CHAPTER

Simulating Landscape Change Using the Landscape Management System

13

Chadwick D. Oliver, James B. McCarter, Jeffrey M. Comnick, Kevin Ceder, and Christopher S. Nelson

Management of forested landscapes is becoming increasingly complex as people are demanding more and diverse values from these landscapes. Different wildlife species can require different forest conditions that often are mutually exclusive. For example, some owl and woodpecker species may require closed, old forests, whereas butterflies and some songbirds in the same forest types may require openings with sparse tree cover. In addition, there are increasing demands for values other than timber such as scenic beauty, fire protection, and carbon sequestration.

Forests are constantly changing through growth and disturbances (Fig. 13-1). Consequently, managers need to anticipate how different forest stands will change and how they can manage the change to ensure that a diversity of values is provided at all times. Because of the mutual exclusivity of different habitats and other values, managers must also make trade-offs among these values. Although necessary, such trade-offs can be minimized with informed management.

Effective landscape management requires rapid processing of large amounts of information on site-specific, local levels. Forest growth models, mapping systems/geographic information systems (GIS), and similar tools are helpful; however, these tools need to be integrated. Proper integration requires methods that allow data to be converted to appropriate formats, analyzed thoroughly, synthesized, and communicated effectively. Such methods and tools need to be based on management and natural sciences. Furthermore, they must also be robust enough to be adjustable for local geographic and administrative variations (Oliver et al. 1992, 1993).

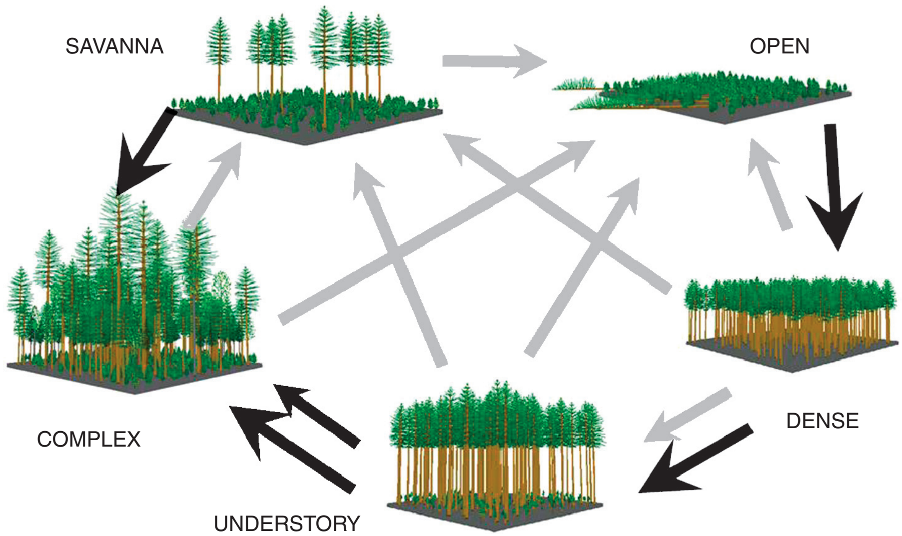


FIG. 13-1

Forests exist in many structures, such as the five-structure classification system shown here (Oliver and Larson 1996). The stands change constantly among structures through growth and disturbances. Each structure provides habitat for some species. *(Copyright, C. Oliver, Yale University, 2006).*

SCIENTIFIC BASIS

In this chapter, we first describe the scientific basis for managing wildlife and other values across forested landscapes. Then we describe the organization of the Landscape Management System (LMS) and how its modularity allows it to be improved and integrated with other systems. We address details of the LMS by describing the methods for applying sequential components followed by results of using those components. These details are described in two parts: the basic tool and how it can be used to make and implement effective decisions. Throughout the chapter, we try to emphasize wildlife habitat as part of a suite of values to be managed across a landscape.

Stand and Landscape Dynamics

The systems we describe herein are based on the natural science understanding that forests are dynamic and constantly changing (Botkin and Sobel 1975, Oliver 1981, Kimmins 1987). Some stand conditions, and their associated values to people, diminish, whereas others increase as stands change (Fig. 13-1). Management is the task of guiding stand changes in coordination with other stands to provide a targeted suite of benefits, the management objectives, across the landscape as a whole. A diversity of stand structures is needed to provide a mixture of noncommodity and commodity objectives (Oliver 1992, Boyce 1995). Using existing forest growth models, GIS, and forest inventories, managers try to predict these stand and landscape changes, and the resulting changes in values, both spatially and temporally; they then try to coordinate these changes using various natural and human activities to achieve the targeted objectives.

The dynamic nature of forests means a stand with a given species, or species mix, can be managed by different silvicultural pathways (Oliver and O'Hara 2004) and produce different consequences. A silvicultural pathway is herein defined as a unique change in the stand over time caused by a combination of growth and specific silvicultural operations at specific times. For example, the same stand would follow different silvicultural pathways if it was managed by the clearcut, shelterwood, or selection method. Different pathways would also result from timing of and selection of treatments (e.g., thinning, prescribed burning, planting to different species and/or densities). Subsequent operations, or lack thereof, will further define the silviculture pathway.

Wildlife, Structures and Functions, Other Values, and Trade-Offs

Managing landscapes can enhance their value to humans by providing appropriate habitats for desired wildlife species. This habitat management is an important determinant of wildlife presence and abundance in addition to hunter harvest of the target species, its prey, or its predators. Habitats often consist of specific stand structures, combinations of stand structures, or such structures within certain proximities to each other or to rock outcrops or to water or beyond certain distances from roads. Forest habitats are managed at two levels: "coarse level" and "fine level" (see Noon et al., this volume). At the coarse level, all habitats (all stand structures in the case of forests) are maintained across the landscape to ensure that most species can survive. For species of conservation concern, more targeted, fine-level management is done to ensure the individual species has the habitat features required (coarse and fine filters; Noon et al., this volume).

Complexity and Systems Theory

Systems approaches are being developed to address complexity in forest management and research by grouping similar entities and then addressing the behavior within a group and among interacting groups (Checkland 1999, Oliver and Twery 1999). Systems approaches integrate the holism and reductionism philosophical approaches and make use of quantitative methods developed in management sciences (Wilson 1887, Taylor 1911, Krick 1962, Cleland and King 1968, von Bertalanffy 1968, Dieter 1991). Grouping naturally leads to variation, which is recognized as inherent in systems. Variation is managed by using summary or (emergent) values of groups and by encouraging the user to develop a more complex "mental model" (i.e., conceptual model, accumulated knowledge) for the level of concern (Senge 1990)—a tree, stand, landscape, or region. We utilize systems theory and these simplistic summary values when developing computer models such as the LMS; however, we expect the user to form more complex mental models using these computer models as frameworks.

Hierarchies and Top-Down Planning

Grouping of stands can form a hierarchy. For example, individual plants and animals can form the base of a hierarchy that is grouped upward to stands, landscapes, watersheds, regions, and even higher (Litterer 1965, Bare 1996, Clegg et al. 1996, Oliver et al. 1999). Inherent variability can be compounded upward through each level of the hierarchy. The compounding error is overcome by managing in a way that avoids excessive centralized planning, especially at lower levels of the hierarchy. Emergent values are targeted at higher levels, but the details of management to accomplish them are left to the lowest possible level. Similarly, variability is addressed in science by avoiding theories (or models) that try to explain too many hierarchical levels in great detail at once (see Probst and Gustafson, this volume).

Decision Analysis

Multiple objectives often cannot be completely achieved when managing a forest landscape; therefore, trade-offs among different amounts of the different objectives that will be provided must be made. Two robust decision approaches have been developed to address trade-offs: the noniterative and iterative approaches (Morgan and Henrion 1990, Rauscher 1995, Oliver and Twery 1999). Noniterative approaches predetermine the relative trade-offs and commonly entail use of optimization programs. Iterative approaches present a variety of management alternatives and display them to enable the decision maker to view the trade-offs among objectives. The iterative approach, often in a matrix format, seems most appropriate for the complexities of modern forest ecosystem management (Krick 1962, Roberts 1979, Oliver and Lippke 1995, Oliver et al. 1997, Oliver and Twery 1999). We use the iterative approach in the "toggle" tool within the LMS Framework.

Overview of the Landscape Management System and Associated Tools

The overall management system consists of two sets of tools: the Landscape Management System containing the LMS tool and the Decision Analysis System

(DAS) Tools containing the "Scope & Group" and "Toggle" tools. All tools and tutorials can be downloaded from: <http//lms.cfr.washington.edu/>.

