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Working Paper 5

Templates for Forest Sustainability on Intensively Managed Private Forests

National Commission on Science for Sustainable Forestry (NCSSF) Research Project C.1

Final report and technical reports

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Final project report to the National Commission on Science for Sustainable Forestry (NCSSF)

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Templates for Forest Sustainability on Intensively Managed Private Forests

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Contents

Abstract

Intensively managed private forestlands are being increasingly called upon to play a larger role in meeting habitat and biodiversity goals. These forestlands have a great potential for contributing to such goals. They are also very sensitive to economic performance, though, and are often under considerable pressure from competing land uses. A key challenge of achieving sustainability on intensively managed private forests is the integration of goals to support increased biodiversity while at the same time maintaining and enhancing the long-term multiple socio-economic benefits derived from harvest activities.

Our approach has been to develop management templates that provide specific but flexible guidelines to help forest managers to successfully meet both economic and biodiversity goals. This approach first identifies desired future stand conditions relative to a given biodiversity goal. Inventory data are then identified that are representative of the desired conditions. A statistical assessment process is used in conjunction with a suitable growth model to evaluate the effectiveness of alternative management pathways in achieving the desired conditions. Combining this assessment with performance thresholds for long-term economic sustainability provides an integrated process that can be used to identify sustainable management strategies that meet both biodiversity and economic goals.

This approach was initially developed to identify sustainable riparian management strategies for young, dense Douglas-fir forests in the Pacific Northwest. Riparian areas are areas of high diversity and thus are of particular importance when managing for biodiversity. Riparian management is also a prominent regulatory issue in the region. The desired riparian forest conditions have been identified as those of mature, natural stands. Literature review findings suggest that repeated, heavy thinnings can accelerate the development of such conditions in dense, intensively managed stands. A draft template identified two riparian management strategies that were likely to achieve long-term desired conditions while protecting short-term functions and maintaining an acceptable economic return. This template has been further developed and tested and shown to perform well under a range of conditions.

This approach was then applied to intensively managed loblolly pine forests in the South. A literature review for this region suggested that open, park-like conditions with rich, herbaceous understories characteristic of historic, fire-maintained pine communities would likely provide high levels of plant and animal diversity while also providing income potential through sawtimber production and hunting leases. Using a reference dataset representative of the desired conditions, a template option was identified that utilizes frequent thinning and prescribed burning over longer rotations to achieve the desired conditions while maintaining an acceptable economic return. While additional data are needed to more fully develop templates for the South, this example template is an important demonstration of how the overall approach can be applied to multiple regions and ecotypes.

Deliverables for this project include this summary report and four technical reports covering literature reviews of both regions and detailed descriptions of the development of both templates. Several presentations will also be prepared to communicate applications of these templates with practitioners in both regions.

I. Introduction

Intensively managed private forestlands are being increasingly called upon to play a larger role in meeting habitat and biodiversity goals. There are a significant number of acres under intensive management in regions such as the South and the Pacific Northwest, and these forestlands have a great potential for contributing to biodiversity goals (Hartley 2002, Wigley et al. 2000). Intensively managed forests already make significant contributions to biodiversity by simply providing forest cover that would be lost with alternative land uses (Hayes et al. 2005). Stand-level management changes can be implemented that can greatly increase the biodiversity that these forests can potentially support (Hartley 2002, Moore and Allen 1999).

An important consideration, though, is that private forestlands, especially those that are used for intensive forest management, are also very sensitive to economic performance and are often under considerable pressure from competing land uses (Murphy et al. 2005). In rapidly urbanizing areas such as western Washington, for example, family-owned Douglas-fir (*Pseudotsuga menziesii*) plantations are being converted to development at a rapid rate (MacLean and Bolsinger 1997, WADNR 1998). Several industrial tree farms in this region have recently been sold as well, further suggesting that economics does and will play an important role in the long-term presence and sustainability of these forests.

With these tensions in mind, one of the key challenges of achieving sustainability on intensively managed private forests is the integration of the Montreal Process goals of conserving biological diversity while at the same time achieving the maintenance and enhancement of long-term, multiple socio-economic benefits derived from harvest activities. The accomplishment of these diverse goals can assisted on both industrial and family ownerships with the development of templates that provide specific but flexible management guidelines for practices that are likely to support both increased biodiversity and favorable economic returns.

An approach has been developed for creating such templates that are designed to enable forest managers to successfully meet both economic and biodiversity goals. This approach identifies desired future stand conditions relative to a given biodiversity goal and establishes inventory data that represent the desired condition. A statistical assessment process is then used in conjunction with growth model projections to evaluate alternative management pathways designed to achieve desired future stand conditions while maintaining a target level of economic return. This integrated assessment process can be used to identify sustainable management strategies that meet both biodiversity and economic goals.

This approach was initially developed in response to riparian management challenges in the Pacific Northwest. Riparian forest management plays a key role in the conservation of biodiversity as well as another Montreal Process goal, the conservation of water resources. This is a particularly critical issue in the Pacific Northwest, where several salmon and steelhead runs have been listed under the Endangered Species Act. However, management limitations designed to protect salmon also limit the use of active management to improve riparian conditions and can result in unsustainable economics, particularly for small landowners (Zobrist 2003, Zobrist and Lippke 2003). Under these circumstances, there will likely be increased rates of forest conversions. Templates were needed that would effectively foster the development of desired structural conditions in young, dense forests while maintaining an economic motivation for landowners to continue managing for forestry. A draft riparian management template was developed that demonstrated how both biodiversity and economic goals could be achieved concurrently (Zobrist et al. 2004, 2005).

The template approach described above has potentially much broader applications for identifying management strategies that support increased biodiversity both in riparian and upland areas. Other regions could also benefit from this template management approach, such as the South where there is interest in the ability of intensively managed loblolly pine (*Pinus taeda*) plantations to function similar to the diverse, fire-maintained longleaf pine (*Pinus palustris*) ecosystems that historically dominated the area (Bragg 2002, Hedman et al. 2000, Noss 1988). Given the declining pulpwood stumpage prices for this region, there is a need for longer-rotation management strategies that produce higher value sawtimber as well as opportunities for supplemental income from hunting leases. Since open stand conditions with rich, herbaceous understories that are characteristic of historic longleaf pine forests favor both game and non-game species, a management template for establishing these conditions could be highly compatible with both economic and biodiversity goals.

II. Purpose

The purpose of this study was twofold:

1. To identify management practices for supporting increased biodiversity in intensively managed Douglas-fir forests in the Pacific Northwest and loblolly pine forests in the South.
2. Demonstrate how these practices could be synthesized into working templates that minimize economic costs and provide specific but flexible implementation guidance for practitioners.

A literature review has been completed for each region. These literature reviews identify the basic principles of managing for increased biodiversity and establish a spectrum of practical management steps that can be applied in both riparian and upland areas. The draft riparian management template for the Pacific Northwest has been refined and more fully developed. A new template has been created for loblolly pine stands, which demonstrates how the template approach can be applied to southern conditions. This report summarizes the findings of both literature reviews, describes the template approach as applied to the Pacific Northwest and the South, and discusses the applications and results for each template.

III. Summary of results

1. Key findings of the Pacific Northwest literature review

A number of changes in stand-level management practices can support significantly increased biodiversity in intensively managed Douglas-fir plantations in the Pacific Northwest. The key to providing for a diversity of species and processes is to develop more diverse and complex stand structures (Helgerson and Bottorff 2003, Muir et al. 2002, Spies 1998). Using heavy, repeated thinnings minimizes the dense stem exclusion stage, stimulates the understory, and accelerates the development of complex, old forest structure. Favoring multiple species and sizes when thinning can enhance structural diversity. Variable density thinning, which creates a mosaic of different densities along with unthinned patches and small openings, also works well for enhancing structural diversity.

When harvesting, biological legacies such as large, live trees, snags, and downed wood should be retained to mitigate harvest impacts and provide structure for the new stand. Retention can be left dispersed throughout the stand, in aggregate clumps, or a combination (Franklin et al. 1997). Riparian areas should be protected, as these are areas of particularly high diversity. Underplanting, selective fertilization, and pruning can also be used to add structural complexity. All of these strategies work best over longer rotation that allow enough time for complex structure to develop and minimize cumulative harvest impacts on the landscape.

These different practices for increasing structural complexity and biodiversity can be combined into overall management strategies called biodiversity pathways (Carey and Curtis 1996, Carey et al. 1996, Carey et al. 1999). Examinations of biodiversity pathways for coastal hemlock forests have been promising, and similar pathways can be developed for Douglas-fir plantations. There are economic costs to these pathways that must be considered in order to ensure successful adoption by private landowners and minimize unintended consequences such as forest conversion. Competitive incentive programs using both education and financial assistance can offset private costs. Identifying management strategies that target both biodiversity and competitive economic returns will likely be the most successful regardless of who bears the costs.

A complete review and reference list is available as a technical report (see Deliverables).

2. Refined Pacific Northwest riparian management template

This project was based on a draft template that comprised two variations of a riparian management plan designed for overstocked Douglas-fir stands on site class II. Both options performed well in accelerating the development of stand structures similar to the reference conditions of mature, natural riparian stands while also maintaining a target rate of return of 5% in the long term (coarse filter analysis). Both options were also projected to provide high levels of potential large woody debris (LWD) recruitment over time, which was a specific function of interest (fine filter analysis).

