Silviculture Ecology Biometrics

Landscape Management through Integration of Existing Tools and Emerging Technologies

A landscape approach to forest management must consider the implications of alternative scenarios across stands and through time. The Landscape Management System, a computer program, facilitates implementation of this approach by integrating forest inventories, spatial information, growth models, visualization, summarization, and analysis. A case study with three scenarios—no harvest, clearcut, and thinning—exposes the complex tradeoffs inherent in forest management and highlights the need for comparative analysis tools.

By James B. McCarter, Jeremy S. Wilson, Patrick J. Baker, Jeffrey L. Moffett, and Chadwick D. Oliver

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Natural resource professionals face the staggering task of assimilating and mobilizing vast amounts of information. Changing market and social values, increasing population growth, and the globalization of trade and transportation continually reshape the demands placed on the world's forest resources. Concurrently, the evolution of ecosystem science and landscape ecology and the recognition of the role of disturbances in forest dynamics have emphasized the complex tradeoffs in values associated with managing these resources (Oliver et al. 1998). Successful management requires looking further into the future and more broadly across the landscape. Coordinating management activities and predicting interactions within and among spatial and temporal scales is the major challenge facing forest management professionals.

The landscape management approach (Oliver 1992; Boyce 1995) addresses the complexity of forest management. To coordinate the vast amount of information at the many spatial and temporal scales, we have designed a computer program to implement the landscape management approach. It allows forest managers and policymakers to develop and evaluate stand- and landscape-scale silvicultural options for both short- and long-term planning.

Landscape Management

Our approach uses a rich history of research and data collection in forest ecology, mensuration, and silviculture at the stand scale. This knowledge provides the basis for classifying forest stands and predicting future conditions at the landscape scale. The approach aggregates these techniques to the landscape scale.

The landscape management approach acknowledges the uncertainty and diversity inherent in managing forests over large areas (Morgan and Henrion 1990). Uncertainty may take the form of natural disturbances (Raup 1964), changing market values for wood commodities (Oliver 1995), or shifting cultural values attached to forests (Oliver 1992). Diversity is characteristic of both landowners and the forest structures on the land. A landscape of moderate size (< 10,000 hectares) nearly anywhere in the United States may include forests managed by nonindustrial private forest owners, forest industry, and state or federal agencies. Stand structures vary within and between landscapes; management objectives and methods vary by ownership.

Diverse stand structures reflect the diverse patterns of previous management practices, forest growth, and natural disturbances. At the landscape scale, this diversity provides forest managers with the flexibility to meet the changing demands on forest resources. Thus, maintaining diverse stand structures across the landscape affords some insurance against the uncertainty inherent in forest management (Oliver 1995).

Traditional forest planning addresses varying spatial and temporal scales. For large forest organizations there are three general levels of planning: strategic, tactical, and operational (Weintraub and Bare 1996). Strategic planning considers whole forest areas, from thousands to millions of acres, over long planning horizons. This scale requires considerable data reduction. Tactical planning considers smaller spatial scales, such as watersheds, on an annual basis over one or two decades. Operational planning implements tactical plans during each year.

Our approach combines aspects of tactical and operational planning for both space and time. Instead of explicitly defining three distinct levels of planning that are vaguely linked, the landscape management approach considers multiple planning levels simultaneously. Managers may compare and contrast stand structures in a given time or over multiple decades. Likewise, stand structures in a given time period can be examined across a large area.

Overview of the System

The Landscape Management System (LMS) provides land managers with a tool for evaluating management alternatives by integrating the large amounts of information necessary for designing complex landscape plans. The system requires knowledge and information at the stand scale to project changes in landscape-scale processes. An understanding of silvics, forest stand dynamics, growth models, silviculture, and geographic information systems (GIS) is necessary for creating and evaluating forest plans. Without this knowledge the program would simply provide output without context.

The development of LMS is part of a cooperative effort between the Silviculture Laboratory, College of Forest Resources, University of Washington and the USDA Forest Service, Pacific Northwest Research Station.