The LMS and DAS tools can be conceptually organized into seven components (Fig. 13-2). NED (Twery et al. 2005), SILVAH (Marquis and Ernst 1992), and other landscape models have similar organizations. Various efforts are underway to link and integrate these systems, as appropriate. LMS can be used independently of the DAS Tools to display and implement a developed forest management plan or to develop a simple plan. The DAS Tools can supplement LMS for developing complex plans of large areas and many objectives. Computer specifications of the tools are described in the following paragraphs.

Land Management System.—The Landscape Management System (McCarter et al. 1998) coordinates the activities of approximately 50 computer programs to facilitate the evaluation of alternative management approaches. The LMS software package uses a point-and-click graphical user interface (GUI) with drop-down menus to interact with information for a specific landscape. LMS 2.x works on computers running Microsoft Windows 98 (and newer). LMS 3.1

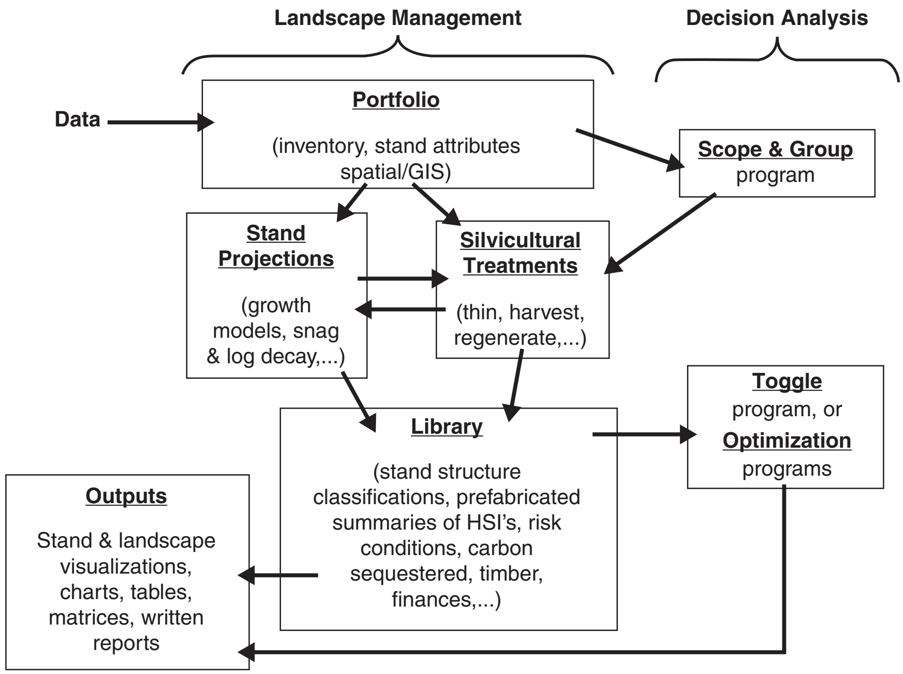


FIG. 13-2

Modular nature of the Landscape Management System, and similar models such as NED (Twery et al. 2005) and SILVAH (Marquis and Ernst 1992). *(Copyright, C. Oliver, Yale University, 2006).*

(released in November 2006) runs on Windows 2000 (and newer). Landscape Management System consists of the following components:

1. Portfolio: the stand, inventory, and spatial information needed to run LMS;
2. Stand Projection: the tree growth models and snag/down log decomposition models;
3. Silvicultural Treatments: the manipulations done to individual stands to simulate either silvicultural operations or natural perturbations and natural regeneration; and
4. Outputs and Library: the display of information through stand and landscape visualizations, graphs, tables, and spreadsheet templates. The visualizations, tables, and spreadsheet templates represent a collection of algorithms for determining structural stages, risk conditions, habitat, carbon, timber, finances, and other values.

Scope & Group.— Scope & Group is a Microsoft Excel® spreadsheet file (~6 MB) used to classify a landscape into groups of similar stands. The version available on the Web is calibrated to Pack Forest and is named "PackScope.xls."

Toggle.—Toggle is currently an Excel spreadsheet file (~10 MB), but is being converted to Visual Basic format to increase user-friendliness. This tool is used to allocate the landscape iteratively among different silvicultural pathways for each group of similar stands. It provides immediate feedback to the user on the consequences of management objectives of having certain stands follow certain pathways. The version available on the Web is calibrated to Pack Forest and is named "PackToggle.xls."

GEOGRAPHIC AREA OF STUDY AND APPLICATION

To date, we have converted the inventory information (and in some cases spatial information) of over 50 separate landscapes (~ 700,000 hectares) to LMS portfolios that they can be used with LMS. These landscapes are in the United States and Canada: Alaska, Arizona, British Columbia, California, Colorado, Connecticut, Florida, Michigan, Mississippi, Missouri, New Brunswick, New Hampshire, North Carolina, Ontario, Oregon, Utah, Washington, and West Virginia. In addition, LMS is being applied to landscapes in China and Ukraine.

We have applied and tested versions of the LMS tool for more than 10 years at the University of Washington, the Yale University School of Forestry and Environmental Studies, Pennsylvania State University, and elsewhere. Additionally, we have used LMS, Scope & Group, and Toggle tools and techniques in 10 mid-career professional development courses and three graduate-level courses using simulated management situations based on real landscapes and management plans. Finally, we have implemented pilot projects using these tools on landscapes in various locations throughout the United States and in other online and offline tests described throughout this chapter.

The most complete application to date was developed for Charles L. Pack Experimental Forest of the University of Washington, College of Forest Resources (1,740 hectares in the western Cascade Range, near Eatonville, Washington, USA). The Pack Forest Landscape Plan (<http://www.packforest.org/plan/>) was developed using LMS and customized versions of Scope & Group and Toggle spreadsheets.

LANDSCAPE MANAGEMENT SYSTEM: APPLICATION METHODS AND RESULTS

A portfolio in LMS consists of a group of stands that are combined into a larger planning unit or landscape. Any user can create a portfolio by using minimal inventory and stand attribute information about individual stands or polygons. Menus within LMS facilitate the performance of functions such as growth, stand treatments (thinning, planting, or mimicking natural disturbances such as mortality from a fire), and visualization of stands and landscapes. Finally, Microsoft Access® and/or Microsoft Excel® tables can be generated for further analyses outside LMS.

Creating an LMS Portfolio

Methods.— Three sources of data are used to create an LMS portfolio for a given landscape. If the data are in digital (computerized) format, application-specific programs can convert them for use within LMS. The sources of data are as follows:

1. *Stand attribute information:* Attributes for each stand such as stand area, site index, habitat type, latitude, slope, aspect, and elevation are inputs required by some growth models and are stored in the portfolio data set. These values are used to localize estimates from the growth models.

2. *Inventory information:* An inventory tree list is required, with species, diameter, heights (if available), and number of trees per record, summarized to the average acre. Missing tree heights are calculated by the embedded growth models and subsequently added to the inventory data set by LMS. If only stand average data are available, the user can expand these data to a tree list. When inventory information is missing from some stands, the user can extrapolate data from similar stands. For all cases, the user is responsible for limitations of the data.

3. *Spatial/GIS information:* Digital elevation models (DEMs) and stand boundary, road, and stream layers from GIS can be used by LMS if management criteria include spatially explicit objectives or if landscape visualization is desired. Currently, LMS supports and interfaces with ESRI software (ArcView and ArcGIS) and files.

Results to Date.— A common issue is the landowner's organization of data, a management concern not limited to forestry. The issue occurs when information about stand inventories, management practices, or treatments are diligently collected but not effectively organized and catalogued. Often a large amount of information is collected, but no easy method for using the information exists, allowing ineffective organization to go unnoticed. The Landscape Management System provides a centralized location for data. Common problems from underutilized data include multiple copies of the master file with conflicting information, mistyped data, and poor definitions of codes and fields. When constructing portfolios, LMS examines the stand and inventory information to find mistyped data and various data conflicts. The user must rectify poorly defined fields and codes prior to using LMS. Additional data organizational issues can be corrected while applying Continuous Quality Improvement (CQI) techniques at the end of the first iteration of the LMS management cycle. LMS does not solve all information management issues but can provide a beginning focus to improve the process.

Treating and Projecting Stands

Methods.— Each LMS portfolio is configured to use one growth model per portfolio. LMS supports the U.S. Forest Service's Forest Vegetation Simulator (FVS; Stage 1973) and Oregon State University's Organon (Hann et al. 1995) growth models. The Forest Vegetation Simulator (U.S. Forest Service 2007) offers variants for most forest types and regions in the United States and portions of Canada. Organon (Organon Growth and Yield Project 2007) provides three variants for use in the Pacific Northwest west of the Cascades. Both models can be used for projecting inventories of individual stands or entire landscapes to a user-specified year in multiples of the time step chosen (i.e., 5- or 10-year increments). Future projected inventories for each time step are stored within the LMS portfolio.