The next step was to further refine and validate this draft template. Using Drew and Flewelling's (1979) density management diagram for Douglas-fir, crown closure, imminent competition mortality, and the maximum size-density relationship (3/2 thinning law) were estimated in relation to the draft template density targets over time. These relationships suggested that the template allowed density to remain too high at some points in time. There was also concern that the last thinning was too heavy and left the remaining overstory too sparse. The draft template was refined in response to these concerns by tightening the allowable density range and by increasing the target density of the last thinning from 25 trees per acre (TPA) to 35 TPA.

The final template options were as follows:

- *Option A*
  - 25-foot bank stability zone with the following prescription:
    - Thin to 180 TPA at age 20
    - Thin to 60 TPA at age 50
    - No further entries to retain shade and bank stability
  - 55-foot additional buffer (80-feet total) with the following prescription:
    - Thin to 180 TPA at age 20
    - Thin to 60 TPA at age 50
    - Thin to 35 TPA at age 70
    - Clear-cut and replant at age 100
- *Option B*
  - 25-foot bank stability zone with the following prescription:
    - Thin to 180 TPA at age 20
    - Thin to 60 TPA at age 50
    - No further entries
  - 25-foot additional buffer (50-feet total) with the following prescription:
    - Thin to 180 TPA at age 20
    - Thin to 60 TPA at age 50
    - Thin to 35 TPA at age 70
    - No further entries

A range of ± 10% around the target density was allowed for operational flexibility, and a range of ± 5 years was allowed for timing flexibility. A range of candidate stands that would likely benefit from the template was then established using the imminent competition mortality relationship. This was done in recognition that stands which have been growing at a high density for a long time such that there is already significant competition-related mortality may no longer have the growth capacity or stability to respond well to the template prescription and thus additional factors need to be considered before pursuing the template. *Figure 1* is the resulting management diagram and illustrates the target density range for both options over time. The shaded area represents stand conditions that would be good candidates for the template.

The key outcomes of the template are summarized in *Table 1*, with the default regulatory option in western Washington included as a reference point. Over a 140-year simulation, the template options achieved the desired conditions more than twice as long as the default regulatory option. This reflects the effectiveness of the repeated, heavy thinnings for accelerating the development of old forest conditions. At the same time, the thinnings generated significant revenue, resulting in a positive return to land (soil expectation value or SEV) of over $200, up from a net loss of $215 under the regulatory option. To validate the results of this template under a range of conditions, additional simulations were done that managed along the boundaries of the target region instead of the midpoint. Additional test stands, representing a range of starting conditions, were also simulated. In all cases the template consistently performed well relative to both criteria.

The results of this template demonstrate how both biodiversity and economic goals can be achieved together. The template format also offers straightforward implementation for practitioners. The conditions of a young overstocked stands (limited to site class II for this example) can be located by age and density on the management diagram in *Figure 1*. If they fall within the candidate stand region, they can be thinned to within the target density region. Subsequent thinnings can then be done over time to maintain a trajectory within the target density region. Timing and operational flexibility are built into the template, as well as additional flexibility by offering two options. While this template has not yet received regulatory approval, which is necessary before actual implementation, it provides a valuable example for landowners and regulators to work with.

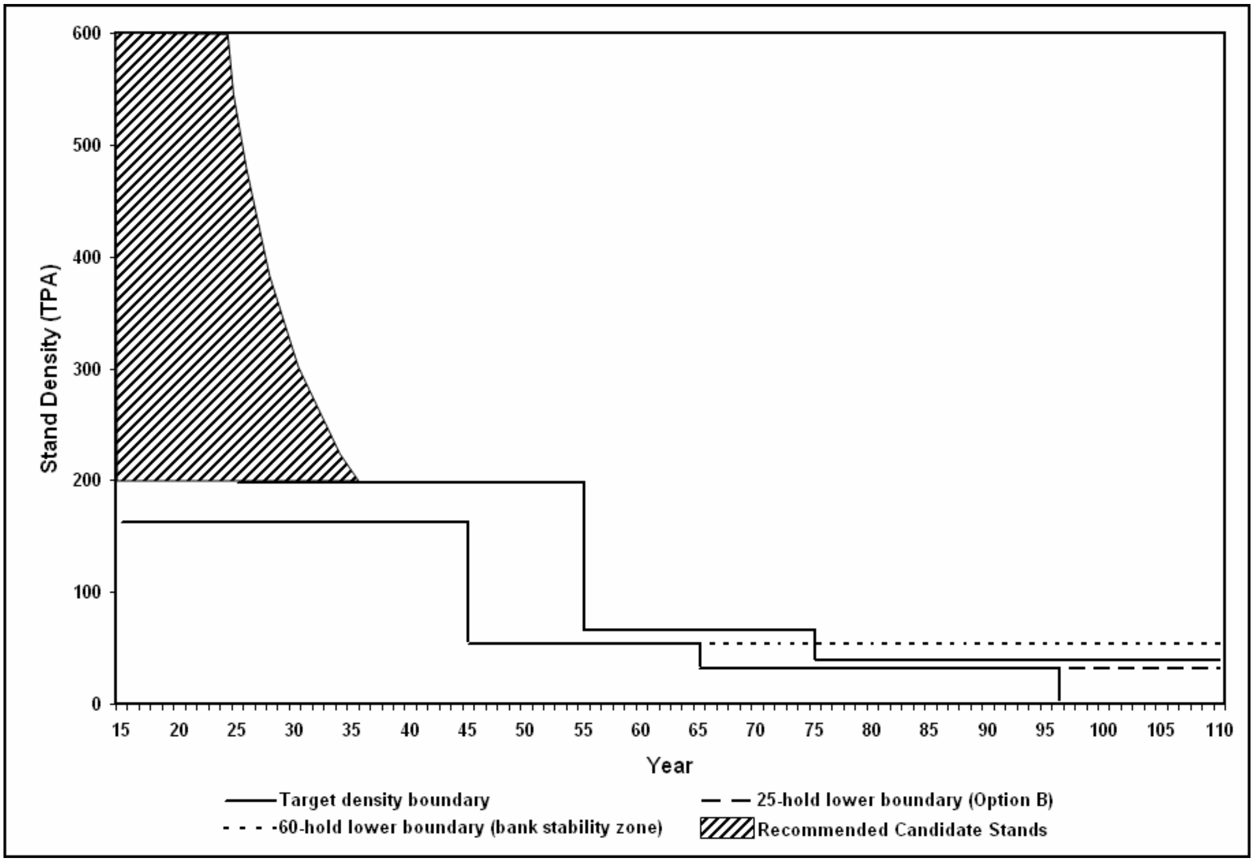

Figure 1: Management diagram for the riparian template. Stands that fall in the shaded candidate stand region can be thinned such that their trajectory follows the target density region. The dashed lines indicate density floors for the bank stability zone and the remaining buffer under Option B.

Table 1: Template results for the key criteria: percent time in the desired structure target over a 140-year simulation (biodiversity performance metric) and return to land or SEV per riparian acre (economic performance metric). Both template options resulted in significant improvement for both criteria relative to the default Washington regulatory option.

Template Option	% of time over 140 years that desired conditions are achieved	Return to land (SEV) per riparian acre
Option A	70.2%	$208
Option B	64.9%	$207
WA regulations	32.1%	-$215

3. Key findings of the southern literature review

As with Douglas-fir forests in the Pacific Northwest, the overall key to providing for biodiversity in southern loblolly pine plantations is to provide structural diversity (Allen et al. 1996, Marion et al. 1986, Sharitz et al. 1992). An open stand structure with a diverse, productive grass-herb understory is more similar to the natural, fire-maintained pine communities that were historically present and can support a broad suite of plants and wildlife (Bragg 2002, Hedman et al. 2000, Noss 1988).

Maintaining an open canopy with a diverse understory can be achieved with heavy thinnings early and often in the rotation. This may allow a dense hardwood midstory to develop, though, which would shade out the understory and negate the benefits of thinning. Consequently, hardwood control will be necessary either by prescribed burning or with mid-rotation herbicide applications. Hardwoods should not be eliminated entirely. A mast producing component should be maintained to provide wildlife food and structural diversity.

Light to moderate site preparation is best for biodiversity, and mechanical methods may perform better in this respect than herbicides. Fertilization can benefit wildlife by increasing understory growth, but it should be done in conjunction with thinning to maximize benefits. Key structural features such as snags, coarse woody debris, and mature trees should be maintained, along with riparian buffers to protect aquatic areas and provide for habitat connectivity. Long rotations are necessary to provide a broader range of age classes, though the economic impacts may be a consideration.

Biodiversity is ultimately achieved at the landscape level, but stand-level changes can go a long way towards making improvements and can be implemented regardless of ownership pattern. Land use history is an important consideration, as old field sites are unlikely to support a diverse stand structure regardless of management practices. Economics should also be considered, as management practices to increase biodiversity need to be economically viable if they are to be successful on private lands. Opportunities for hunting lease revenue may offset some of the costs of managing for biodiversity.

A complete review and reference list is available as a technical report (see Deliverables).

4. Southern template results

In the South, open, park-like stands with rich, herbaceous understories characteristic of the longleaf pine/wiregrass communities that historically dominated the region are recognized to provide for high levels of biodiversity (Bragg 2002, Hedman et al. 2000, Noss 1988). Using the same overall approach as the Pacific Northwest riparian template, we developed an example southern template was designed to achieve these conditions while maintaining acceptable economic returns through the production of high-quality sawtimber and increased potential for supplemental income through hunting leases. A dataset of “benchmark” stands representative of the desired conditions (collected by Hedman et al. 2000) was used as a target against which to assess potential template options. The percentage of time over a 100-year rotation that the desired conditions target was achieved served as the biodiversity performance metric. The net return to land or soil expectation value (SEV) was used as the economic performance metric.