LMS is a Microsoft Windows application that coordinates the flow of information among growth models, computer visualization software, and analysis tools (see McCarter et al. 1996 and McCarter 1997). LMS organizes activities that include application management, growth simulation, silviculture and disturbance simulation, and output processing. Preferred management scenarios are developed iteratively in LMS by critically evaluating and refining multiple projections.

Filter programs translate data from one format to another, generating the system network that ultimately links inputs to outputs *(fig. 1)*. Incorporating new growth models or inventory data formats into LMS requires changing specific filter programs, not the general architecture of the system (McCarter 1997).

Landscapes in LMS are organized as portfolios containing forest stand inventory data, a growth model, stand boundaries, and a digital elevation model for the landscape. At the individual stand scale, growth models project stands into the future. Specific silvicultural treatments, such as thinning, regeneration planting, and clearcutting, can be modeled. The same process can be applied at the landscape scale, either on a stand-by-stand basis or as a uniform whole.

LMS has been developed to incorporate some existing forest models and computer tools (McCarter 1997). Data and estimated future conditions can be analyzed and evaluated by a variety of methods, ranging from tables and graphs to three-dimensional stand and landscape visualizations (SVS, McGaughey 1997; and UVIEW, Ager and McGaughey 1997). Further, the benefits and risks estimated for a given alternative, such as stand structure diversity versus spruce budworm susceptibility (Wilson et al., in press), can be assessed either by using algorithms within LMS or by exporting output to other analysis tools. Additional examples of interpreting LMS output in-