Any stand can be treated at any time step by manipulating the stand inventory. These treatments will be directly reflected in the inventory files; future projections will be adjusted accordingly. The treatment menu allows any specification of trees to be harvested and retained (thinned from above, below, proportional; by species or diameter; and to a specified number of trees, basal area, or stand density index). The user designates the expected regeneration, which will appear in the following time step. The regeneration editor allows the user to create, name, and save regeneration files within LMS for current and future use. Common treatments can also be named and stored in LMS for future use. Treatments to be done at different years to many stands in a landscape can be created as a "scenario" and stored for later use. Disturbances can be modeled using the treatment procedures to simulate the effects of disturbances on stands.

All inventory information, including harvested tree information, is stored within the LMS portfolio for each stand and time step. These changes over time form a silvicultural pathway for the stand (Fig. 13-3). Trees that the growth

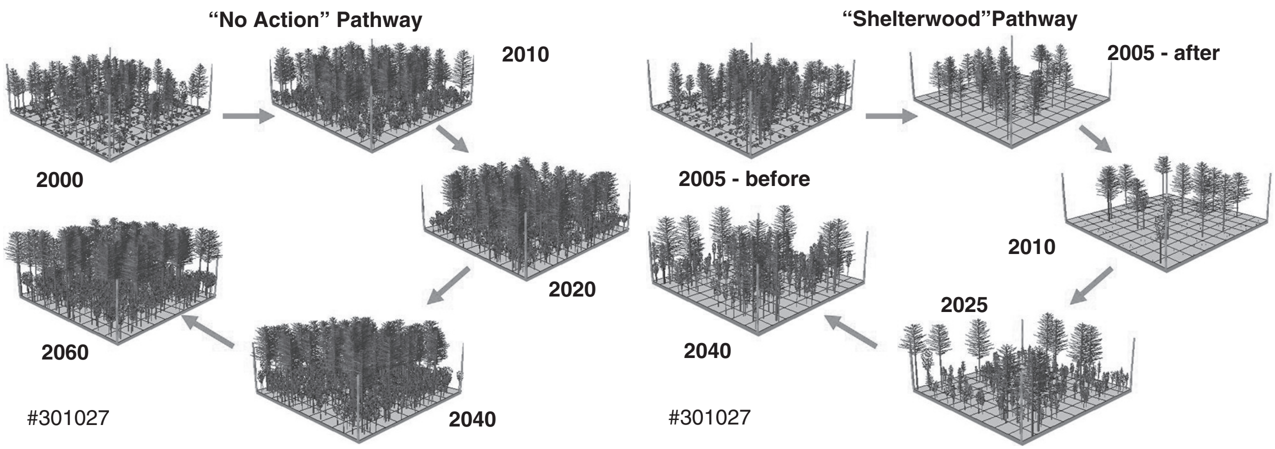


FIG. 13-3

Silvicultural pathways, such as the two shown here for Pacific Northwest mixed conifer forests in the USA, consist of intended changes in a stand with time as a result of growth and silvicultural operations. They can be planned, projected, attributes assessed, and reported (Fig. 13-4), and visualized, as shown here. *(Copyright, C. Oliver, Yale University, 2006).*

model predicts to die, as well as trees intentionally treated to create snags and other coarse woody material, are tracked separately.

Results to Date.— Projections of standing volume for long intervals (e.g., 50 years) using different growth projections inside LMS reveal differences that are inherent in the growth models. For example, systematic differences in projected volumes are observed when the same portfolio is projected using FVS (PN variant) and Organon because of differences in the growth models resulting from differences in the modeling databases used to develop each growth model. Although important, local managers can generally interpret the variations in growth model outputs while the models are being improved, once they are aware of the different models' tendencies.

Outputs and Library: Analyzing and Displaying Objectives

Methods.—The Land Management System provides three types of output:

1. *Inventory Information:* Inventory data can be exported to Excel® spreadsheet, database, or ASCII formats from LMS. In these familiar formats, the data can be manipulated to calculate measurable criteria for management objectives. The results of these queries can then be displayed as tables, graphs, and charts.

2. *Summarized Information:* LMS provides a variety of prefabricated tables that present summarized information to address specific management issues. Some of these tables calculate common forest information summaries, such as canopy layers and species and diameter distributions (Baker and Wilson 2000). Other tables calculate less traditional summaries such as stand structural stages (Oliver and Larson 1996) and habitat suitability for a specific species (Marzluff et al. 2002). These tables' algorithms are typically written in the Python programming language; additional tables can be inserted by a user knowledgeable in Python. The tables can be exported to spreadsheet and database formats. These data can then be pasted into user-defined templates that show outputs over time in graph and/or chart form.

3. *Visualizations:* Visualizations can be made for any year, any stand, and from any viewpoint for both stands and entire landscapes using the included U.S. Forest Service Stand Visualization System (SVS; McGaughey 1997) and EnVision (McGaughey 2000) programs. Stand-level visualizations utilize the LMS tree lists and are displayed on a unit area basis. Landscape visualization uses the LMS tree list and such GIS information as stand boundaries and digital elevation models (DEMs). Realism of the visualization can be adjusted from stick figure trees to photorealistic images (Wilson and McGaughey 2000).

We have developed local interpretations and measurable values for most "Criteria for Sustainable Forestry" of the Montreal Process (Forestry Commission 1998). These are displayed within many LMS tables. These criteria are as follows:

1. *Criterion # 1: Biological Diversity:* Several considerations relative to biological diversity entail analysis of both "coarse filter" and "fine filter" biodiversity. Measures of coarse filter biodiversity (Hunter 1990) on the landscape can be calculated by using any of the seven stand structure classification systems within LMS (O'Hara et al. 1996, Oliver and Larson 1996, Carey et al. 1999, Johnson and O'Neil 2001). Most of these classification systems use mutually exclusive categories that include "sharp boundaries." Each uses a hierarchical classification system to assign each stand to a specific stand structure at each time step. The hierarchy means that all stands are analyzed for their "fit" into the criteria of the different structures sequentially; a "default" structure accepts stands that do not fit any of the other classes. Usually, the "open" structure is the default. Fine filter biodiversity measures can be calculated as the amount of a specific structure in the landscape or species-specific Habitat Suitability Indexes (HSIs). Some habitat suitability indices have been incorporated into LMS and others can be added (Ceder and Comnick 2001, Raedeke 2001, Marzluff et al. 2002). Another technique being developed for calculating carrying capacity for species in mixed forest/grassland areas is to integrate rangeland analyses of animal unit months (AUMs) from forage conditions with assessments of hiding and thermal cover (Han 2006). By transferring data between GIS and LMS, the user can assign spatial attributes to the different stands and lengths of contiguous boundaries between stands. These additional data enable calculations of animal habitats that require different stand structures to be within a certain proximity or that require an edge between two specific structures. Finally, changes in the total area and the conditions (structure, density, species composition, and others) of stands held in reserve can be monitored over time.

2. *Criterion # 2: Productive Capacity:* Tree volume growth, harvest, and standing volume can be calculated and displayed over time to evaluate the sustainability of timber harvest. Volumes by tree sizes, species, and log grades can be calculated for any stands or the landscape and for each time period of the simulation by using locally adaptable log sort tables within LMS.

3. *Criterion # 3: Forest Health:* The user can calculate wind, fire, and insect susceptibility using LMS and/or interfacing LMS with GIS information (Wilson and Baker 1998, Wilson et al. 1998, Wilson and Oliver 2000).

4. *Criterion # 4: Soil and Water Protection:* Soil protection measures have been developed as a combination of the silvicultural operations (e.g., for soil compaction), the type of soil and slope, and the time between

operations. Water protection measures have been developed as analyses of riparian zones (e.g., direct sunlight, coarse woody debris, and particulate organic matter reaching streams).

5. *Criterion # 5: Global Carbon Sequestration:* Carbon sequestration in the standing forest, in nondecomposed wood products, and in unburned fossil fuel when forest products replace more fossil fuel-consuming substitutes (e.g., steel, concrete) have been developed after Lippke et al. (2004) and are available as summarized tables and charts in LMS.

6. *Criterion # 6: Socio-Economic Benefits:* Economic benefits can be analyzed from a Financial Analysis module within LMS. This module allows the user to define costs and prices, and it displays the costs, returns, and cash flow for stands or the landscape for any or all time steps. Discounted cash flow and internal rate of return can be analyzed by exporting the tables to spreadsheets. Social benefit measures relate employment to various silvicultural activities and to the amount and quality of outputs (Oliver and Lippke 1995).

7. *Criterion # 7: Legal, Institutional, Economic Framework:* The Landscape Management System and Decision Analysis System methods and tools can be used to analyze legal, institutional, research, and economic policy alternatives.