Nine potential options were examined, with rotation lengths ranging from 25 to 55 years and different frequencies and intensities of thinning (*Table 2*). The results of each alternative are summarized in *Table 3*. Three of the 55-year rotations (alternatives 6-8) resulted in the highest percentage of time in the desired stand structure target over a 100-year simulation (48%). These alternatives did not achieve the highest SEV, which implies an opportunity cost relative to the alternative that performed the best economically (alternative 5). However, the economic performance of these three alternatives was still competitive, especially if it is assumed that hunting lease premiums are associated with higher time in target scores. Of these three alternatives that had high time in target scores, alternative 7 had the lowest SEV cost per percent time in target, producing the desired structure very efficiently. For supporting significantly increased biodiversity while maintaining a competitive economic performance, this emerged as the overall most desirable template option.

Table 2: Timelines for the nine potential southern template alternatives that were examined. Each alternative included a commercial thin at age 15 that removed 30% by volume. Subsequent commercial thins were either to 60 or 80 ft^2 of basal area (BA). Rotation lengths ranged from 25 to 55 years.

Alt	Year 15	20	25	30	35	40	45	50	55
1	Thin 30%		Clear-cut						
2	Thin 30%		Thin 60 BA		Clear-cut				
3	Thin 30%		Thin 80 BA		Clear-cut				
4	Thin 30%		Thin 60 BA			Clear-cut			
5	Thin 30%		Thin 80 BA			Clear-cut			
6	Thin 30%		Thin 60 BA		Thin 60 BA		Thin 60 BA		Clear-cut
7	Thin 30%		Thin 80 BA		Thin 80 BA		Thin 80 BA		Clear-cut
8	Thin 30%		Thin 60 BA			Thin 60 BA			Clear-cut
9	Thin 30%		Thin 80 BA			Thin 80 BA			Clear-cut

The full prescription for alternative 7 is as follows:

- First commercial thin at age 15, removing 30% of the volume
- Prescribed burning starting at age 20 and repeated every 5 years
- Next commercial thin at age 25 to 80 ft^2 of basal area (BA), repeated every 10 years
- Maintenance of a mast-producing hardwood component throughout the rotation
- Clear-cut harvest at age 55

Table 3: Results of the nine template alternatives, including the percent time in the desired structure target over a 100-year simulation (biodiversity performance metric) and SEV/acre (economic performance metric) with and without hunting lease premiums. Alternative 7 emerged as the preferred alternative, achieving the highest time in target score at a relatively low cost.

Alternative	% Time in Target	Without hunting lease premium			With hunting lease premium		
		SEV/Acre	**SEV Cost**	**Cost/% in target**	**SEV/Acre**	**SEV Cost**	**Cost/% in target**
1	0%	($20)	$639	N/A	($2)	$639	N/A
2	14%	$423	$196	$14	$442	$195	$13.93
3	14%	$480	$139	$9.93	$499	$138	$9.86
4	24%	$466	$153	$6.38	$503	$134	$5.58
5	14%	$619	$0	$0	$637	$0	$0
6	48%	$305	$314	$6.54	$360	$277	$5.77
7	48%	$413	$206	$4.29	$469	$168	$3.50
8	48%	$382	$237	$4.94	$438	$199	$4.15
9	38%	$415	$204	$5.37	$452	$185	$4.87

The results of this template demonstrate how the same approach used in the Pacific Northwest can be used to achieve biodiversity and economic goals in southern loblolly pine plantations. One difference in the southern template process was that the coarse filter analysis using time in target and SEV provided good discrimination between alternatives such that a fine filter metric (e.g. LWD in the Pacific Northwest) was not necessary to identify a preferred alternative. One of the challenges in developing the southern template was that data were not as readily available. The Hedman dataset was adequate to develop an example template, but it was fairly small and should be augmented with additional data points for a more robust template development process. Given the "proof of concept" established by this example template, once additional data is available it should be straightforward to create additional southern templates for a range of conditions and with a range of outcomes.

IV. Approach

The overall approach for developing templates is illustrated in *Figure 2*. The foundation of the approach was a review of scientific literature to identify desired structure conditions that were likely to support high levels of biodiversity. The desired conditions for riparian Douglas-fir stands in the Pacific Northwest were identified as those of mature, natural stands that are characterized by large conifers and high structural diversity. For southern loblolly pine stands, the desired conditions were identified as open, park-like conditions with rich, herbaceous understory vegetation characteristic of the fire-maintained longleaf pine forests that historically dominated the region.

The next step was to quantify the desired conditions using a reference dataset of actual stands that are representative of the desired conditions. The simultaneous distributions of key structure variables from the reference dataset can be used to establish a management target. A statistical assessment procedure can then be used to determine whether or not the structure attributes of an observed stand fall within that target. Observed stand conditions that fall within the target are statistically similar to the reference dataset (Gehringer in press).

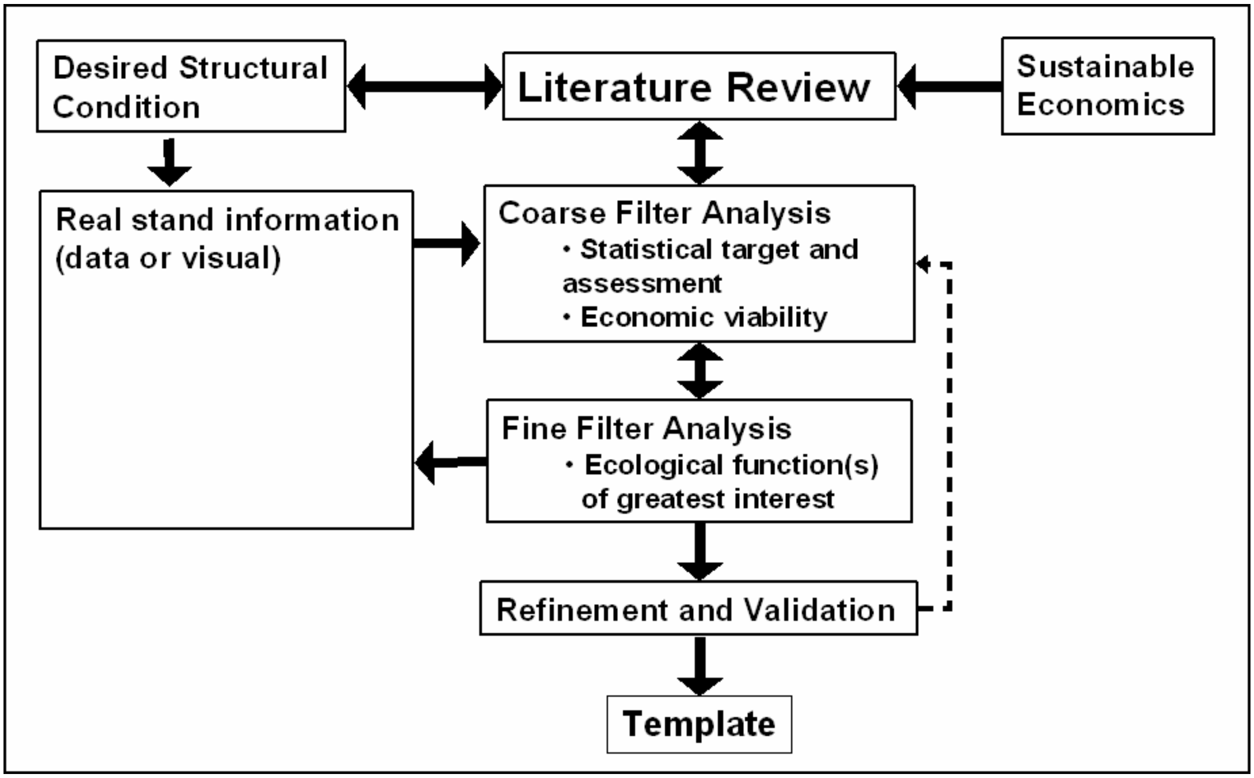

Figure 2: An illustration of the overall approach for this project. A literature review is the foundation for identifying desired stand conditions and generating potential management alternatives. These alternatives are then put through several levels of analysis to identify preferred template alternatives.

For the Pacific Northwest template, a reference dataset was established using subplots from the Pacific Resource Inventory, Monitoring, and Evaluation (PRIME) database, which is part of the USDA Forest Service's Forest Inventory and Analysis (FIA) program. Subplots were selected that were representative of mature, unmanaged, riparian stands based on their age, distance from a stream, and management history. Three attributes were used to describe the structure of this dataset: stand density in trees per acre (TPA), quadratic mean diameter (QMD), and average height computed using only trees greater than 12 inches in DBH. The distribution of values for these attributes, when considered simultaneously, established a three-dimensional target region. This target region was then refined by identifying a 90% acceptance region around the mode (the most likely value of the data distribution) to reduce the influence of the most extreme or outlying data points(*Figure 3*).

A dataset collected by Hedman et al. (2000) of "benchmark" plots that were characteristic of historic, open longleaf pine stands was used to represent the desired conditions for the southern template. Four key structural attributes were identified from this dataset: the density and quadratic mean diameter (QMD) of larger trees, and the density and QMD of smaller trees. The distributions of values for these four attributes were used to create a four-dimensional target region. The four-dimensional target can be represented visually by splitting the large tree and small tree density and QMD components into sub-targets that can be plotted in two dimensions

(*Figure 4*). Because of the small size of this dataset, a 95% acceptance level was used to refine this target.