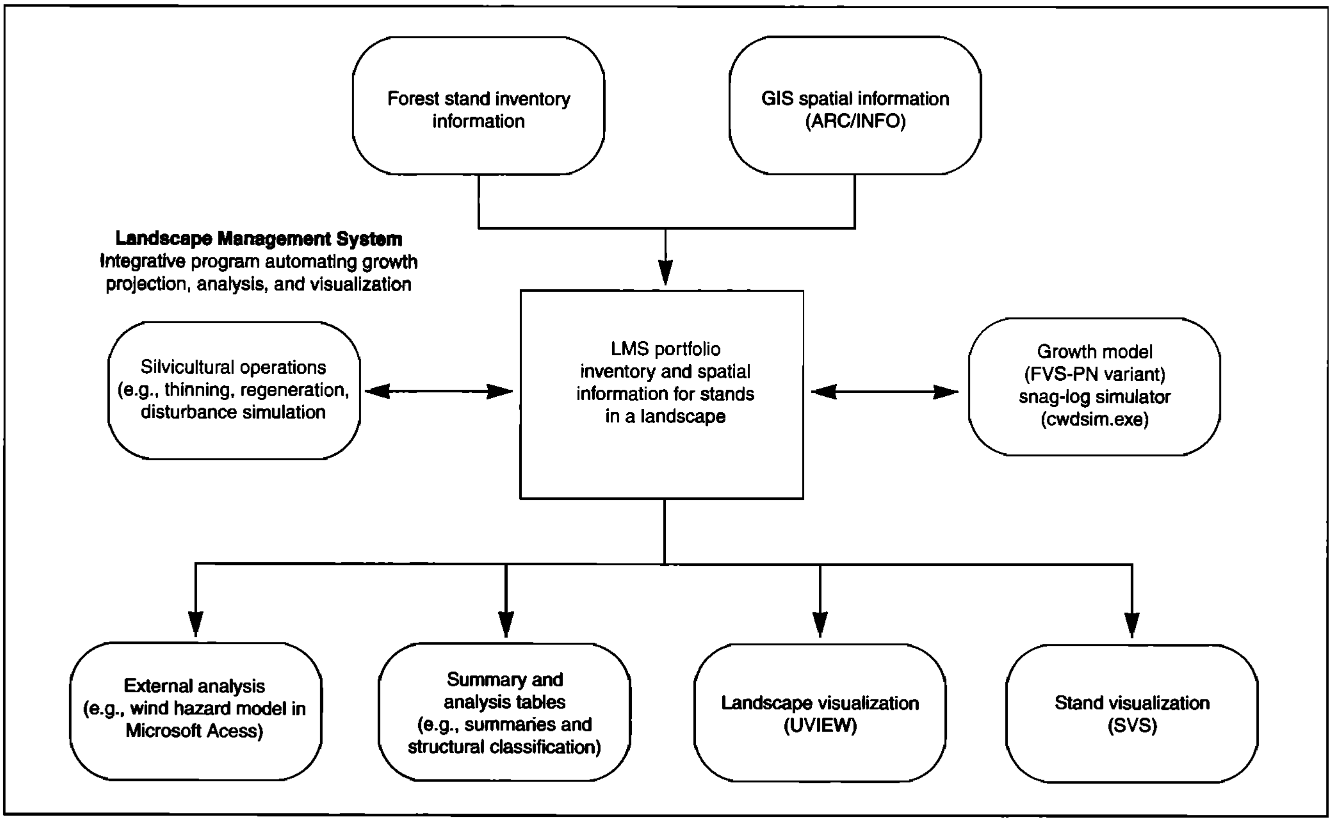

Figure 1. **The flow of information into and through the Landscape Management System. Each connecting line represents one or more filter programs that format information being transferred according to the client's requirements. The shaded area identifies the core components of LMS.**

clude assessment of crown-fire hazard (Wilson and Baker, in press) and wind hazard (Wilson in prep.), classification of stand structures (e.g., Carey and Elliott 1994; Oliver and Larson 1996), and evaluation of financial returns.

The system has been designed as an interface to growth models that operate at the individual tree, distance-independent level, for two reasons. First, most growth models operate at this resolution (Vanclay 1994). Second, most forest sampling methods currently provide this level of information or can be readily modified to do so. Because the individual tree, distance-independent level provides within-stand size distributions, it offers a compromise between spatial resolution and data intensity for evaluating landscape-scale processes and management alternatives.

To be applied at the landscape scale, modeling at the individual tree level with spatially explicit data would require prohibitively large amounts of information. The cost of obtaining tree locations is high, and the spatial competition indices they predict rarely perform better than stand-scale measures (Vanclay 1994; Wimberly and Bare 1996). In addition, few forest growth models that incorporate spatial information are available.

Modeling at the stand scale does not require the large amounts of data that individual tree, distance-dependent models do; however, in an environment of changing management goals, stand averages do not always provide enough information to address diverse questions either spatially or temporally. Stand averaging limits the applicability of the model as new questions or criteria arise by adopting a classification scheme early in the modeling process.

The Clallam Bay Portfolio

A case study, comparing three management scenarios, shows some features of LMS. For purposes of illustration we restricted the example to a small area and few measurable criteria.

The case study landscape is a 400-hectare basin near Clallam Bay on the Olympic Peninsula managed by the Washington State Department of Natural Resources. Approximately half the landscape is composed of young plantations; the remainder is mostly 60- to 80-year-old second-growth. The Forest Vegetation Simulator–Pacific Northwest Variant (FVS-PN) (Donnelly 1996; Teck et al. 1996) was used as the growth model for all stand projections.

Three management alternatives were projected over five decades. The first alternative excluded harvesting. The second clearcut a portion of the landscape in each decade; the harvested stands were replanted and precommerically thinned after two decades. The third combined commercial thinning and limited clearcutting in the older stands.

For simplicity, only three criteria were used to compare the management scenarios: wood volume, stand structure, and windthrow susceptibility. The standing and cut volume in different size classes of wood being harvested from the landscape were provided in an LMS output table. Forest structure classes provided a subjective classification of wildlife habitat (see "Oliver's Stand Structure Classification," p. 22). *Figure 2* presents visualizations of each forest structure classification.

Forests on the Olympic Peninsula have been affected by catastrophic windstorms (Lynott and Cramer 1966; Henderson et al. 1989). The wind hazard model for Clallam Bay incorporates complex spatial and temporal information to compare the susceptibility of stands to windstorms (see "Wind Hazard Model," p. 20). Wind hazard ratings for the entire landscape are estimated for each time period.