Results to Date.— We describe examples of specific interpretations and measurements for different landscapes in <http://lms.cfr.washington.edu/> under "Case Studies." Specific concerns regarding wildlife habitats are as follows:

1. The algorithms currently used to calculate stand structures (e.g., for use in "coarse filter" biodiversity analyses) create an artifact of sharp boundaries between structures within a classification because of the binary nature of the current classification systems. Consequently, if a stand does not meet all minimum criteria for a certain structure, it is completely excluded from being considered to have that structure. Alternative classification systems are being investigated that allow more "fuzzy" boundaries.

2. We have compared habitat suitability indices within LMS with other methods of analysis by Marzluff et al. (2002) and found them to be consistent.

   Specific analyses of other outputs from LMS to date suggest the following results as well:

3. Currently, LMS can merchandize logs by sizes into grades using a simple bucking algorithm. The bucking algorithm is being enhanced to allow better handling of additional species, especially hardwoods, and more flexibility in log lengths, merchandizing options, and output volumes.

4. Projections of stand structures appear relatively insensitive to growth models.

5. Projections of height/diameter (Ht/DBH) ratios of the tallest 247 trees per hectare using different growth models indicate that measures of wind susceptibility are highly sensitive to the growth model used (Wilson and Oliver 2000).

6. Carbon sequestration has been calibrated for the Pacific northwestern and southeastern United States coniferous forests (Lippke et al. 2004); however, they are less reliable in other forest types, especially hardwood forests.

We suggest three ways to address the issues described here. First, local managers can adjust these output variances within their "mental model" of the expected behavior of the forest. For example, they would know that a low height/diameter ratio projected using the FVS (PN variant) model does not necessarily indicate low wind risk, nor does a high height/diameter ratio projected in the Organon (SWO variant) model necessarily indicate high wind risk. Second, over time the user can calibrate these regional growth models to simulate local conditions better. Last, it is understood that over time the specific growth models will improve. The integrative LMS tool now allows growth models to be used in ways for which they were not originally developed. Already, developers of growth models are improving the predictive capabilities of current and new growth models.

Applying LMS to Management

Methods.— The Land Management System can be used to evaluate an existing management plan, or it can be used to develop a new management plan. If applied to an existing plan, LMS can display the planned treatments and expected results in a variety of tabular, graphical, and visual ways, and on both temporal and spatial scales. The Decision Analysis System in conjunction with LMS can also help develop complex plans for large landscapes, as described later in this chapter.

The management plan can be divided into two time frames: the "planning horizon" and the "management cycle." The planning horizon is the total time for which management treatments and expected results are projected, commonly 50, 80, or 100 years. While accuracy is likely to diminish with longer growth periods, the projection is useful for several reasons: (1) to ensure the temporal sustainability of the different values; (2) to compare long-term differences and trade-offs in alternative management approaches; (3) to estimate future trends in operations, equipment, and labor needs for strategic planning and policy development; and (4) to estimate future trends in availability of commodity and noncommodity products (e.g., habitats for certain species, products of certain dimensions).

The management cycle is the first projection period of the growth model used within LMS (user-defined, but usually 5 or 10 years). The chosen management plan results from specific treatments having been assigned to each stand in

LMS. The user projects all treatments in LMS as if they were implemented at the beginning of each growth cycle.

During implementation, the treatments are done opportunistically within the management cycle, allowing the local manager to respond to variations in markets, weather, and other operational opportunities/constraints. Allowing this variation is consistent with the systems approach of addressing variation within a system by not externally specifying inputs/outputs too precisely (e.g., through central planning).

The user is expected to correct deviations caused by variations in treatment times by updating the plan at the end of each 5- or 10-year management cycle. At this update, the manager can revisit and refine any objectives. The objectives are revisited and the analytical techniques can be refined using the Continuous Quality Improvement process or similar processes (Deming 1982, Ishikawa 1982, Feigenbaum 1983, Juran and Gryna 1988, Dieter 1991).

For the management cycle, the user can generate a treatment-outcome list from LMS tables showing each stand name, treatment (if any), and expected outcome for a variety of objectives (Fig. 13-4). The manager can use this list as a business portfolio (Oliver 1994, Wilson and Baker 2001). Knowing the intended inputs and outputs for the current management cycle, the manager can "bundle" high- and low-value products to ensure they are sold, sell marginal products (e.g., floral greens) by being specific about where they are to be found, sell wildlife access by demonstrating the number and location of target species, sell products at optimum market or labor cycles, and otherwise balance the "cash flow" for the different treatments.

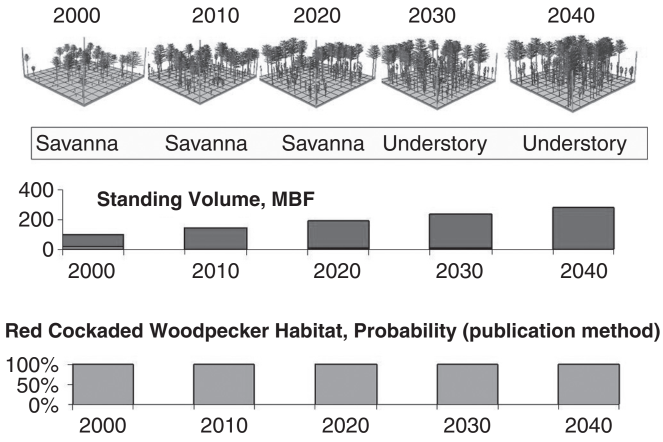


FIG. 13-4

Many attributes for a given stand at each time period can be assessed and displayed in different ways, as shown here for longleaf pine stands in Florida, USA. *(Copyright, C. Oliver, Yale University, 2006).*

People want assurances that the forests will actually provide the values as stated in the management plans. The Land Management System can help provide that assurance. Using stand and landscape visualizations and GIS, it can identify and display how any stand or landscape will be treated, and where expected conditions (e.g., stand structures or habitats for specific animals) will be found at each future time (Figs. 13-4 and 13-5).

Results to Date.— One test plan at Pack Forest has been carried through the step of developing treatment-outcome lists for the management cycle and each subsequent cycle in the planning horizon. The treatment list for the current management cycle is proving helpful in the test by giving managers the information as a "portfolio," with the certainty and flexibility helpful in a business environment. The treatment-outcome lists for subsequent cycles enable the managers to begin activities (e.g., order seedlings, upgrade roads) needed for operations to be implemented in the more distant future. The LMS treatment lists and visualizations are proving helpful for communicating with the public, other managers, loggers, and silviculture contractors. Wilson and McGaughey

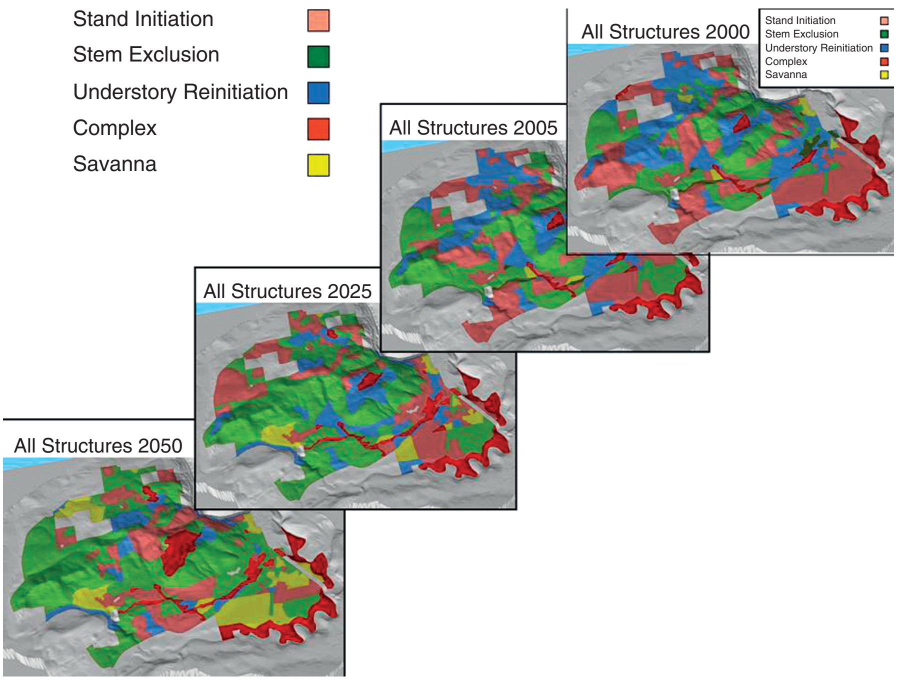


FIG. 13-5

The anticipated results of different attributes can be visually displayed across the landscape over time, as shown here for stand structures (Fig. 13-1) in the Pacific Northwest Pack Forest Plan, USA. *(Copyright, C. Oliver, Yale University, 2006).*

(2000) evaluated the use of photorealistic visualizations and the potential for misleading the intended audience. No management plan using LMS has yet completed its first management cycle; therefore, the monitoring and CQI system using LMS has not been fully tested online. Offline testing of simulated plans on real landscapes in mid-career short courses suggests the techniques described previously will be effective.