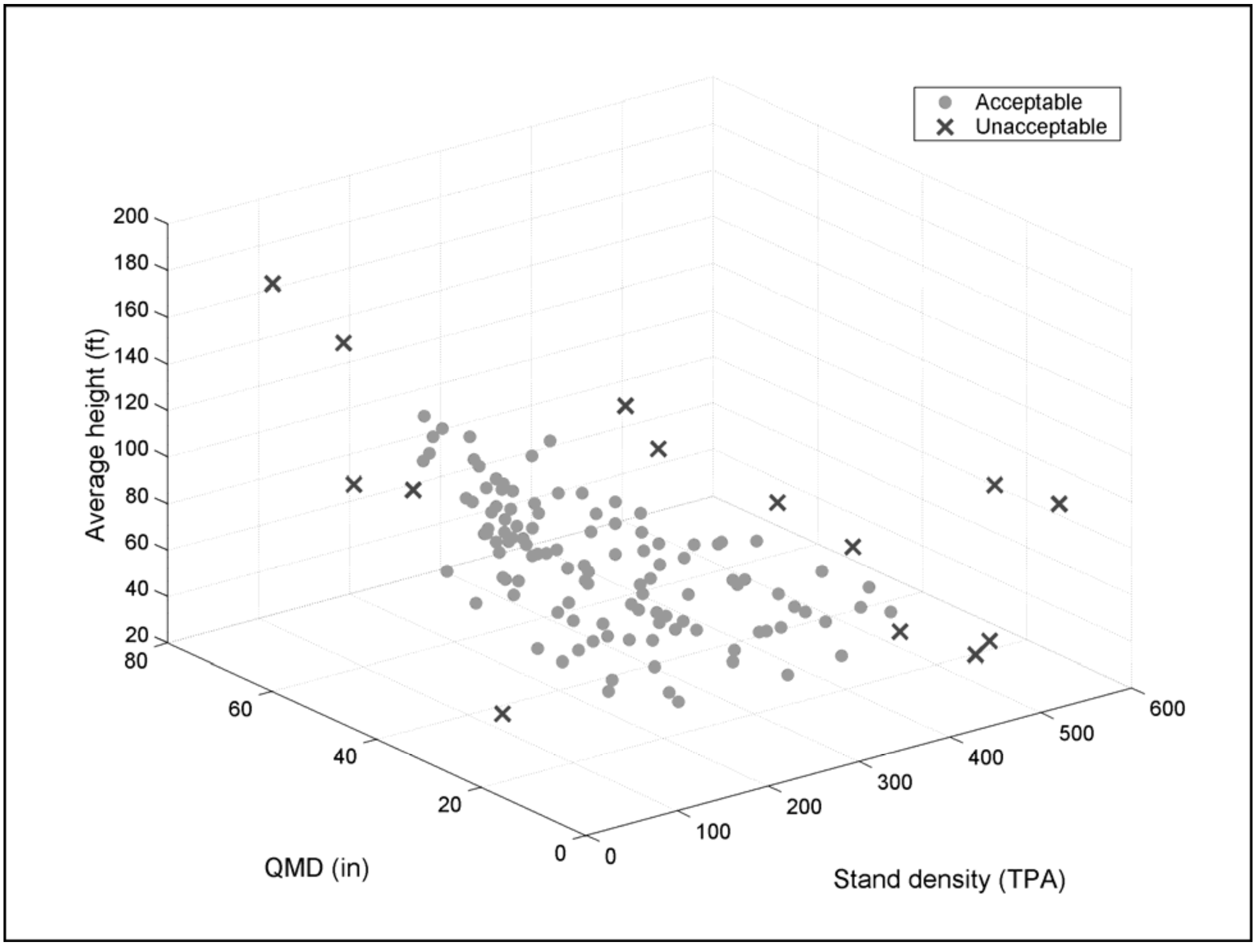

Figure 3: The three-dimensional management target for the Pacific Northwest template. The grey dots represent the 90% acceptance region. A stand whose observed attributes fall within this cluster is statistically similar to the reference dataset of desired conditions.

The literature was then used to identify management strategies that were likely to achieve the desired conditions, with an emphasis on practices that were also compatible with timber production and economic goals. A series of potential template options was then developed for simulation using the Landscape Management System (LMS). LMS is a program that integrates growth, treatment, and visualization models under a single, user-friendly interface (McCarter et al. 1998). LMS includes a number of regional variants of publicly available single-tree growth models. The Stand Management Cooperative (SMC) variant of the ORGANON growth model (Hann et al. 1997) was used to simulate the Pacific Northwest template options. The southern simulations were done using the Southern Variant of the USDA Forest Service's Forest Vegetation Simulator (FVS) (Donnelly et al. 2001, Stage 1973, Wykoff et al. 1982).

Alternatives were simulated using actual inventory data that were representative of the starting conditions to which the template was intended to be applied. A 20-year-old Douglas-fir plantation in southwest Washington that was representative of a dense plantation approaching its first commercial thinning was used as the test stand for the Pacific Northwest template. A 10-year-old loblolly pine plantation from southwest Georgia (part of the dataset collected by Hedman et al., 2000) was used as the test stand for the southern template.

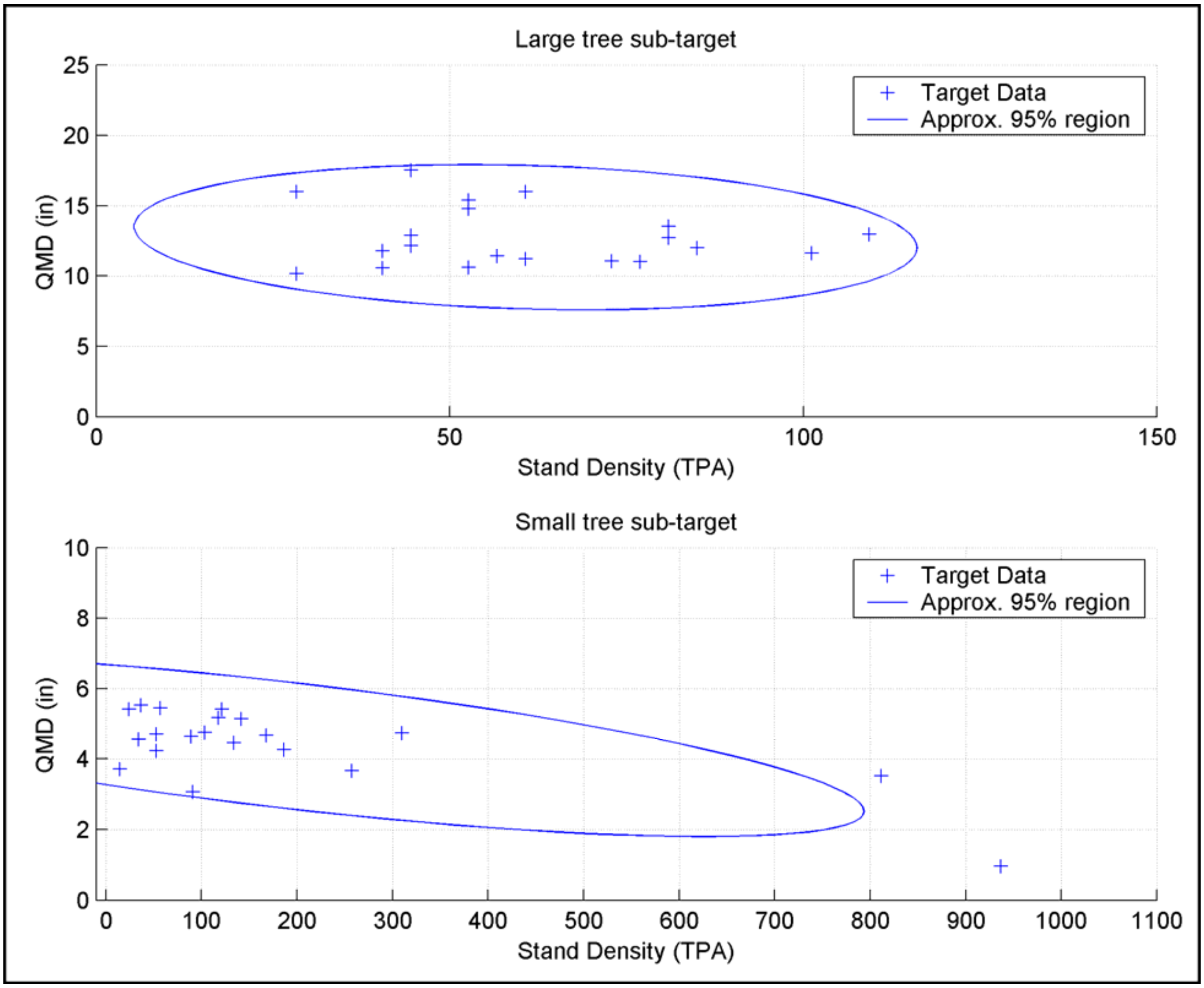

Figure 4: The 4-dimensional management target for the southern template is split into larger tree and smaller tree stand density and QMD sub-targets that can each be plotted visually in two dimensions. A stand whose observed attributes simultaneously fall between both of these ellipses is statistically similar to the reference dataset of desired conditions.