Case Study Results

At the end of five decades the projected landscape conditions under the three management regimes differ considerably *(fig. 3, p. 20)*. The no-harvest scenario results in a landscape of dense stands with large trees and no harvest openings (inventory and GIS data were provided by the Washington State DNR). The clearcut scenario creates a mosaic of openings and dense young plantations. The thinning scenario produces fewer openings, less-dense stands, and greater

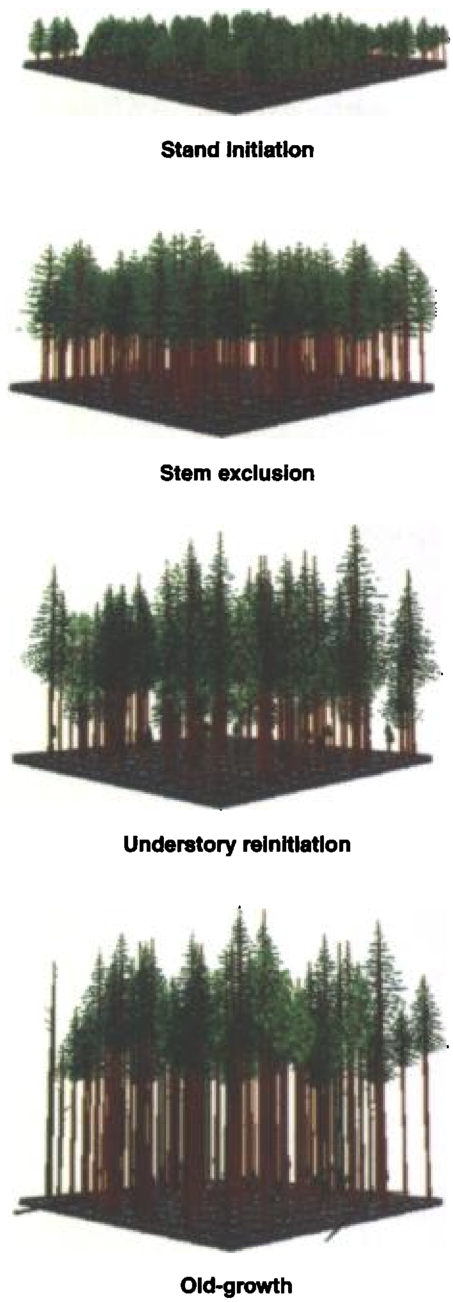

***Figure 2.* Representative stand visualization of the four forest structures being used to evaluate the landscape in this analysis.**

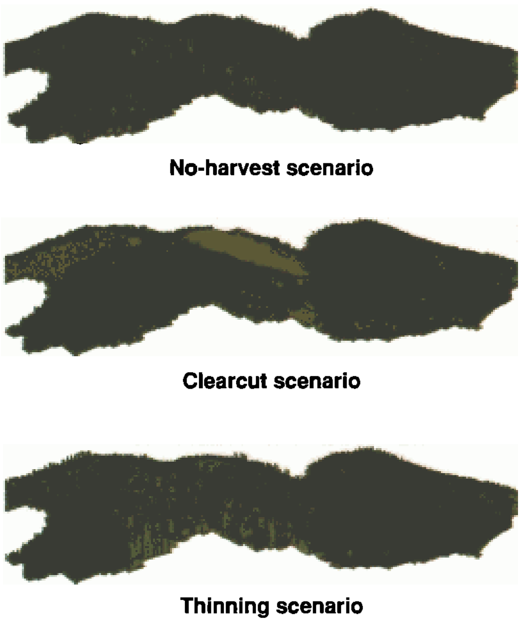

Figure 3. **Landscape visualization of the Clallam Bay case study landscape. The landscapes are depicted during the fifth decade of each scenario.**

variation of tree sizes.

Standing and cut volumes on the Clallam Bay landscape vary through time and among scenarios *(figs. 4, 5).* With no harvesting, the volume of both standing sawtimber and large sawtimber increases over time. Harvesting in the clearcut scenario generates an increasing flow of cut volume, particularly in the sawtimber and large sawtimber size class. Standing volume remains relatively constant but is considerably less than the no-harvest scenario. The harvest levels in the thinning scenario produce less standing volume than the no-harvest scenario but result in a higher proportion of large sawtimber.