DECISION ANALYSIS SYSTEM: APPLICATION METHODS AND RESULTS

Forest planning over large spatial scales (10,000 to 100,000 acres), long time periods (50–100 years), and for multiple objectives is a complex problem. As the number of stands in a landscape increases, the ability of the manager to analyze and understand the trade-offs among many alternatives becomes limited. A number of analytical approaches have been developed to address this problem. Each approach requires simplification of real-world complexity but emphasizes different forest dynamics (e.g., spatial patterns, stand growth, and response to treatments).

Comparing different approaches is facilitated by identifying the most common simplifications used in forest modeling. Many models retain the spatial complexity of the landscape but simplify the data used to describe each stand and the response of stands to treatment and growth. Simplification is accomplished by reducing the number of unique forest types used to represent the forest, the sophistication of the within-stand growth projections, or the detail of the stand data. Alternatively, models can retain the stand data at the expense of spatial complexity.

The LMS is designed to use the most detailed forest inventory data available, to link to growth models, and to function with a built-in library of outputs. It is very well suited to analyzing both forest growth and responses to various treatments. A Decision Analysis System (DAS) was developed to aid in the most common analysis tasks needed for developing and presenting landscape alternatives and their consequences. It does not choose or recommend any alternative. After describing the DAS, we will contrast it with two other models: LANDIS (He, this volume) and Woodstock.

Systems approaches reduce complexity by grouping, or stratifying, many entities into a manageable number of groups. The utility of the system is based on how well the groups are formed, with a desire for much lower variation within groups than between groups. The systems approach can be applied to planning large landscapes by grouping similar stands managing within and among groups. We have developed the "Scope & Group" program to facilitate effective grouping and the "Toggle" program to examine the effects of alternative management actions within and among groups.

Grouping Stands and Developing Alternative Silvicultural Pathways

Methods.— The Scope & Group program facilitates the process of grouping stands and selecting a representative stand for each group. When select tables generated in LMS are imported into the Scope & Group program, multiple graphs and charts are immediately generated that show the landscape's area distribution by combinations of dominant species, age classes, site indexes, slopes, and aspects. The user then stratifies the landscape into ecologically similar groups of stands based on this information, and the stands within each group are listed. The user can then choose a stand to represent each group based on the key variables (e.g., site index, slope, aspect, average DBH, trees per acre, and density measures) and local knowledge of the area.

The user then develops several silvicultural pathways for each group and applies them to the representative stand using LMS. Fifteen independent pathways have commonly been used for each group; however, more or fewer can be applied at the user's discretion. One pathway is usually a no-action pathway, reflecting the stand's development and values provided in the absence of all natural and anthropogenic disturbances.

Using LMS, the user can create a separate portfolio for the representative stand for each group by using the *subset* command under the *tools* drop-down menu. This stand is copied and renamed to create numerous "stands" of identical initial characteristics. A different pathway is applied to each initially identical stand within a group's portfolio and projected for the planning horizon. The results are displayed in output tables showing how the different objectives would change over time under each silvicultural pathway.

Results to Date.— We have applied the techniques and program described in the preceding paragraph to six landscapes in eastern and western Washington and Oregon. For all landscapes, we readily transferred the information from LMS to the Scope & Group program and displayed the information graphically. We then divided each landscape into six or more groups based on combinations of the following criteria chosen by the users: age, species composition, site index, slope, aspect, and/or elevation.

We also developed silvicultural pathways for each group in each of these six landscapes. Experience to date suggests that the results are effective, but that considerable silvicultural expertise is necessary to develop realistic silvicultural pathways.

Developing Alternative Landscape Plans

Methods.— Two methods can be used to develop a landscape plan that optimizes trade-offs among values. One method is to use an optimization program, such as LINDO (LINDO Systems Inc., Chicago, Illinois, USA). Another method is to use an iterative approach guided by the user. Both methods entail similar processing of data by grouping and developing silvicultural alternatives for each group.

A program named Toggle was developed with LMS to facilitate the iterative approach. The user transfers output tables of the alternative pathways for each group into the Toggle program. This program allows the user to view the effects on all objectives when specified proportions of each group's area are allocated to different pathways (Fig. 13-6). Inside the Toggle program, the user can change the proportion of a group allocated to each pathway rapidly. The outputs for a pathway are weighted by the proportion of the group area allocated and the total area in that group. The area-weighted outputs for all pathways across all groups are automatically summed. The Toggle program displays the summary outputs for the entire landscape in a series of charts showing the changing values over time. The user can develop different landscape alternatives by changing the proportions of any pathways in any group and can immediately understand the effects on the multiple objectives by viewing the changing graphs. The different landscape alternatives can be saved for later use.

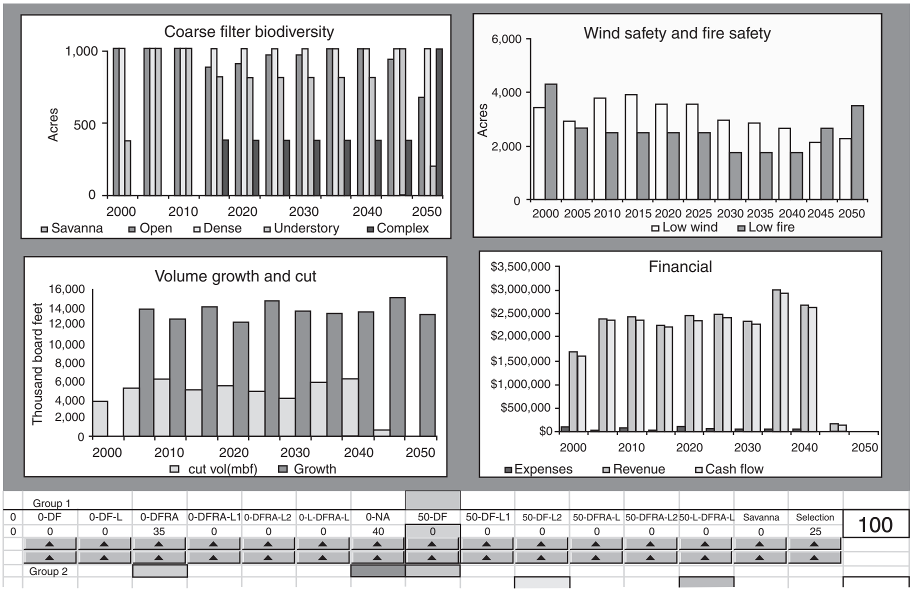


FIG. 13-6

The flow over time of many attributes can be viewed in the Toggle program. By pressing the "spinner" buttons at the bottom, the user changes the proportion of each group of stands that follows each silvicultural pathway. The values of all graphs change instantaneously, so the user can develop a management alternative consisting of a series of silvicultural pathways that provide a given trade-off of many values over time. *(Copyright, C. Oliver, Yale University, 2006).*

The Toggle program also develops a summary value for each management objective, a single number for each objective generalizing how well that objective is achieved over time. The summary value number for each objective also changes as the proportions treated by the different pathways change, showing the summary effects of changing management alternatives. Decision makers first gain an overview of the effects of different management alternatives through summary values. Then the decision maker examines promising alternatives in more depth by viewing the charts underlying the summary values. The user can store potentially interesting summary values, as well as the pathway proportions that generated them, in a matrix of objectives and alternatives (Fig. 13-7) inside the Toggle program.

The Toggle program facilitates manual (but rapid) completion of common steps required to develop multiple (nonspatial) landscape alternatives. While these steps can be accomplished with optimization tools, the iterative process is an important element of the analysis, helping the user develop a mental model of the full effects of the alternatives.

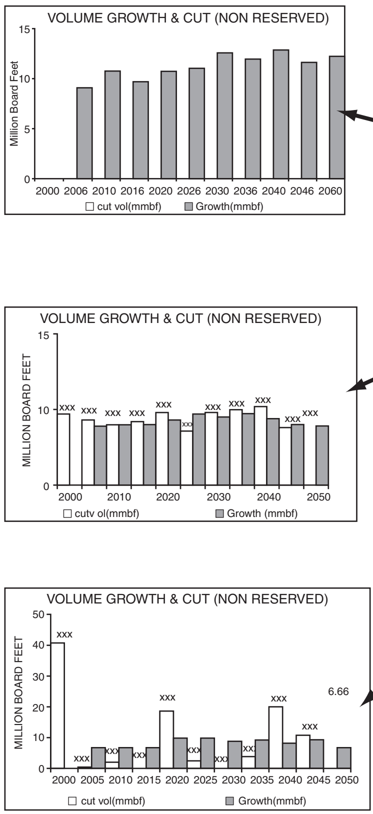
Results to Date.— In its present form, we have applied the Toggle program to six landscapes of 1,000 to 40,000 acres in western and eastern Washington and Oregon. Up to 13 graphs projected one or more objectives over time, and 18 summary values have been displayed dynamically in the Toggle program.

