1}$	*Year*	$Ft^2 \cdot ac^{-1}$
Mean	86.38	62.42	56.79	41.24	149.59	10.53	119.01
Standard deviation	121.74	105.75	119.63	87.59	72.17	0.90	74.23
Maximum	1,246.45	1,982.99	1,223.36	1,056.16	300.00	23.00	418.66
Minimum	0	0	0	0	10.00	9.00	2.40
Number of plots	2,706	2,706	2,706	2,706	2,706	2,706	2,706

	Recruitment						
	Douglas-fir	Other shade intolerants	Western hemlock	Other shade tolerants	Species diversity	Size diversity	Total volume
	$Trees \cdot ac^{-1}$						$Ft^3 \cdot ac^{-1}$
Mean	2.22	1.55	1.34	1.01	0.54	1.65	4,733.54
Standard deviation	7.32	6.35	5.67	4.48	0.39	0.63	3,588.06
Maximum	103.87	165.25	96.76	96.37	1.38	2.76	22,122.76
Minimum	0	0	0	0	0	0	28.15
Number of plots	2,706	2,706	2,706	2,706	2,706	2,706	2,706

Note: Recruitment is change between the two inventories.

Table 5—Summary statistics for individual tree data

	Douglas-fir	Other shade-intolerant species	Western hemlock	Other shade-tolerant species
Diameter (in)				
Mean	15.28	12.01	12.97	16.06
Standard deviation	8.39	6.33	7.69	10.69
Maximum	81.81	51.42	68.37	119.90
Minimum	1.57	1.57	1.57	1.57
Number of trees	23,161	11,831	11,612	8,900
Diameter growth (in yr^{-1})				
Mean	0.28	0.18	0.23	0.23
Standard deviation	0.17	0.14	0.15	0.17
Maximum	5.50	6.47	3.77	3.33
Minimum	0	-0.11	0	-0.45
Number of trees	23,161	11,831	11,612	8,900
Mortality rate (y^{-1})				
Mean	0.003	0.006	0.003	0.004
Standard deviation	0.016	0.023	0.017	0.019
Maximum	0.111	0.111	0.111	0.111
Minimum	0	0	0	0
Number of trees	23,838	12,650	12,007	9,295
Volume (ft^3 $tree^{-1}$)				
Mean	77.69	39.55	61.09	83.34
Standard deviation	99.59	51.91	90.41	154.33
Maximum	1,986.80	790.70	1,353.26	5,826.92
Minimum	0.35	0.35	0.35	0
Number of trees	23,161	11,831	11,612	8,900

Note: Diameter and volume are at the time of the first inventory, diameter growth and mortality rate are between the two inventories.

Appendix 2—Growth-and-Yield Model

The growth model of WestProPlus has the following form (Liang et al. 2005):

$$\mathbf{y}_{t+1} = \mathbf{G}\mathbf{y}_t + \mathbf{r} + \mathbf{u}_{t+1} \qquad (1)$$

where $\mathbf{y}_t = [y_{ijt}]$ is the number of trees per unit area of species group i, and diameter class j, at time t, and i = 1 for Douglas-fir, i = 2 for other shade-intolerant species, i = 3 for western hemlock, and i = 4 for other shade-tolerant species. The matrix **G** and the vector **r** are defined as:

$$\mathbf{G} = \begin{bmatrix} \mathbf{G}_1 & & & \\ & \mathbf{G}_2 & & \\ & & \mathbf{G}_3 & \\ & & & \mathbf{G}_4 \end{bmatrix}, \quad \mathbf{G}_i = \begin{bmatrix} a_{i1} & & & & \\ b_{i1} & a_{i2} & & & \\ & \ddots & \ddots & & \\ & & b_{i,17} & a_{i,18} & \\ & & & b_{i,18} & a_{i,19} \end{bmatrix}$$

$$\mathbf{r} = \begin{bmatrix} \mathbf{r}_1 \\ \mathbf{r}_2 \\ \mathbf{r}_3 \\ \mathbf{r}_4 \end{bmatrix}, \quad \mathbf{r}_i = \begin{bmatrix} r_i \\ 0 \\ \vdots \\ 0 \end{bmatrix}$$