Figure 6 compares the proportion of the landscape in each structural stage among scenarios. The no-harvest option generates old-growth structure by the fourth decade; however, without any cutting, the stand initiation structure is lost in the same decade. The clearcut scenario generates little understory reinitiation and no old-growth. Stands are cycled between stand initiation and stem exclusion. In the thinning scenario old-growth structure is created by the third decade. The lim-

Wind Hazard Model

Mitchell (1995) proposed a simple model for combining site and stand hazard ratings into an overall wind hazard rating. Site hazards index rooting depth, soil moisture, topographic exposure, and other environmental conditions that are not generally altered by forest management (Cremer et al. 1982; Mitchell 1995; Quine 1995). Stand characteristics, such as tree height and diameter, crown size, species, trees per area, and the condition of neighboring upwind stands, are determined by the individual trees in the stand and landscape and respond to changing stand conditions (Cremer et al. 1982; Becquey and Riou-Nivert 1987; Lohmander and Helles 1987). Site and stand ratings are combined to provide a wind hazard rating.

Instead of explicitly predicting and simulating disturbance events, this approach rates the susceptibility of each stand to wind. Matrices for soil, exposure, and stand rankings are combined into an overall wind hazard value. Values for *site hazard* from the first matrix are used for *site* in the second matrix (modified from Mitchell 1995).

Site Hazard

		Exposure		
		low	moderate	severe
Soil	low	*low*	*low*	*moderate*
	moderate	*low*	*moderate*	*severe*
	severe	*moderate*	*severe*	*severe*

Wind Hazard

		Site		
		low	moderate	severe
Stand	low	*low*	*low*	*moderate*
	moderate	*low*	*moderate*	*severe*
	severe	*moderate*	*severe*	*severe*

Exposure is a measure of a stand's topographic position relative to upwind stands (wind direction is variable in the model). Severe exposure = ridges, mid- and upper-slope stands with aspects parallel to the wind, and upper slopes with windward aspects. Moderate exposure = upper-slope stands protected by higher elevations upwind, mid-slope stands with windward aspects, and bottom-slope stands having aspects parallel to storm winds. Low exposure = mid- or bottom-slope stands protected by higher elevations upwind.

Soil describes the effect of a stand's soil attributes on windthrow potential. For the Clallam Bay landscape we used a soil windthrow hazard code developed by the Washington State Department of Natural Resources. Soils receive a severe, medium, or low ranking based on their maximum rooting depth and soil drainage rates.

Stand refers to the conditions of trees in a stand and relative conditions of upwind neighbors. Stand factors and their weighting have been developed from a review of the wind hazard literature (Cremer et al. 1982; Becquey and Riou-Nivert 1987; Lohmander and Helles 1987; Mitchell 1995). Each of these factors is given equal rating.

1. Height of the largest 250 trees per hectare:
   low < 15 meters, moderate ≤ 30 meters, severe > 30 meters
2. Height to diameter ratio (same units) of the largest 250 trees per hectare:
   low < 80, moderate ≤ 90, severe > 90
3. Upwind neighbor height/focus stand height ratio:
   low > .75, moderate ≤ .75, severe < .50 (minimum 20 percent of focus stand border)
4. Percent of trees retained in thinnings during previous decade:
   low > 80, moderate ≤ 80, severe ≤ 60