In two cases, Pack Forest (McKinley 2002), and Satsop Forest (Ceder 2001), the Toggle program was calibrated with groups, silviculture pathways, and objectives for the targeted forest landscape, and the calibrated program was given to representative stakeholders. These stakeholders aided in developing management alternatives. A general consensus was that the Toggle was a useful method for displaying trade-offs among objectives and for generating alternative management scenarios.

Generating Stand-Specific Prescriptions from the Groups

Methods.— After the designated decision maker chooses an alternative from the matrix described previously, local managers use their understanding of variations among stands within groups to assign specific pathways to specific stands. When managers are allocating stands to pathways, the objective is to have the same proportion of the group's area in each pathway as was assigned by the chosen alternative inside the Toggle program. Local managers can use local knowledge, matrixes generated in spreadsheets, maps, road layout and harvest scheduling programs, and GIS tools to assist in these assignments. Those stands to be treated will then receive considerable measurement attention. At the same time, the managers may be less concerned with the measurement precision of stands that will not be targeted for treatment for several decades. Consequently, an intensive inventory may not be needed on those stands to be treated much later.

Harvest



ALTERNATIVES

	A	B	C	D	E	F	G	H	I
BIODIVERSITY									
COARSE FILTER (Oluer SC structures)	6	7	7	8	7	7	5	5	6
COARSE FILTER (HCSSPT Structures)	4	5	5	6	4	6	5	6	5
LATE SUCCESSIONAL STRUCTURES	10	7	7	5	10	4	2	3	3
OLD GROWTH STRUCTURES	9	9	9	9	9	5	2	5	9
PRODUCTIVE CAPACITY									
TOTAL GROWTH	10	9	9	7	10	5	7	7	7
TOTAL HARVEST	0	10	10	7	1	7	7	7	7
FINAL/INITIAL STANDING VOLUME	0	6	7	10	1	9	8	8	7
SUSTAINED STANDING QUALITY	4	4	5	5	4	5	5	5	5
SUSTAINED HARVESTED QUALITY	0	5	4	2	0	2	2	1	1
FOREST HEALTH, SOIL, & WATER									
WIND SAFETY	4	4	4	4	4	4	4	5	4
FIRE SAFETY	10	10	10	10	10	10	10	10	10
FINANCIAL									
MINIMUM INCOME STREAM	0	0	0	0	0	10	0	10	10
TOTAL NET CASH FLOW	0	8	10	6	0	6	7	5	7
NET PRESENT VALUE RANK	0	3	5	6	0	6	10	7	7
SOCIAL BENEFITS									
TOTAL EMPLOYMENT	0	10	10	6	1	7	7	5	7

Biodiversity

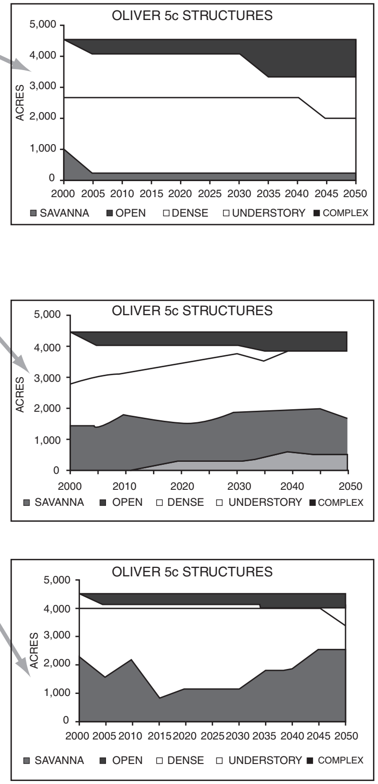


FIG. 13-7

The flow of each attribute following each management alternative can be converted to a number in the Toggle program and put into a matrix, allowing the decision maker to view a summary of the effects of a variety of management alternatives on a suite of management objectives. *(Copyright, C. Oliver, Yale University, 2006).*

Results to Date.— McKinley (2002) chose a management alternative for Pack Forest using the Toggle program and assigned stands to specific pathways using the local managers' knowledge aided by a matrix of all stands in each group and the targeted percentages of area to be treated by each pathway for the group. He ran a scenario containing the targeted prescription for each stand in LMS for the planning horizon and then compared the resulting flows of objectives over time with the chosen alternative from the Toggle program. He further modified stand assignments and again projected the alternative with LMS. After two iterations of such modifications and reprojections, the flow of objectives over time was very similar to those of the chosen alternative.

COMPARISON OF LMS WITH OTHER FOREST PLANNING MODELS

Comparing LMS with other forest models allows relative strengths and weaknesses to be identified; though one model may be more appropriate for a particular task, ultimately they are complementary, and will be discussed in that context.

LMS and LANDIS

LANDIS is a landscape disturbance and succession model that emphasizes spatial processes and patterns at broad spatial scales (Scheller et al. 2007; He, this volume). Landscapes are represented as a grid of interacting cells, with vegetation described by attributes of age-defined cohorts (longevity, shade tolerance, disturbance tolerance). LANDIS is designed as an extensible simulation environment that allows scientists to develop new forest models (i.e., new ecoregions or new disturbance modules) within the established model structure.

LANDIS simulates over larger areas and longer time periods than LMS, with a focus on spatial processes. Compared to LMS, LANDIS may help the manager understand the interaction between landscape management alternatives and disturbance agents such as fire or wind. Translating desired landscape patterns from LANDIS to silvicultural prescriptions for specific stands is better suited to LMS. The relationship between the models could also work in reverse, with the robustness of landscape alternatives developed in LMS tested against disturbance agents in LANDIS.

An important distinction should be made between the LMS and LANDIS modeling environments and potential analysts. LANDIS models are developed using a programming language, requiring higher technical skills by the analyst. LMS utilizes a graphical user interface to facilitate analysis by a wider range of individuals, including field personnel. While all analysts must understand the assumptions and limitations of a model (enforced by LANDIS), local knowledge and practical management expertise can be important elements of the analysis.

LMS and Spatial Woodstock

Spatial Woodstock (Remsoft Inc., Fredericton, New Brunswick, Canada) is a spatial harvest scheduling system with a spatial (~100,000 acres) and temporal (~100 years) planning scale similar to LMS. The model uses a hierarchical approach to forest planning, first producing long-term nonspatial landscape alternatives and then suggesting short-term spatial solutions (Walters et al. 1999). Spatial Woodstock is commonly used in places in the United States and Canada where a primary objective is timber production.

Like LANDIS, Woodstock requires a relatively sophisticated analyst to develop a forest model within a programming environment. Woodstock can directly access growth models such as those used in LMS but also commonly uses preprocessed stand growth and treatment simulations for a limited number of forest types. The LMS could be useful for stratifying the forest and simulating growth as an input to Woodstock. Though Woodstock can be run as a simulator, forest management alternatives are often developed through optimization. Optimization is a more efficient and powerful technique than the iterative approach suggested with the LMS Decision Analysis System but may be less informative for analysts and transparent for other interested parties. Hall (2001) compared the results of an optimization program (LINDO) and Toggle and noted that the optimization program appears slightly more accurate but less easy to use and less informative to the user.

Differences between LMS and Woodstock may correspond to the flow of information within an organization. Forest management plans would generally be developed in Woodstock at a central office (such as a corporate office). These plans could be resimulated in LMS for viewing by personnel in field offices. Local managers can then account for inherent system variation with their "mental models." For example, local foresters and wildlife biologists often need to refine generalized treatments from broader plans. For wildlife management, snag creation or minor vegetation conditions may influence silvicultural prescriptions, which could not be previously accounted for (especially if snag, log, and minor vegetation data are limited). Refined analysis with LMS that is augmented with local knowledge can then inform future modeling efforts in Woodstock.

DISCUSSION

The LMS and companion Decision Analysis Tools (Scope & Group and Toggle) allow wildlife habitats and other management objectives to be managed across forested landscapes of different sizes. Recognition of the strengths and weaknesses of LMS is important to use the technology appropriately and effectively.