where a_{ij} is the probability that a tree of species i and diameter class j stays alive and in the same diameter class between t and t+1, b_{ij} is the probability that a tree of species i and diameter class j stays alive and grows into diameter class j+1, and r_i is the number of trees of species group i recruited in the smallest diameter class between t and t+1, with a period of 1 year. The vector $\mathbf{u}_{t+1}$ represents the stochastic part of growth. $\mathbf{u}_{t+1}$ is bootstrapped each year from the set of vector differences between the observed and the deterministically predicted stand state, for each of the 2,706 plots in Oregon and Washington (Liang et al., in press). The b_{ij} probability is equal to the annual tree diameter growth, g_{ij} (in • yr^{-1}), divided by the width of the diameter class. Diameter growth is a function of tree diameter D_j (in), stand basal area B (ft^2 • ac^{-1}), site productivity Q (ft^3 • ac^{-1} • yr^{-1}), tree species diversity H_s, and tree size diversity H_d.

$$g_{1j} = 0.3094 + 0.0124D_j - 0.0001D_j^2 - 0.0010B + 0.0007Q + 0.0259H_s - 0.0955H_d$$
$$g_{2j} = 0.2403 + 0.0038D_j - 0.0001D_j^2 - 0.0007B + 0.0005Q + 0.0278H_s - 0.0273H_d$$
$$g_{3j} = 0.3553 + 0.0148D_j - 0.0003D_j^2 - 0.0010B + 0.0002Q + 0.0098H_s - 0.0689H_d$$
$$g_{4j} = 0.2304 + 0.0081D_j - 0.0001D_j^2 - 0.0008B + 0.0005Q + 0.0506H_s - 0.0568H_d$$

The expected recruitment r_i (trees • ac^{-1} • yr^{-1}) of species i is represented by a Tobit model:

$$r_i = \Phi(\beta_i x_i / \sigma_i)\beta_i x_i + \sigma_i \phi(\beta_i x_i / \sigma_i)$$

with:

$$\beta_1 x_1 = -8.8824 - 0.1211B + 0.0971N_1 + 0.0227Q + 4.5033H_s - 2.7500H_d$$
$$\beta_2 x_2 = -9.5715 - 0.0773B + 0.0975N_2 + 0.0058Q + 3.4070H_s - 2.4200H_d$$
$$\beta_3 x_3 = -12.508 - 0.0872B + 0.0926N_3 + 0.0190Q + 5.9506H_s - 4.0100H_d$$
$$\beta_4 x_4 = -13.987 - 0.0700B + 0.0924N_4 + 0.0209Q + 3.2546H_s - 0.9200H_d$$

where N_i is the number of trees per acre in species group i; Φ and ϕ are respectively the standard normal cumulative and density functions, and the standard deviations of the residuals are, $\sigma_1 = 9.5366$, $\sigma_2 = 9.0863$, $\sigma_3 = 11.0664$, $\sigma_4 = 9.3270$.

The probability of tree mortality per year, m_{ij}, is a species-dependent probit function of tree size and stand state:

$$m_1 = \frac{1}{10.5}\Phi(-2.1103 - 0.0905D_j + 0.0012D_j^2 + 0.0019B - 0.0014Q + 0.0059H_s + 0.5110H_d)$$
$$m_2 = \frac{1}{10.5}\Phi(-1.4063 - 0.0519D_j + 0.0010D_j^2 + 0.0012B - 0.0010Q + 0.0022H_s + 0.1411H_d)$$
$$m_3 = \frac{1}{10.5}\Phi(-3.1746 - 0.1057D_j + 0.0019D_j^2 + 0.0036B - 0.0016Q + 0.3252H_s + 0.4192H_d)$$
$$m_4 = \frac{1}{10.5}\Phi(-1.5188 - 0.0236D_j + 0.0002D_j^2 + 0.0010B - 0.0021Q + 0.2721H_s + 0.3528H_d)$$

The probability that a tree stays alive and in the same size class from t to t+1 is, then:

$$a_{ij} = 1 - b_{ij} - m_{ij}$$

The expected single-tree volume v_{ij} (ft^3) is a species-dependent function of tree and stand characteristics:

$$v_{1j} = -0.01712 - 0.00013D_j + 0.00001D_j^2 + 0.00161B + 0.01174Q + 0.00350H_s + 0.00092H_d$$

$$v_{2j} = -0.01536 - 0.00004D_j + 0.00000D_j^2 + 0.00054B + 0.00691Q + 0.00038H_s + 0.00100H_d$$

$$v_{3j} = -0.01294 - 0.00016D_j + 0.00001D_j^2 + 0.00087B + 0.00416Q + 0.00185H_s + 0.00145H_d$$

$$v_{4j} = -0.00392 - 0.00019D_j + 0.00000D_j^2 + 0.00105B + 0.00584Q + 0.00692H_s + 0.00035H_d$$

Total stand volume in cubic feet has to be converted to total stand volume in thousand board feet (mbf) in order to calculate the value of stocking and harvest. The conversion ratios for different log sizes are shown in table 6.