A "coarse filter" analysis of each alternative was done by evaluating projected outcomes relative to specific performance criteria for both biodiversity and economics. The percent of time that the target conditions were achieved over the simulation period (140 years for the Pacific Northwest; 100 years for the South) was used as the biodiversity performance criterion. Soil expectation value (SEV) was used as the economic performance criterion. SEV represents the net return to bare land for a complete management rotation repeated in perpetuity (Klemperer 1995). SEV was used as the criterion in recognition that the long-term (multiple rotation) application of a template requires achieving an acceptable rate of return when starting from bare land. A 5% target real rate of return was used, which is typical for financial analysis calculations.

The coarse filter analysis was used to identify viable template options that met minimum criteria for sustainability. In the case of the southern template, the coarse filter analysis offered enough discrimination between alternatives such that a preferred alternative emerged. For the Pacific Northwest template, there were several viable options and so a "fine filter" analysis was done by evaluating template performance relative to an ecological function of particular interest. In this case, potentially available LWD volume was chosen as a fine filter criterion. LWD provides important in-stream functions, and long-term sources of LWD are typically lacking in areas of intensive management (Bilby and Bisson 1998). Conditions that provide for a long-term source of LWD recruitment are also likely to provide for other important functions such as shade, bank stability, and organic inputs, as well as streamside habitat. The potential LWD volume was simulated for the 12 viable template alternatives using a potentially available LWD model (Gehringer 2005). Based on the fine filter analysis, two preferred alternatives emerged.

Once preferred template alternatives are identified, they can be further refined and validated as needed. Management pathways can be adjusted and tested to see if performance can be further improved. Template options can be simulated using additional test stands to evaluate a range of starting conditions. Finished templates become the basis for a set of specific but flexible management steps and implementation guidelines for practitioners.

V. Deliverables

The deliverables for this project include four technical reports:

1. *A literature review of management practices to support increased biodiversity in intensively managed Douglas-fir plantations*

2. *A template for managing riparian areas in dense, Douglas-fir plantations for increased biodiversity and economics*

3. *A literature review of management practices to support increased biodiversity in intensively managed loblolly pine plantations*

4. *Management templates for increased biodiversity and economics in intensively managed loblolly pine plantations*

The technical reports are intended for use by practitioners and provide detailed information about the four main parts of this project. The literature reviews identify a wide spectrum of different management practices that can be used to support increased biodiversity in intensively managed forest plantations. These literature reviews are the foundation of the templates, and they include extensive reference lists. The template reports include detailed descriptions of the methods and results of each template, including diagrams and implementation guidelines.

Several presentations will be delivered to help communicate the results of this project. A presentation covering the southern template process and applications will be given at the NCSSF Sustainable Forestry Tools and Applications Workshop in Washington, DC in September 2005.

A presentation giving an overview of the entire project, including both templates, will be given at the Society of American Foresters (SAF) National Convention in Dallas, TX in October 2005. Additional presentations will be given to regional forester and landowner groups as opportunities arise, and streaming video of key presentations will be made available online to a worldwide audience through the Rural Technology Initiative (www.ruraltech.org).

A paper corresponding to the SAF convention presentation will be submitted for publication in the convention proceedings. An article specifically covering the southern template will be submitted to a refereed, scientific journal. A refereed journal article on the Pacific Northwest template has already been published (See Zobrist et al. 2004). While this article predates the sponsorship from NCSSF, it was the basis for this project and is thus an important associated deliverable.

VI. References

This list of references includes literature cited in this report as well as selected key references from the four technical reports.

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Technical Report A: A literature review of management practices to support increased biodiversity in intensively managed Douglas-fir plantations

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A literature review of management practices to support increased biodiversity in intensively managed Douglas-fir plantations

Final Technical Report to the National Commission on Science for Sustainable Forestry (NCSSF)

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Technical Report A Contents

I. Introduction

The west side of the Cascade Range in the Pacific Northwest region of the United States is home to highly productive forestland in a mix of public and private ownerships. While public ownerships have been managed predominantly for non-timber objectives in recent years, private ownerships are often comprised of Douglas-fir (*Pseudotsuga menziesii*) plantations that are intensively managed for wood production. These plantations supply important wood products, but there is also interest in the ability of these lands to provide non-timber values, such as biodiversity, at the same time.

Intensively managed Douglas-fir plantations are characterized by relatively short, clear-cut rotations and the use of genetically superior stock, vegetation control, thinning, and other practices to improve production (Adams et al. 2005). As such, these plantations are very different in structure and function from natural forests, as they tend to lack structural diversity and later seral stages (Hansen et al. 1991, Hayes et al. 2005, Helgerson and Bottorff 2003). Even so, intensively managed plantations still provide forest cover and thus support greater biodiversity than competing, non-forest land uses such as agriculture or development (Hayes et al. 2005, Moore and Allen 1999). More importantly, there are stand-level management changes that can support increased biodiversity in plantations while still achieving wood production and economic goals (Hartley 2002, Moore and Allen 1999). In this report we review the literature to identify a spectrum of practices that support increased biodiversity in intensively managed Douglas-fir plantations.

II. Management practices to support increased biodiversity

Biodiversity is the variety of all life at the genetic, species, and ecosystem scale for a given area (Hunter 1999, Oliver 1992, Patel-Weynand 2002, Reid and Miller 1989). Management approaches for increasing biodiversity should target a broad range of species, as focusing on individual species can be costly and result in management conflicts (Curtis and Carey 1996, Wigley and Loehle 2004). To meet the needs of a broad range of species, structural diversity is needed to provide a variety of habitat elements (Helgerson and Bottorff 2003, Muir et al. 2002). This requires complex three-dimensional canopy attributes and spatial relationships (Franklin and Van Pelt 2004, Helgerson and Bottorff 2003, Ishii et al. 2004, Parker et al. 2004, Spies 1998, Zenner 2004). This report will focus on increasing structural complexity at the stand level, though maximum complexity is ultimately achieved at the landscape scale (Helgerson and Bottorff 2003, Oliver 1992).

Our review on practices to increase complexity will examine ways to promote both vertical (e.g., layers) and horizontal elements of structural diversity. Increased vertical and horizontal structural diversity are noted elements of old-growth forests, and these elements are highly correlated with both increased biological diversity and specific diversity and functions uniquely associated with old-growth systems. However, it is important to note that the immediate creation of one or more elements of structural diversity (e.g., multiple canopy layers, large live and dead trees, gaps, etc.) is not instantaneously translated into conditions suitable for old-growth or late-seral dependent wildlife or epiphytic species; there may be a delay. Structural manipulations merely create the structures suitable for these old-growth or late-seral dependent species; however, these manipulations should greatly shorten the time necessary for occupancy.

One of the most important ways to increase stand-level structural diversity is by thinning. Plantations are usually established at high densities, typically around 435 trees per acre or greater (Scott et al. 1998, Talbert and Marshall 2005, Woodruff et al. 2002). Under these conditions, the canopy quickly closes, and the stand moves into the stem exclusion stage in which the understory vegetation is shaded out (Oliver and Larson 1990). Dense stands in this stage support few wildlife species (Hayes et al. 1997, Oliver and Larson 1990). In addition, many planted and naturally regenerated stands of Douglas-fir are so dense in the stem exclusion stage that stand differentiation is slowed and delaying thinning may result in considerable risk to wind throw (Wilson and Oliver 2000).

Numerous studies have documented the positive effects of thinning on stand structure and biodiversity. Thinning opens up the stand and allows light to reach the forest floor. This provides for better developed understories with greater richness, diversity, and cover (Bailey et al. 1998, Curtis et al. 1997, Thomas et al. 1999, Thysell and Carey 2000). Studies have found that thinned stands have greater herbaceous cover (Carey and Wilson 2001, Muir et al. 2002), greater understory trees and shrubs (Bailey and Tappeiner 1998, Muir et al. 2002, Tappeiner and Zasada 1993), and greater density, survival, and growth of conifer seedlings (Bailey and Tappeiner 1998, Brandeis et al. 2001, DeBell et al. 1997, Muir et al. 2002). These elements provide forage for wildlife. They also allow the stand to develop multiple layers, which increases vertical diversity (Bailey et al. 1998, Bailey and Tappeiner 1998, Muir et al. 2002). To keep the canopy open and minimize the stem exclusion stage, thinnings should be heavy (Beggs et al. 2005) and intervals should be frequent (He and Barclay 2000).

In addition to identifying links between thinning and stand structure, studies have also found direct links between thinning and wildlife abundance. Havari and Carey (2000) observed that thinning resulted in more winter birds. Similarly, Hayes et al. (2003) noted that thinning had an overall positive impact on birds, including providing for birds that were otherwise rare or absent. Thinning has also been noted to increase the abundance of small mammals (Suzuki and Hayes 2003, Wilson and Carey 2000).

Thinning can accelerate the development of old forest conditions. This type of structure is particularly desirable for biodiversity, as it is highly complex (Franklin and Van Pelt 2004) and supports a variety of species, some of which depend on late seral structures (Franklin and Spies 1991). This structure is the most lacking on the landscape and difficult to replace (Curtis et al. 1998). Key features of the structural complexity of old forests are large conifers (Zenner 2004). Lower stand densities allow for greater tree diameter growth (Curtis et al. 1997), and early, heavy thinnings can thus accelerate the development of large trees (Beggs et al. 2005, Poage and Tappeiner 2002, Zenner 2004). Indeed, retrospective studies of natural, old-growth stands have found that these stands often developed at much lower densities and over much longer initiation periods than today's dense, intensively managed plantations (Poage and Tappeiner 2002, Tappeiner et al. 1997). Not all old-growth stands developed at low densities, and natural, well-differentiated stands may not need thinning to achieve old forest structure (Winter et al. 2002).