The strengths of LMS include that it (1) incorporates modern concepts of decision analysis, systems approaches, forest dynamics, and wildlife habitat identification; (2) enables the user to perform detailed analyses with a user-friendly, point-and-click interface; (3) provides the user with multiple options for user-friendly display; (4) allows the user to adjust the input data in many ways; (5) can be applied to landscapes in many places by using relatively standard data; and (6) is available on IBM-compatible PCs.

On the other hand, there remain a number of challenges and weaknesses, which include (1) the classification algorithms classify stands into stand structures ("coarse filter" biodiversity) that have "sharp boundaries" and give no credit for being close to a desired structural classification; (2) LMS does not account well for within-stand heterogeneity or for edge effects on stand growth and therefore does not represent some of the existing variation in our landscapes; and (3) LMS visualizations and charts may give the novice user a greater sense of accuracy with the projections than is warranted.

The LMS is more useful in projecting trends than in providing exact values of wildlife habitat, timber volume, carbon sequestration, fire and insect risks, and other values. The inaccuracies involved with data collection and growth model projection reduce its effectiveness in predicting exact outcomes. On the other hand, the systematically repeated nature of the precise measurements and projections means that the errors will be systematic in nature and therefore makes the system suitable for investigating and identifying trends.

This system does not simulate stochastic stand changes because it does not simulate disturbances such as windstorms or insect outbreaks. It can, however, provide estimates of the relative susceptibility of each stand to disturbances during each time step. LMS can be used to estimate risk. Then the users can determine the level of susceptibility of disturbance they are comfortable with when managing a specific landscape. The users can simulate any disturbance with the treatment tools and project the consequences of specific events.

We anticipate both incremental and large changes in the LMS. Incrementally, we expect continuous improvement of the system as problems are identified and corrected. We also anticipate improvements to the Toggle system. We plan to develop stand structure classification algorithms that address the problem with sharp boundaries between classes. We also expect to include more prefabricated summaries of objectives (e.g., inclusion of habitat suitability indices for more species).

The LMS was designed with a modular architecture so that its components can be improved, replaced, and/or integrated with similar systems (e.g., NED and SILVAH). Improved integration with existing GIS systems is also planned. We are receiving strong interest to apply LMS to different parts of the world and to include more growth models. For this, we need to develop a stronger methodology for improving projections, perhaps through the Continuous Quality Improvement process.

Our method of inventory may change as spectral imagery and Light Detection and Ranging (LiDAR) systems become more common and further development of feature extraction occurs. In the future, it may be possible to take a "census" of all upper stratum trees in a forest, rather than the current field-based sampling methodology. This census will lead to changes in growth models, visualizations systems, and many other functions within the LMS.

CONCLUSIONS

The LMS, and similar tools, can revolutionize management from the policy to the application levels. At the policy level, an easily understood demonstration that the forest changes without human actions can avoid a presumption of stability in natural systems and a realization that wildlife habitats and risks of fire and insect damage change with time. The tools can also make managers' actions transparent, since they can demonstrate what they expect of the forest before any manipulations for management. If the forest does not appear as projected, the managers can be held accountable.

Environmental services such as carbon sequestration, wildlife habitat, fire protection, and forest cover can be more easily marketed because the buyer can know the amounts, times, and places where the services are provided. The tools allow the data to be understood and analyzed in different degrees of analytical depth, from simple visualizations to in-depth analysis of the variations within and between stands. The tools enable Continuous Quality Improvement techniques to be applied, since the projections can be compared with future monitoring and the differences corrected iteratively in projections.

A major constraint of the tools is their potential inaccuracy. This inaccuracy is caused by inaccuracies in the collection of data and can be compounded by inaccuracies in growth projections and prefabricated classifications such as habitat suitability indices. On the other hand, the precision and consistency of treatment of the data allow trends to be projected quite well. Such trends include directions of change of habitats for various wildlife species, of fire or insect risk, of standing timber volume, of carbon sequestration, and others.

SUMMARY

The Landscape Management System includes a suite of tools (current forest inventory, growth models, treatment and disturbance simulation, habitat suitability indices, hazard risk measures, carbon sequestration and economic analyses, and visualization tools) for assessing changes in tree inventory information in stands across landscapes over time. It automates many of the routine steps necessary for simulating many stands over several decades. It does not offer prescriptions for predefined goals, nor does it automatically include stochastic events such as fire or windstorms; instead, it provides estimates of susceptibility to these events. The projected tree inventory information is converted to habitat, hazard, carbon, financial, timber, and other measures. It can then be analyzed and visualized to determine current and future stand and landscape conditions. Because the users define their own objectives, they can evaluate the landscape for timber, habitat, conservation, scenic, and other objectives.

ACKNOWLEDGMENTS

Development of LMS system has been partially supported by the U.S. Forest Service.

LITERATURE CITED

Baker, P. J., and J. S. Wilson. 2000. A quantitative technique for the identification of canopy stratification in tropical and temperate forests. *Forest Ecology and Management* 127:77–86.

Bare, B. B. 1996. Hierarchical forest planning: Some general observations. Proceedings of a workshop on hierarchical approaches to forest management in public and private organizations. Pages 164–165 *in* Information Report PI-X-124, Petawawa National Forestry Institute, Canadian Forestry Service. University of Toronto, May 25–29, 1992.

Botkin, D. B., and M. T. Sobel. 1975. Stability in time-varying ecosystems. *The American Naturalist* 109:625–646.

Boyce, S. G. 1995. *Landscape forestry*. John Wiley and Sons, New York, New York, USA.

Carey, A. B., B. R. Lippke, and J. Sessions. 1999. Intentional systems management: Managing forests for biodiversity. *Journal of Sustainable Forestry* 9:83–125.

Ceder, K. R. 2001. *Using silviculture to sustain wildlife habitat: Assessing changes and trade-offs in forest habitats using a habitat evaluation procedure within the landscape management system*. Thesis, University of Washington, Seattle, USA.

Ceder, K. R., and J. M. Comnick. 2001. Potential Roosevelt elk populations on the Sol Duc Adaptive Management Area under various management prescriptions: Simulation and analysis. *In* M. E. Ferry, T. S. Peterson, and J. C. Calhoun, technical editors. *Status of elk populations on the Olympic Peninsula. Olympic Natural Resources Center Conference Proceedings.* University of Washington, Olympic Natural Resources Center, Forks, Washington, USA.

Checkland, P. 1999. *Systems thinking, systems practice*. John Wiley and Sons, New York, New York, USA.

Clegg, S. R., C. Hardy, and W. R. Nord, editors. 1996. *Handbook of organization studies.* Sage Publications, London, United Kingdom.

Cleland, D. I., and W. R. King. 1968. *Systems analysis and project management*. McGraw-Hill, New York, New York, USA.

Deming, W. E. 1982. *Out of the crisis*. Massachusetts Institute of Technology, Center for Advanced Engineering Study, Cambridge, Massachusetts, USA.

Dieter, G. E. 1991. *Engineering design*. Second edition. McGraw-Hill, New York, New York, USA.

Feigenbaum, A. V. 1983. *Total quality control*. Third edition. McGraw-Hill, New York, New York, USA.

Forestry Commission. 1998. *The UK Forestry Standard: The government's approach to sustainable forestry.* Forestry Commission, Edinburgh, United Kingdom.

Hall, J. S. 2001. *Forest management planning: A comparison between linear programming and new tools in the landscape management system*. Thesis, University of Washington, Seattle, USA.

Han, X. 2006. *Assessing the Amur tigers' current habitat and evaluating the habitat fluctuations within the dynamic forests in Northeast China and the Russian Far East*. Ph.D. Prospectus. Yale University School of Forestry and Environmental Studies, New Haven, Connecticut, USA.

Hann, D. W., A. S. Hester, and C. L. Olsen. 1995. *Organon user's manual: Edition 5.0*. Department of Forest Resources, Oregon State University, Corvallis, USA.

Hunter, M. L., Jr. 1990. *Wildlife, forests, and forestry.* Prentice Hall, Englewood Cliffs, New Jersey, USA.

Ishikawa, K. 1982. *Guide to quality control*. Asian Productivity Organization. Quality Resources. White Plains, New York, USA.

Johnson, D. H., and T. A. O'Neil. 2001. *Wildlife habitat relations in Oregon and Washington*. Oregon State University Press, Corvallis, USA.

Juran, J. M., and F. M. Gryna, editors. 1988. *Juran's quality control handbook*. Fourth edition. McGraw-Hill, New York, New York, USA.

Kimmins, J. P. 1987. *Forest ecology.* Macmillan Publishing, New York, New York, USA.

Krick, E. V. 1962. *Methods engineering: Design and measurement of work methods*. John Wiley and Sons, New York, New York, USA.

Lippke, B., J. Wilson, J. Perez-Garcia, J. Bowyer, and J. Meil. 2004. CORRIM: Life-cycle environmental performance of renewable building materials. *Forest Products Journal* 54:8–19.