Table 6—Effect of log diameter at 20 ft log length on cubic volume to board foot conversion (no defects, no trim, taper 0.125 in • ft^{-1})

Diameter	Cubic feet per thousand Scribner board feet
Inches	*$ft^3 \cdot mbf^{-1}$*
5–7	221.4
7–9	303.6
9–11	242.9
11–13	200.0
13–15	189.3
15–17	182.1
17–19	164.3
19–21	157.1
21–23	142.9
23–25	139.3
27+	142.9

Source: Spelter (2004).

Appendix 3—Log Grade Model

The equations to predict log grade were calibrated with data from 3,378 logs in the USFS Product Recovery Database (Stevens and Barbour 2000). The logs are classified into five grade categories, according to their diameter, branch size, growth rate, and minimum length (Barbour and Parry 2001, Northwest Log Rules Advisory Group 1998). For WestProPlus, the logs were divided into the four species groups recognized by the growth model (app. 2).

In addition to the log grade, the diameter of the logs was known for all species groups. The database also contains information on the stands from which the logs were taken. However, for Douglas-fir and western hemlock, only the tree diameter D (in) and the site index S (ft) influenced log grade significantly (Liang et al., in press).

The log grade was predicted with a logistic regression and a nominal response

$$\ln\left(\frac{\pi_{ijl}}{\pi_{ijm}}\right) = \beta_{il} + \beta_{ilD} \cdot D + \beta_{ilS} \cdot S$$

variable:

where π_{ijl}/π_{ijm} was the ratio between the probability of log grade *l* (l = 1, 2, …, *m*-1), and log grade *m*, for species *i* and diameter class *j*. The parameters, β_{il}, of the log grade equation for Douglas-fir and western hemlock are in table 7. For both species, log grade was higher for larger trees on sites with lower site index.

There were no data on stand characteristics for other shade-tolerant and shade-intolerant species, and no systematic relation was observed between grade and diameter for these species groups. WestProPlus uses the observed percentages of total volume by log grade for each diameter class, and assumes that they are constant (table 8).

Table 7—Estimation results of the nominal-logistic equations of log grade

Dependent variable	Independent variable	Coefficient	Standard error	Probability *P* (α = 0.05)
Douglas-fir				
π_1/π_4	Constant	2.91	1.20	0.02
	D	0.02	0	0
	S	-0.33	0.10	0
π_3/π_4	Constant	1.66	1.43	0.25
	D	0.02	0	0
	S	-0.33	0.13	0.03
Western hemlock				
π_1/π_4	Constant	-8.94	4.28	0.04
	D	0.16	0.02	0
	S	-1.33	0.50	0.03
π_2/π_4	Constant	-8.37	4.04	0.04
	D	0.14	0.02	0
	S	-1.00	0.43	0.07
π_3/π_4	Constant	-5.90	1.59	0
	D	0.10	0.01	0
	S	-0.43	0.13	0

π_l = probability of log grade *l* (no Douglas-fir logs were observed for grade 2; grade 5 was not observed for either species).

D = tree diameter.

S = site index.

P = level at which the effect of the control variable would be just significant.