However, the uniform age and spacing of plantations makes them particularly subject to poor differentiation and even stagnation (Oliver and Larson 1990). Repeated, heavy thinnings in these stands can allow them to develop structure similar to natural, old forests in a much shorter time period than would occur if high densities were maintained (Barbour et al. 1997, Busing and Garman 2002, Carey et al. 1999a, Garman et al. 2003, Latta and Montgomery 2004, McComb et al. 1993, Poage and Tappeiner 2002, Tappeiner et al. 1997).

How thinning is done can have a significant impact on its effectiveness towards increasing structural diversity. Thinning can be done from below, which maximizes tree size and canopy height diversity (Busing and Garman 2002) and promotes understory development (Carey and Johnson 1995). Thinning can also be done proportionally, allowing shade-tolerant species to be recruited into the overstory (Busing and Garman 2002). Instead of traditional, uniform thinning, irregular thinning with different densities, unthinned areas, and openings can greatly enhance structural diversity (Curtis et al. 1998, Helgerson and Bottorff 2003). This is also called variable density thinning, which treats alternating areas of usually around 0.25 to 0.5 acres leaving two or more different levels of residual density (Carey and Curtis 1996, Carey and Johnson 1995, Carey et al. 1999b, Carey and Wilson 2001). Variable density thinning is intended to mimic natural forest processes of suppression and mortality to create a structural mosaic and maintain wind stability (Carey et al. 1999b).

In addition to maintaining a mix of different densities, maintaining a mix of different species is also important for creating structural diversity (Curtis et al. 1998, Hayes et al. 1997, Helgerson and Bottorff 2003). Hardwoods are particularly important habitat elements for wildlife, including small mammals (Carey and Johnson 1995) and birds (Hagar et al. 1996, Muir et al. 2002). Maintaining a mixture of different conifer species, especially shade tolerant species, further adds structural complexity by providing different tree sizes, live-crown lengths, and shapes (Zenner 2000). Thinning practices, especially pre-commercial thinnings that typically remove non-crop trees, should be modified to leave a variety of tree sizes and species (Curtis et al. 1998, DeBell et al. 1997). Douglas-fir plantations can even be planted with other species, such as red alder (*Alnus rubra*) or western redcedar (*Thuja plicata*), to develop a multilayered stand (Tappeiner et al. 1997).

Another important way to increase stand-level structural diversity is to retain biological legacies. Retaining biological legacies such as large, live trees, snags, and downed wood can better mimic natural disturbances and give plantations a structure more similar to natural stands (Franklin et al. 2002, Hansen et al. 1991). Variable retention harvests retain some level of these key features at the time of harvest and leaves them through the subsequent rotation to enhance structure (Barg and Hanley 2001, Franklin et al. 1997). Variable retention harvests can “lifeboat” species by helping them to tolerate harvest conditions, create habitat features much sooner than would be possible without legacies, and facilitate dispersion (Franklin et al. 1997).

There are two spatial approaches to variable retention harvests: leaving retention evenly dispersed throughout the stand or aggregating it in clumps. Dispersed retention provides retention throughout the stand, but it also poses some operational challenges and hazards. Aggregated retention has fewer operational challenges and allows for protection of elements like snags, sensitive areas, and undisturbed areas (Barg and Hanley 2001, Franklin et al. 1997). A mix of aggregated and dispersed retention can achieve good results for both biodiversity and timber production (Franklin et al. 1997). In addition to protecting existing snags and downed wood as part of a retention strategy, these features may also need to be artificially created in stands that are lacking dead wood (Barbour et al. 1997, Curtis et al. 1998, DeBell et al. 1997, Franklin et al. 2002, Garman et al. 2003).

Retaining buffers to protect riparian areas from harvest impacts is another important practice when managing for biodiversity. Riparian forests are areas of high diversity of both species and ecological processes (Naiman et al. 1993, 1998). Riparian areas not only provide habitat for obligate species that depend on them, but they provide significant habitat for generalist species as well (Carey and Johnson 1995, Kelsey and West 1998). Because of the high diversity and important habitat provisions of these areas, riparian protection can play a significant role and should be a priority for providing for biodiversity on the landscape (Carey and Johnson 1995, Naiman et al. 1993). Leaving riparian buffers can also help meet legacy retention needs (Franklin et al.1997).

Additional management activities such as underplanting, fertilization, and pruning can also be used to improve structural diversity in plantations. Underplanting in gaps or thinned areas may be needed to help establish multiple layers (Barbour et al. 1997, Brandeis et al. 2001, DeBell et al. 1997, Thysell and Carey 2000). Fertilization can hinder understory development by accelerating canopy closure (Thomas et al. 1999). However, applying fertilizer to individuals or groups rather than uniformly can promote differentiation and greater vertical diversity (Curtis et al. 1998, DeBell et al. 1997). Pruning can also be applied variably to add diversity and allow more light to reach the forest floor (DeBell et al. 1997). Relatively early pruning, coupled with thinning, can create increased space for birds to fly within the stand. In addition to structurally altering the treated stand, this intermediate operation may enhance the ability of young stands to serve as connectors between older, more structurally diverse stands.

Ultimately, practices to increase biodiversity in intensively managed plantations will be most effective in conjunction with longer rotations. Longer rotations are necessary to accommodate pathways that use multiple thinnings to increase structural diversity. Even though thinning and legacy retention can greatly accelerate the development of complex, old forest conditions, it still takes around 100 years to develop these conditions (Carey et al. 1999a, Latta and Montgomery 2004, McComb et al. 1993). Typical commercial rotations of Douglas-fir range from 30 to 50 years (Adams et al. 2005).

Longer rotations also have significant landscape-level benefits. Long rotations can help balance the distribution of age classes on the landscape by allowing for the development of later seral stages, whereas short rotation management limits stands to only the early seral stages with the majority of stands being in the stem exclusion stage (Curtis 1997, Curtis and Carey 1996, Curtis et al. 1998). Longer rotations would also reduce the amount of land harvested each year, minimizing the level of major disturbance on the landscape (Curtis 1997, Franklin et al. 1997).

III. Biodiversity pathways

The practices described above can be combined to create "biodiversity pathways" for forest management. Biodiversity pathways begin with legacy retention at the time of harvest, less intensive site preparation to conserve downed wood and other forest floor substrates, and planting at wider spacing. Successive variable density thinnings are done over longer rotations. These thinnings are heavier than traditional commercial thinnings and favor multiple species. The goal of biodiversity pathways is to minimize the dense stem-exclusion stage and accelerate the development of old forest structure and function to support increased biodiversity (Carey and Curtis 1996, Carey et al. 1996).

Simulations of biodiversity pathways for western hemlock forests of the Olympic Peninsula in Washington predicted that 98% of potential ecosystem health would be achieved and that 30% of the landscape would be in late seral conditions within 100-120 years. In comparison, timber production pathways did not achieve desired conditions because rotations were too short. It took at least 180 years for the desired conditions to be achieved under the no action alternative, leaving much of the landscape in a prolonged stem exclusion stage in the meantime (Carey et al. 1996, Carey et al. 1999a). Using the same principles, biodiversity pathways could also be developed for intensively managed Douglas-fir plantations as an overall strategy for supporting increased biodiversity in both riparian and upland areas.

IV. Economic considerations

When considering management practices to support increased biodiversity, it is important to also consider the economic impacts. Intensively managed Douglas-fir plantations on private ownerships are business enterprises for which landowners expect some level of economic return. Practices to increase biodiversity are unlikely to be successfully implemented on these ownerships if they are cost prohibitive. Unfavorable economic returns can even motivate landowners to convert their forestland to non-forest uses (Murphy et al. 2005). There is already concern about recent trends in forestland conversion in the Pacific Northwest (MacLean and Bolsinger 1997, WADNR 1998). Maintaining favorable economic returns should be a key component of strategies to increase biodiversity on intensively managed plantations, as forest conversion is the worst scenario for biodiversity.

The practices described above do have associated economic trade-offs. Heavy thinnings can result in lower economic returns, as growing space is not as fully utilized (Carey et al. 1999a, Hayes et al. 1997, Lippke et al. 1996). Variable retention harvesting increases logging costs and retention can impact the growth of the subsequent rotation, which decreases wood production (Franklin et al. 1997). Long rotations result in perhaps the most significant costs, as delaying harvest revenues until further in the future significantly discounts the present value of those revenues relative to management costs (Carey et al. 1999a, Latta and Montgomery 2004, Lippke et al. 1996). Some even suggest that shorter rotations are necessary if plantations in the Pacific Northwest are to remain economically competitive (Talbert and Marshall 2005).

Heavier biodiversity thinnings do have some economic benefit in that more wood is removed sooner, which can offset some present value losses. There is also some speculation that heavier thinnings and longer rotations will produce larger, higher quality wood later in the rotation that will be of higher value and thus further offset costs (Carey et al. 1999a, Lippke et al. 1996). However, more open-grown trees can also have more branches, so the overall impact on quality is unclear (Latta and Montgomery 2004). Also, more recent evidence suggests that lost price premiums have reduced the incentive to produce large logs (Talbert and Marshall 2005). Thus, high quality wood production should not be relied upon as a solution to offset biodiversity costs.