Litterer, J. A. 1965. *The analysis of organizations*. John Wiley and Sons, New York, New York, USA.

Marquis, D. A., and R. L. Ernst. 1992. *User's guide to SILVAH: Stand analysis, prescription, and management simulator program for hardwood stands of the Alleghenies*. U.S. Forest Service, Northeastern Forest Experiment Station, General Technical Report NE-162, Newtown Square, Pennsylvania, USA.

Marzluff, J. M., J. J. Millspaugh, K. R. Ceder, C. D. Oliver, J. Withey, J. B. McCarter, C. L. Mason, and J. Comnick. 2002. Modeling changes in wildlife habitat and timber revenues in response to timber management. *Forest Science* 48:191–202.

McCarter, J. B., J. S. Wilson, P. J. Baker, J. L. Moffett, and C. D. Oliver. 1998. Landscape management through integration of existing tools and emerging technologies. *Journal of Forestry* 96:17–23.

McGaughey, R. J. 1997. Visualizing forest stand dynamics using the stand visualization system. Pages 248–257 *in Proceedings of the 1997 ACSM/ASPRS Annual Convention and Exposition and American Society for Photogrammetic and Remote Sensing* 4:248–257.

McGaughey, R. J. 2000. Seeing the forest and the trees: Visualizing stand and landscape conditions. Pages 105–109 *in* H. Gucinski, C. Miner, and B. Bittner, editors. *Proceedings of Views from the Ridge: Considerations for planning at the landscape level.* U.S. Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-596, Portland, Oregon, USA.

McKinley, M. 2002. *Final development of Pack Forest landscape management plan*. Thesis, University of Washington, Seattle, USA.

Morgan, M. G., and M. Henrion. 1990. *Uncertainty: A guide to dealing with uncertainty in quantitative risk and policy analysis*. Cambridge University Press, Cambridge, United Kingdom.

O'Hara, K. L., P. A. Latham, P. Hessburg, and B. G. Smith. 1996. A structural classification for inland northwest forest vegetation. *Western Journal of Applied Forestry* 11:97–102.

Oliver, C., D. Adams, T. Bonnicksen, J. Bowyer, F. Cubibage, N. Sampson, S. Schlarbaum, R. Whaley, H. Wiant, and J. Sebelius. 1997. *Report on forest health of the United States by the Forest Health Science Panel.* A panel chartered by Charles Taylor, Member, United States Congress, 11th District, North Carolina. (Submitted April 7, 1997), Also available as reprint through University of Washington College of Forest Resources CINTRAFOR RE43 (main document) and RE43A (summary).

Oliver, C. D. 1981. Forest development in North America following major disturbances. *Forest Ecology and Management* 3:153–168.

Oliver, C. D. 1992. A landscape approach: Achieving and maintaining biodiversity and economic productivity. *Journal of Forestry* 90:20–25.

Oliver, C. D. 1994. A portfolio approach to landscape management: An economically, ecologically, and socially sustainable approach to forestry. Pages 66–76 *in* C. R. Bamsey, editor. *Proceedings of Innovative Silvicultural Systems in Boreal Forests.* Clear Lake Limited, Edmonton, Alberta, Canada.

Oliver, C. D., D. R. Berg, D. R. Larsen, and K. L. O'Hara. 1992. Integrating management tools, ecological knowledge, and silviculture. Pages 361–382 *in* R. Naiman, editor. *New perspectives for watershed management.* Springer-Verlag, New York, New York, USA.

Oliver, C. D., M. Boydak, G. Segura, and B. B. Bare. 1999. Forest organization, management, and policy. Pages 556–596 *in* M. L. Hunter, Jr., editor. *Maintaining biodiversity in forest ecosystems.* Oxford University, United Kingdom.

Oliver, C. D., W. H. Knapp, and R. Everett. 1993. A system for implementing ecosystem management. Pages 377–388 *in* M. E. Jensen and P. S. Bourgeron, editors. *Eastside Forest Ecosystem Health Assessment: Volume 2: Ecosystem management: Principles and applications.* U.S. Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-318, Portland, Oregon, USA.

Oliver, C. D., and B. C. Larson. 1996. *Forest stand dynamics*. Update edition. John Wiley and Sons, New York, New York, USA.

Oliver, C. D., and B. R. Lippke. 1995. Wood supply and other values and ecosystem management in western Interior Forests. *In* R. L. Everett and D. M. Baumgartner, editor. *Ecosystem management in western interior forests.* Washington State University, Pullman, Washington, USA.

Oliver, C. D., and K. L. O'Hara. 2004. Effects of restoration at the stand level. Pages 31–59 *in* J. A. Stanturf and P. Marsden, editors. *Restoration of boreal and temperate forests.* CRC Press, New York, New York, USA.

Oliver, C. D., and M. Twery. 1999. Decision support systems: Models and analyses. Pages 661–685 *in* N. C. Johnson, A. J. Malk, W. T. Sexton, and R. C. Szaro, editors. *Ecological stewardship: A common reference for ecosystem management.* Elsevier Science Ltd., Oxford, United Kingdom.

Organon Growth and Yield Project. 2007 November 20. Organon Growth and Yield Project Home Page. <http://www.cof.orst.edu/cof/fr/research/organon/index.htm>. Accessed 20 November 2007.

Raedeke, K. 2001. Model approach to habitat conditions influencing elk populations: An approach to habitat modeling. *In* M. E. Ferry, T. S. Peterson, and J. C. Calhoun, technical editors. *Status of elk populations on the Olympic Peninsula*. Olympic Natural Resources Center Conference Proceedings, University of Washington, Olympic Natural Resources Center, Forks, Washington, USA.

Rauscher, H. M. 1995. Natural resource decision support: Theory and practice. *AI Applications* 9:1–2.

Roberts, J. C. 1979. Principles of land use planning. Pages 47–63 *in Planning the uses and management of land.* ASA-CSSA-SSSA, Madison, Wisconsin, USA.

Scheller, R. M., J. B. Domingo, B. R. Sturtevant, J. S. Williams, A. Rudy, E. J. Gustafson, and D. J. Mladenoff. 2007. Design, development, and application of LANDIS-II, a spatial landscape simulation model with flexible temporal and spatial resolution. *Ecological Modeling* 201:409–419.

Senge, P. S. 1990. *The fifth discipline: The art and practice of the learning organization*. Currency Doubleday, New York, New York, USA.

Stage, A. R. 1973. *Prognosis model for stand development*. U.S. Forest Service, Intermountain Forest and Range Experiment Station, Research Paper INT-137, Ogden, Utah, USA.

Taylor, F. W. 1911. *The principles of scientific management*. Harper and Brothers, New York, New York, USA.

Twery, M. J., P. D. Knopp, S. A. Thomasma, H. M. Rauscher, D. E. Nute, W. D. Potter, F. Maier, J. Wang, M. Dass, H. Uchiyama, A. Glende, and R. E. Hoffman. 2005. NED-2: A decision support system for integrated forest ecosystem management. *Computers and Electronics in Agriculture* 49:24–43.

U.S. Forest Service. 2007. USFS Forest Vegetation Simulator Home Page. <http://www.fs.fed.us/fmsc/fvs/>. Accessed 20 November 2007.

von Bertalanffy, L. 1968. *General systems theory: Foundations, development, applications*. George Braziller, New York, New York, USA.

Walters, K. R., U. Feunekes, A. Cogswell, and E. Cox. 1999. *A forest planning system for solving spatial harvest scheduling problems.* CORS National Conference. Toronto. 7–9 June 1999.

Wilson, J. S., and P. J. Baker. 1998. Mitigating fire risk to late-successional forest reserves on the east slope of the Washington Cascade Range, USA. *Forest Ecology and Management* 110:59–75.

Wilson, J. S., and P. J. Baker. 2001. Flexibility in forest management: Managing uncertainty in Douglas-fir forests of the Pacific Northwest. *Forest Ecology and Management* 145:219–227.

Wilson, J. S., E. S. Isaac, and R. I. Gara. 1998. Impacts of mountain pine beetle (*Dendroctonus ponderosae*) infestation on future landscape susceptibility to the western spruce budworm (*Choristoneura occidentalis*) in north central Washington. *Journal of Applied Entomology* 122:239–245.

Wilson, J. S., and R. McGaughey. 2000. Presenting landscape-scale forest information: What is sufficient and what is appropriate? *Journal of Forestry* 98:21–27.

Wilson, J. S., and C. D. Oliver. 2000. Stability and density management in Douglas-fir plantations. *Canadian Journal of Forest Research* 30:910–920.

Wilson, W. 1887. The study of administration. *Political Science Quarterly* 2:197–222.