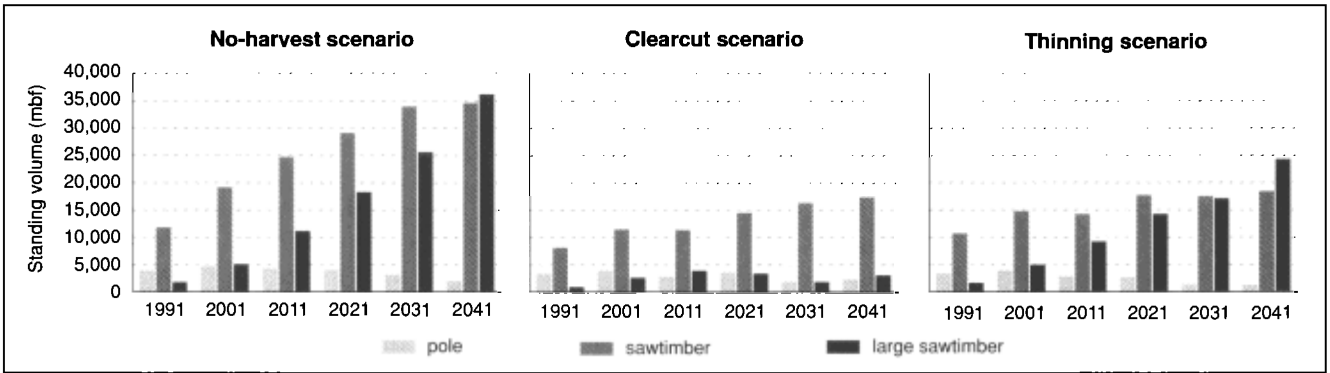

***Figure 4.* Standing volume by year and size class in each of the three scenarios.**

ited clearcut harvesting in the thinning scenario continues to generate the stand initiation structure throughout the 50-year projection.

The proportion of the landscape in various wind hazard classes is compared among scenarios in *figure 7*. In the clearcut scenario, a large proportion of the landscape is maintained in the low hazard class through the creation of openings and the young stands that develop in them. Severe wind hazard on a small proportion of the landscape results from the creation of openings up-