Table 8—Percentage of timber volume by log grade (1 through 5) and size for the shade-intolerant species except Douglas-fir, and the shade-tolerant species except western hemlock

	Other shade-intolerant species					Other shade-tolerant species				
Diameter	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
in					*Percent*					
4	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	30	0	58	12
8	0	0	0	100	0	0	30	0	66	4
10	0	20	0	80	0	0	37	0	61	1
12	0	24	0	76	0	0	35	0	64	1
14	0	23	10	66	0	0	33	12	55	0
16	0	16	59	25	0	0	28	50	20	2
18	0	20	69	7	4	0	36	47	16	1
20	0	16	78	6	0	0	36	48	11	4
22	0	21	79	0	0	0	29	60	9	2
24	0	14	77	4	5	0	37	50	11	2
26	6	27	64	3	0	1	26	66	6	1
28	7	33	58	2	0	1	40	52	6	1
30	19	43	36	2	0	1	32	56	7	4
32	21	43	29	0	7	3	42	50	5	0
34	13	69	13	0	6	0	44	52	4	0
36	0	70	20	0	10	0	44	48	8	0
38	0	40	60	0	0	8	62	31	0	0
40	0	75	25	0	0	0	43	50	0	7

Appendix 4—Stochastic Stumpage Price and Interest Rate Models

The stumpage price model in WestProPlus (Liang et al., in press) was calibrated with quarterly stumpage prices of Douglas-fir grade 1 logs from 1977 to 2003 in Oregon (Oregon Department of Forestry 2005). The following autoregressive-moving average model was used to represent quarterly price changes:

$$\Delta P_{t+1} = -0.60\Delta P_t + 0.05e_t + e_{t+1} \qquad (3)$$

where P_t and P_{t+1} were stumpage prices ($\$ \bullet \text{mbf}^{-1}$) at quarter t and quarter t+1, respectively, and e_t was a white-noise residual error. The parameters were estimated from the data with the Box-Jenkins method. WestProPlus simulates stochastic price series with this model by bootstrapping, i.e., by drawing randomly with replacement at each step t a pair of shocks e_t and e_{t+1} from the residuals obtained by fitting model (3) to the data.

The initial price of Douglas-fir grade 1 logs is equal to that entered by the user (fig. 1), or lacking this, it is bootstrapped from the prices observed from 1977 to 2003. With bootstrapped initial prices, the mean predicted stumpage prices of Douglas-fir grade 1 logs and the standard error over 500 replications of 100-year simulations had a slight positive trend over time, but it was not statistically significant.

The prices of logs of grades other than grade 1 is calculated according to the relative prices entered by the user (fig. 1), or lacking this, according to the relative prices in table 9. In either case, the relative prices are assumed to be constant over time.

Table 9—Stumpage prices ($\$ \bullet \text{mbf}^{-1}$) in Oregon by log grade and species group in 2005

Log grade	Douglas-fir	Other shade-intolerant species	Western hemlock	Other shade-tolerant species
		$ • mbf⁻¹		
1	765	550	275	650
2	465	540	270	625
3	435	440	245	625
4	390	375	205	625
5	50	50	50	65

Price source: Oregon Department of Forestry (2005), and an assumed logging and hauling cost of $180 mbf $^{-1}$.

The annual rate of return of AAA bonds from 1970 to 2004 (US GPO 2005) was used as the interest rate. WestProPlus uses an autoregressive model of interest rates:

$$r_{t+1} = 0.72 + 0.81 r_t + \varepsilon_t \quad (4)$$

where r_t was the interest rate at year t, and ε_t was the white-noise residual. WestProPlus simulates stochastic interest rates by bootstrapping: at each step t, a shock was drawn randomly with replacement from the sample of the residuals obtained by fitting the model to the data. With bootstrapped initial interest rate, the mean predicted interest rate over 500 simulations showed no trend over time.

Appendix 5—Definition of Diversity of Tree Species and Size

WestProPlus uses Shannon's index to measure the stand diversity in terms of tree species (how uniformly trees are distributed across species groups), and timber size classes. WestProPlus measures the presence of trees in a class by their basal area, which gives more weight to larger trees.

The tree species diversity is defined in WestProPlus as:

$$H_{species} = -\sum_{i=1}^{m} \frac{y_i}{y} \ln\left(\frac{y_i}{y}\right)$$

where y_i is the basal area of trees of species group *i* per acre, and *y* is total basal area. In WestProPlus, $m = 4$ (there are four species groups). The tree species diversity has a maximum value of $ln(4) = 1.39$, when basal area is equally distributed in the four species groups, and a minimum value of zero when all trees are in the same species group.

Similarly, tree size diversity is:

$$H_{size} = -\sum_{j=1}^{n} \frac{y_j}{y} \ln\left(\frac{y_j}{y}\right)$$

where y_j is the basal area of trees in diameter class j per acre. In WestProPlus, $n = 19$ diameter classes. The tree size diversity has a maximum $ln(19) = 2.94$ when basal area is equally distributed in all 19 diameter classes, and a minimum of zero when all trees are the same diameter class.