Economic incentive programs may be a cost-effective way of encouraging landowners to implement measures to increase biodiversity. Incentives can include direct financial assistance as well as educational and technical assistance. Awarding financial incentives competitively can ensure efficient allocation (Johnson 1995, Lippke et al. 1996). Regardless of whether the costs of biodiversity are borne by private landowners or by the public through cost-sharing, efforts will be most successful if the costs are minimized (Latta and Montgomery 2004). Management strategies that balance biodiversity needs with economic returns can and should be pursued.

V. Summary

Changes in stand-level management practices can support significantly increased biodiversity in intensively managed Douglas-fir plantations in the Pacific Northwest. The key to providing for a diversity of species and processes is to develop more diverse and complex stand structures. Using heavy, repeated thinnings minimizes the dense stem exclusion stage, stimulates the understory, and accelerates the development of complex, old forest structure. Favoring multiple species and sizes when thinning can enhance structural diversity. Variable density thinning, which creates a mosaic of different densities along with unthinned patches and small openings, also works well for enhancing structural diversity.

When harvesting, biological legacies such as large, live trees, snags, and downed wood should be retained to mitigate harvest impacts and provide structure for the new stand. Retention can be left dispersed throughout the stand, in aggregate clumps, or a combination. Riparian areas should be protected, as these are areas of particularly high diversity. Underplanting, selective fertilization, and pruning can also be used to add structural complexity. All of these strategies work best over longer rotation that allow enough time for complex structure to develop and minimize cumulative harvest impacts on the landscape.

These different practices for increasing structural complexity and biodiversity can be combined into overall management strategies called biodiversity pathways. Examinations of biodiversity pathways for coastal hemlock forests have been promising, and similar pathways can be developed for Douglas-fir plantations. There are economic costs to these pathways that must be considered in order to ensure successful adoption by private landowners and minimize unintended consequences such as forest conversion. Competitive incentive programs using both education and financial assistance can offset private costs. Identifying management strategies that target both biodiversity and competitive economic returns will likely be the most successful regardless of who bears the costs.

Metric equivalents

When you know:	Multiply by:	To find:
Acres	0.4047	Hectares
Trees per acre (TPA)	2.471	Trees per hectare

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Technical Report B: A template for managing riparian areas in dense, Douglas-fir plantations for increased biodiversity and economics

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A template for managing riparian areas in dense, Douglas-fir plantations for increased biodiversity and economics

Final Technical Report to the National Commission on Science for Sustainable Forestry (NCSSF)

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Technical Report B Contents

I. Introduction

Intensively managed plantation and naturally regenerated Douglas-fir forests in the Pacific Northwest are an important source of raw material for wood products and an important part of the economy in the region. These forests also support a number of other ecosystem services including non-timber forest products (NTFP) (Alexander et al. 2001, Freed 2001, Jones et al. 2004, Pilz and Molina 2002).[1] The potential of intensively managed Douglas-fir forests to support biodiversity is also becoming of greater interest. Increased biodiversity in these stands may be supported by a number of stand-level management practices. These practices include legacy retention, repeated variable density thinnings, and long rotations, among others (for a complete review, see Zobrist and Hinckley 2005). For landowners and managers interested in managing for increased biodiversity it is useful to summarize these practices as specific, but flexible, management guidelines or "templates." It is especially important to identify templates that can increase biodiversity with low costs to provide a greater likelihood of successful implementation on private ownerships (Latta and Montgomery 2004).

Riparian areas are of particular importance when managing for biodiversity, as they are "hot spots" having a high degree of species and process diversity, and they can make significant contributions to biodiversity on a landscape (Carey and Johnson 1995, Naiman et al. 1993, 1998). Riparian management is also a prominent regulatory issue in the Pacific Northwest. Both Washington and Oregon have forest practices regulations that restrict timber harvest in riparian areas to protect endangered salmon and other aquatic resources.

The goal of the regulations in Washington and Oregon is to allow the development of desired future conditions (DFC), which should mimic or equal those of complex, old forest structure in riparian areas, especially large conifers that are an important source of shade and long-term large woody debris (LWD) recruitment to streams. In the absence of active management it will likely take an undesirably long time for riparian areas in young, dense stands to achieve DFC (Carey et al. 1996, Carey et al. 1999, Chan et al. 2004). This is especially true in Washington, which requires wider buffers with significant portions where no harvesting is allowed.

Both the Oregon and Washington regulations permit landowners to deviate from the regulatory prescription and pursue alternative management plans for stands that are unlikely to achieve DFC without active management. The Washington regulations further suggest that management templates be developed for riparian stands that are overly dense, which are expected to be common situations given historical management practices. Templates would provide specific guidelines to streamline the process for developing and approving alternate plans.

Riparian management templates also provide an opportunity to improve economic returns for landowners by allowing additional revenue to be generated through biodiversity thinnings. Improving economic returns for private landowners is very important, as harvest restrictions in riparian buffers can result in significant economic losses (Zobrist 2003, Zobrist and Lippke 2003). If forestry is no longer economically competitive, the land may be converted to non-forest

[1] Many of these authors suggest that economic incentives derived from NTFP would encourage landowners to leave their forests for longer-rotations.

uses (Murphy et al. 2005), which can have a significant negative impact on biodiversity. Properties where a high proportion of the land is restricted by riparian zones would be at high risk for conversion, and these properties can be the most important for conservation.

Management templates that accelerate the development of DFC, provide favorable economic returns, and offer simple and flexible implementation for landowners and regulators are needed. Zobrist et al. (2004, 2005) have outlined a process for developing such templates and have illustrated a sample template. This sample template has now been further refined and tested. In this report we describe the methodology for developing and refining this template, expected outcomes for both biodiversity and economics, and other potential template applications.

II. Establishing template criteria

The first step in developing a template was to establish specific, measurable performance criteria. Performance criteria were needed relative to both biodiversity and economic outcomes. The key to managing for biodiversity is to achieve a desired stand structure, which is used as a surrogate for ecological functions, including the support of biodiversity (Franklin et al. 2002). A complex forest structure that includes vertical and horizontal diversity, a variety of species, and live and dead wood, is needed to support a diversity of species and processes (Helgerson and Bottorff 2003, Muir et al. 2002, Spies 1998; reviewed by Zobrist and Hinckley 2005). The structures present in natural, old forests provide a good management target (McComb et al. 1993). The processes of natural forest development result in high levels of diversity (Franklin et al. 2002), and produce a high degree of complexity (Franklin and Van Pelt 2004). Large conifers that characterize natural, old forests can provide key elements to support riparian structure and functions, such as shade and LWD recruitment.

The regulations of both Washington and Oregon specify a forest structure similar to that of natural, mature forests as the DFC. This structure can be quantified by establishing a reference data set of stands representative of the DFC. A DFC dataset has been established using subplots from the Pacific Resource Inventory, Monitoring, and Evaluation (PRIME) database, which is part of the USDA Forest Service's Forest Inventory and Analysis (FIA) program. To select conditions representative of mature, unmanaged, riparian stands, subplots were selected that were at least 80 years old, were within 215 feet of a stream, had not been treated since the previous FIA inventory,[2] and included measurements of tree heights and diameters at breast height (DBH) (*Figure 1*). The dataset includes a total of 184 subplots, 81 of which (44%) overlap with a similar dataset used in the development of the Washington regulations and the associated (linked) DFC concept.

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[2] This data selection criterion did not guarantee that selected subplots were unmanaged. With these data it was not possible to identify subplots that were treated, thinned, or harvested, prior to the last inventory taken 10 years previously. A comparison of the forest structure attributes represented in this dataset with values obtained from other old forest datasets in the region (Hiserote and Waddell 2004) indicated that the attribute values used here were consistent with those computed from the other datasets in both their ranges and distributions. These data were considered to be sufficient for demonstrating the target definition and assessment procedures and using them to develop a riparian management target.

The structural attributes of the DFC dataset were used to create a quantitative management target. Potential management plans could then be assessed to determine whether they achieve the target, producing a structure that was statistically similar to the DFC (Gehringer in press). Three attributes were used to describe the structure of the DFC dataset: stand density in trees per acre (TPA), quadratic mean diameter (QMD), and average height computed using only trees greater than 12 inches in DBH. The distribution of values for these attributes, when considered simultaneously, established a three-dimensional target region. The target region was then refined by identifying a 90% acceptance region around the mode (the most likely value of the data distribution) to reduce the influence of the most extreme or outlying data points (*Figure 2*). An observed stand whose density, QMD, and average height fell simultaneously within the 90% target acceptance region would be statistically similar to the DFC dataset.