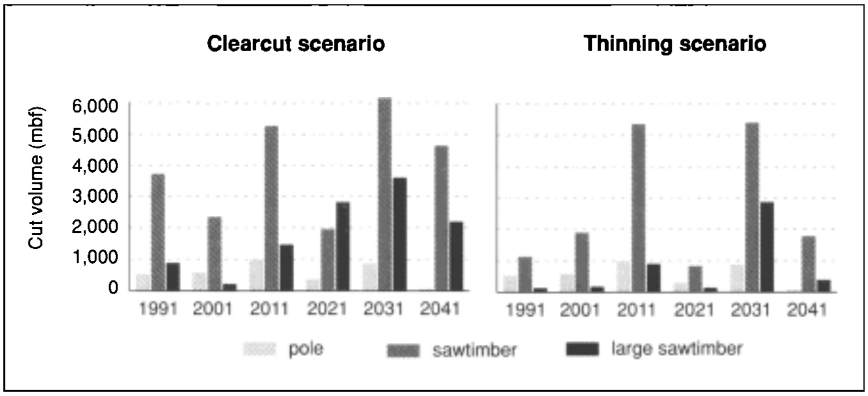

***Figure 5.* Cut volume by year and size class in each harvesting scenario.**

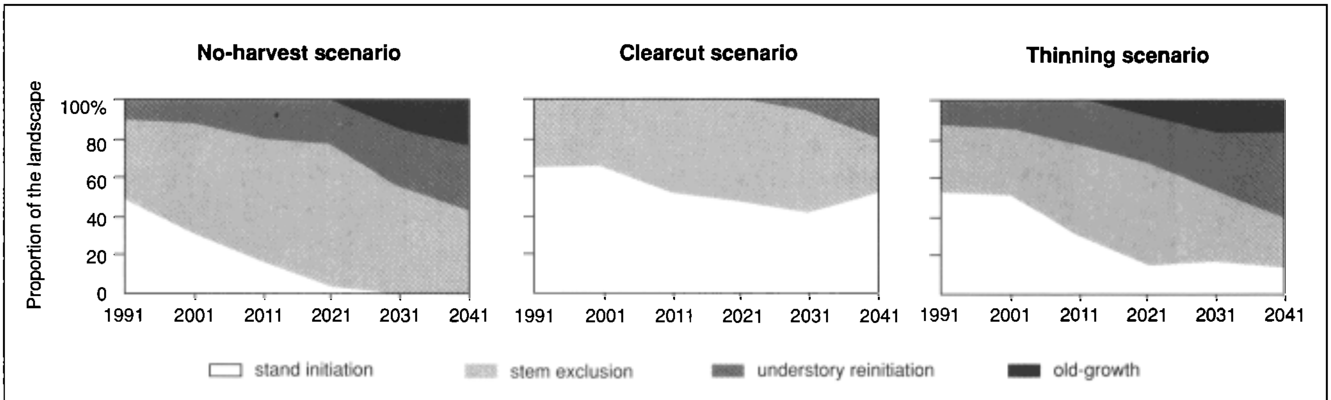

***Figure 6.* Proportions of the landscape in different forest structural stages throughout each management scenario.**

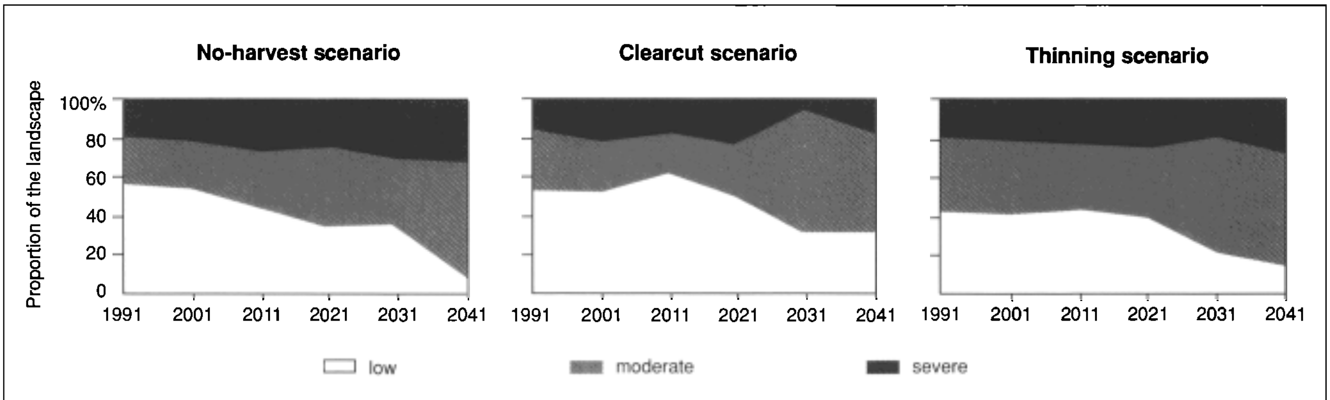

***Figure 7.* Proportions of the landscape in different wind hazard classes throughout each management scenario.**

Oliver's Stand Structure Classification

The classification of stand structure used for the Clallam Bay case study is based on Oliver's (1981) four structural stages: old-growth, understory reinitiation, stem exclusion, and stand initiation. Although there are many classifications (e.g., Oliver 1981; Brown 1985; FEMAT 1993; Carey and Elliott 1994), we chose Oliver's (1981) because it is widely applicable in western Washington. Stands were evaluated for structural class in the order presented below; if a stand did not meet the requirements of one structural class, it was passed to the next one down.

Old-growth (OGDTG 1986)
2 or more species
20 or more trees per hectare >81.3 centimeters dbh
30 or more shade-tolerant trees per hectare >40.6 centimeters dbh
7 or more conifer snags per hectare >51 centimeters dbh and >4.5 meters tall
10 or more logs per hectare >61 centimeters diameter and >15 meters long
Canopy closure > 30 percent

Understory reinitiation
Average dbh of the largest 250 trees per hectare ≥ 51 centimeters
Canopy closure > 40 percent

Stem exclusion
Average dbh of the largest 250 trees per hectare < 51 centimeters
Canopy closure > 60 percent

Stand initiation
Any stand that does not fit in another category

wind of uncut stands. As trees grow taller in the no-harvest scenario, more stands move into the moderate and severe wind hazard class. By the fifth decade only 10 percent of the landscape is in the lowest wind-hazard class. The thinning scenario produces similar results. Increases in wind risk because of the creation of upwind openings and thinning in stands are offset by reduced height-to-diameter ratios resulting from thinning and the creation of young stands, which have lower wind risk.

Discussion

The integration of growth models, inventory data, geographic information, and analysis tools in LMS creates a framework to help users compare management scenarios. *Table 1* summarizes the tradeoffs among the Clallam Bay alternatives. Both harvesting scenarios produce substantial cut volumes in the sawtimber and large sawtimber categories. The no-harvest and thinning scenarios produce old-growth structure on the landscape, although the thinning scenario creates old-growth structure sooner, develops more understory reinitiation structure, and maintains some stand initiation structure. These three structures have been identified as supporting the highest relative diversity of wildlife (Franklin et al. 1986).