Glossary

BA chart—A WestProPlus-generated chart showing, for a selected range of years, the per-acre basal area of softwoods, hardwoods, and the whole stand.

BDq distribution—A tree distribution, by diameter class, defined by a stand basal area (B), a maximum and minimum tree diameter (D), and a q-ratio (q), the ratio of the number of trees in a given diameter class to the number of trees in the next larger class.

bootstrap method—When used in stochastic simulations, this technique simulates random variables by sampling randomly (with replacement) from actual observations of the variable, rather than from an assumed distribution. See Efron and Tibshirani 1994 for the details.

cutting cycle—The number of years between successive harvests. For two-cut silvicultural systems, this is the number of years between the two harvests.

diameter class—One of nineteen 2-in diameter at breast height (d.b.h.) categories used by WestProPlus to classify trees by size. Diameter classes range from 4 to 40+ in, with each class denoted by its midpoint diameter. Diameter class 4 is for trees with diameters from 3 to less than 5 in. The 40+ in class is for all trees with 39 in diameter and larger.

diversity chart—A WestProPlus-generated chart showing changes in the Shannon index of species or size diversity over a selected range of years.

initial stand state—The number of live trees per acre, by species and size, at the start of a simulation.

input data worksheet—A worksheet to enter the data for running a WestProPlus simulation.

log grade— An estimate of the type and quality of lumber recovered when the log is sawed.

Microsoft Excel add-in—A command, function, or software program that runs within Microsoft Excel and adds special capabilities. WestProPlus is an add-in.

net present value (NPV)—The net revenue discounted to the present.

preharvest stand state—The number of live trees per acre, by species and size, immediately before a harvest.

products worksheet—A WestProPlus output worksheet that shows, for each harvest, the basal area cut, the volume removed by grade, the gross income generated, and the net present value of the harvest, as well as the total net present value of the stand and its mean annual production in terms of basal area cut and volume harvested, on a per acre basis.

re-entry costs—Costs per acre associated with each harvest that are not reflected in the stumpage prices. These may include, e.g., the added expense of marking the stand for single-tree selection or for controlling hardwood competition.

setup file worksheet—A worksheet to store WestProPlus setup files. It is typically hidden.

setup files—Collections of related input data that are stored together on a Setup File worksheet. Setup files may contain data for initial stand states, target stand states, cutting cycle parameters, stumpage prices, or fixed costs, and may be used in varying combinations as input for WestProPlus simulations.

site index—The average height of a stand's dominant and codominant trees at age 50 years.

size diversity—The diversity of tree diameter classes as measured by the Shannon index. With 19 diameter classes, size diversity reaches its maximum value of 2.94 when the basal area or number of trees is distributed evenly among the diameter classes.

species diversity—The diversity of species groups as measured by the Shannon index. With four species classes, species diversity reaches its maximum value of 1.39 when the basal area or number of trees is distributed evenly among the species groups.

species groups—The four categories used by WestProPlus to classify trees by species. For a complete list of species, see table 3.

> **Douglas-fir**—*Pseudotsuga menziesii.*
>
> **Other shade-intolerant species**—Including *Alnus rubra, Pinus ponderosa, Pinus contorta,* etc.
>
> **Western hemlock**—*Tsuga heterophylla.*
>
> **Other shade-tolerant species**—Including *Thuja plicata, Acer macrophyllum, Abies grandis,* etc.

stumpage prices—Prices paid to a landowner for standing timber.

target stand state—The desired number of live trees per acre in each species group and diameter class after a harvest.

total net present value—The sum of all discounted revenues minus the sum of all discounted costs.

workbook—The workbook is the normal document or file type in Microsoft Excel. A workbook is the electronic equivalent of a three-ring binder. Inside workbooks you will find sheets, such as worksheets and chart sheets.

worksheet—Most of the work you do in Excel will be on a worksheet. A worksheet is a grid of rows and columns. Each cell is the intersection of a row and a column and has a unique address, or reference.

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U.S. Department of Agriculture
Pacific Northwest Research Station
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P.O. Box 3890
Portland, OR 97208-3890

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