In the absence of large-scale disturbance or harvesting, the stand initiation structure will eventually disappear from the landscape. If landscape-scale hazards—wind, fires, insect infestations—are high, some stand initiation can be expected from natural disturbances. The clearcut scenario produces the landscape mosaic with the lowest cumulative wind hazard rating; the no-harvest and thinning scenarios have higher ratings. Because wind hazard ratings are determined for individual stands, managers can plan to reduce stand-specific wind hazard associated with certain sites or allow stand structures that are relatively more susceptible to windthrow to grow in protected sites (Wilson, in prep.).

For our example we chose a relatively small landscape and just three analysis criteria. Real management problems are more complex, and including other objectives—balanced timber flow, aesthetics, or recreation—would require development of additional management scenarios and measurable criteria. Nevertheless, even this limited case study shows that LMS efficiently automates the many repetitive routines necessary to use stand-scale information for landscape-level projections. Projecting the Clallam Bay landscape (26 stands) one time period using FVS–PN takes approximately 15 seconds using a Pentium 133 MHz desktop computer.

Changes in forest management objectives generate new suites of questions. Consequently, analysis tools need to be readily adaptable to variable management environments. LMS includes several analysis programs, such as summary stand statistics, landscape timber valuation (standing or cut volume), and harvest adjacency constraints. At the same time, LMS output is sufficiently generic that it can be readily transferred to a wide range of analysis tools. For example, the wind hazard rating module was developed in a database program, and stand structural classifications have been developed in a spreadsheet program.

The substand resolution of LMS information allows for detailed analysis For example, in our stand structure classification, the old-growth category requires an estimate of the number of trees of shade-tolerant species greater than 40.6 centimeters dbh. Aggregation of stand-scale information might obscure this level of resolution. In contrast to optimization methodologies, a desired stand structure distribution for

Table 1. Comparison of rankings for four measurable criteria in each of the three scenarios (+ positive impact, 0 neutral impact, – negative impact).

	Scenario		
Measurable criteria	No harvest	Clearcut	Thinning
Harvest volumes	–	+	0 to +
Standing volume	+	–	+
Balance of forest structures	–	–	+
Landscape wind hazard	0 to –	+	0

a landscape is obtained iteratively with multiple projections; however, optimization techniques can be used to develop scenarios in conjunction with LMS (Hitchcock 1996).

All models are abstractions of reality, and LMS is no exception to this limitation. Where growth models do not exist or are not readily transferable, managers cannot project potential changes in forest growth or structure. Compromises in data quality limit the predictive ability of any model (Vanclay 1994). For example, inventory information that is biased toward certain forest types, insufficiently detailed, or that inaccurately represents stands, limits the utility of any analysis. In some areas forest practices may not divide a landscape into discrete stands. Management units may be composed of heterogeneous patches of different species or stand structures. Such limitations are not unique to LMS; rather, they reflect the fundamental requirements for analysis of landscape-scale management options. Where models, inventory data, or stand definitions are absent or suboptimal, a first approximation can be attempted by adapting growth models or extrapolating from existing inventory information.

Conclusion

The landscape management approach addresses the uncertainty, complexity, and tradeoffs associated with managing forest resources. LMS allows forest managers to synthesize and integrate data and information from growth models, forest inventories, and GIS databases to implement the landscape management approach. By providing graphical, tabular, and visual outputs, LMS facilitates exploration of current and projected stand- and landscape-scale conditions and comparative analysis of potential risks and benefits, as well as outreach and education. As the demands on the forests of the world continue to increase, managers need the means to create and assess innovative management options. We believe that LMS is a strong step toward this goal.

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James B. McCarter (e-mail: jmac@silvae.cfr.washington.edu), Jeremy S. Wilson, Patrick J. Baker, and Jeffrey L. Moffett are research assistants and Chadwick D. Oliver is professor, College of Forest Resources, University of Washington, Seattle, 98195. LMS can be obtained from the World Wide Web site of the Silviculture Laboratory, College of Forest Resources, University of Washington (http://silvae.cfr.washington.edu/lms/). The software is public domain and may be downloaded free of charge.