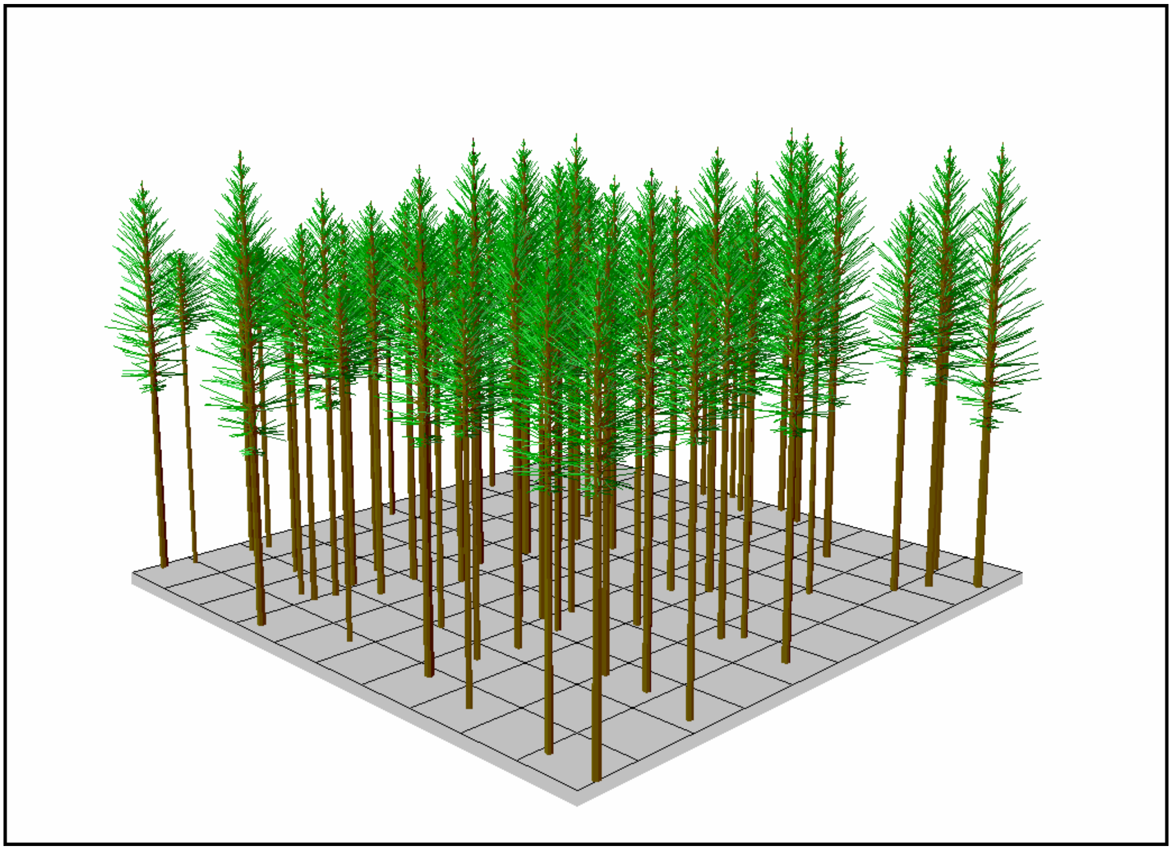

Figure 1: A visualization of the stand structure for one of the subplots in the DFC dataset that is characteristic of conditions near the mode of the dataset. This visualization was generated by the Stand Visualization System (SVS) (McGaughey 1997).

The percentage of time over a 140-year assessment period (assessed at 5-year intervals) that the stand structure for a projected management option fell within the target was established as the specific performance criterion for potential management templates. This criterion allowed the selection of template options that achieved the DFC quickly, maintained it until a regeneration harvest, and then quickly reattained it in the subsequent rotation.

In addition to a DFC criterion, an economic criterion was needed. Several metrics were considered. Soil expectation value (SEV), or bare land value, is the net present value of a complete forest rotation repeated in perpetuity given a target rate of return (Klemperer 1995). This is perhaps the most important single economic criterion, as it reflects the economic performance of the initial investment in establishing a plantation given an expected management regime. This is the metric of most relevance for landowners implementing a template that starts from bare land.

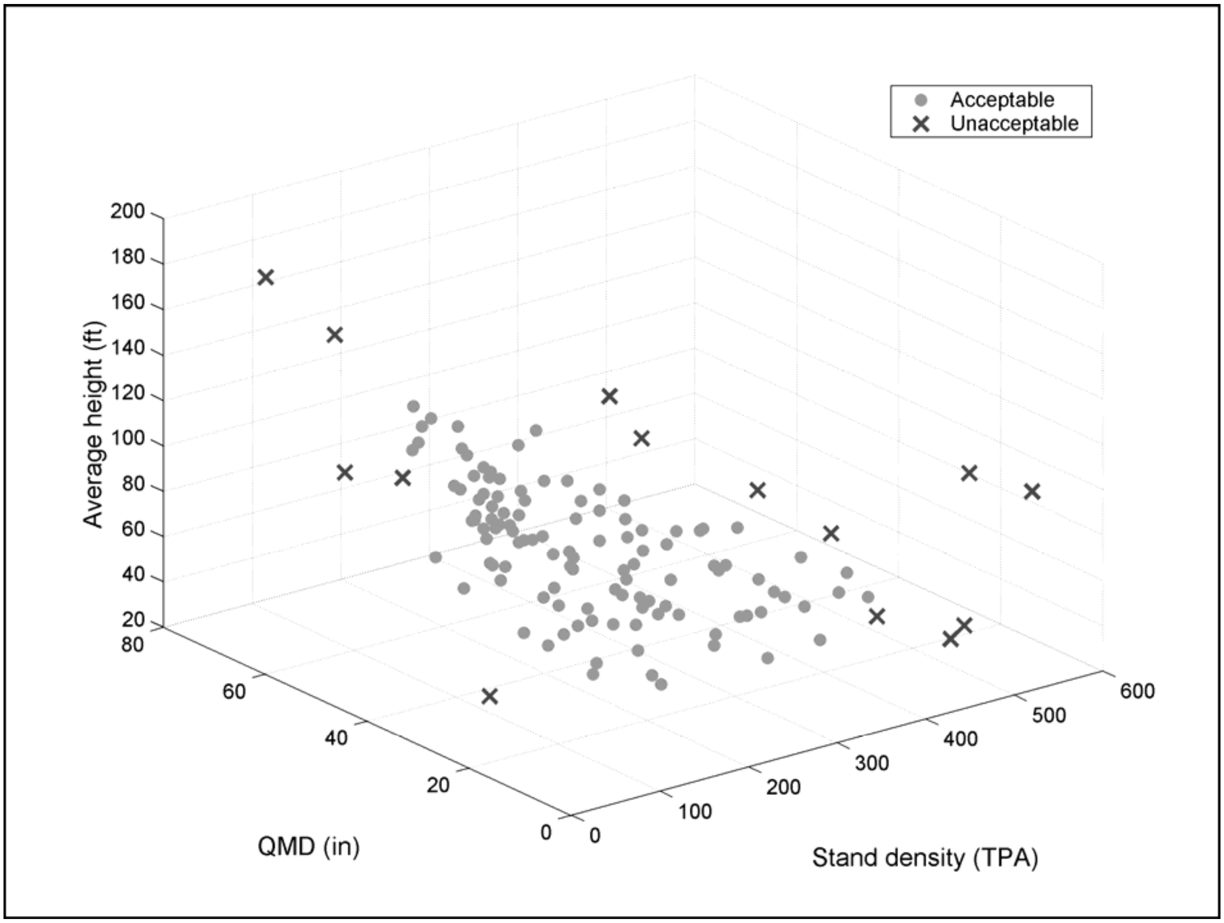

Figure 2: The 90% acceptance region of the three-dimensional structure target. The grey dots represent the central 90% of the DFC dataset, while the black Xs represent the most extreme 10% of the data points that are rejected as the outlying values. A stand whose observed attributes fell within the 90% acceptance cluster would be statistically similar to the DFC dataset.

SEV is also relevant for landowners starting with mid-rotation stands, as at some point they will reach the end of a rotation and be faced with the decision of whether or not to continue the template for additional rotations. Thus, SEV is the best indicator of long-term economic acceptability. However, landowners with mid-rotation stands may also be interested in the overall forest value (FV), which is also known as land and timber value (Klemperer 1995). FV includes SEV along with the net present value of the expected costs and revenues to hold the existing timber through the end of the current rotation, including the opportunity cost of using the land. In developing the template, we used SEV as the primary economic criterion but also considered FV for mid-rotation stands. In both cases, 5% was used as the target real rate of return, which is typical for financial analysis calculations.

III. Simulating management alternatives

We used "biodiversity pathways" as a model for developing potential template alternatives that would enhance riparian forest structure while providing acceptable economic returns. Biodiversity pathways utilize heavy, repeated thinnings over long rotations to produce complex, old forest structure more quickly and at a lower cost than with no action (Carey and Curtis 1996, Carey et al. 1996, Carey et al. 1999, Lippke et al. 1996). Based on this approach, we defined a 100-year Douglas-fir rotation assuming site class II; a 50-year site index of 115-135 feet (King 1966). The 100-year rotation included multiple thinnings, the first of which was an early commercial thinning from below to 180 TPA at age 20. Early commercial thinnings are being utilized in lieu of pre-commercial thinnings, given new markets for small diameter wood (Talbert and Marshall 2005). Subsequent thinnings from below to 60 TPA at age 50 and to 25 TPA at age 70 were performed. A clear-cut harvest was done at age 100, followed by replanting Douglas-fir to a typical density of 435 TPA (Talbert and Marshall 2005). In order to keep the costs of riparian treatments low, the timing of these entries was chosen to correspond with upland operations, which were assumed to be done on a 50-year rotation with a commercial thin at age 20 (*Table 1*).

Table 1: Timeline of riparian entries and corresponding upland operations for the 100-year Douglas-fir rotation defined for potential riparian template options based on the biodiversity pathway approach.

Year	Riparian entry	Corresponding upland operation
20	Thin to 180 TPA	Thin to 180 TPA
50	Thin to 60 TPA	Clear-cut & replant
70	Thin to 25 TPA	Thin to 180 TPA
100	Clear-cut & replant	Clear-cut & replant

Using variations of a riparian management prescription based on this 100-year rotation, 18 potential template alternatives were generated from which to select those with the best ecological and economic performance as the basis for template development. Each alternative included a 25-foot no clear-cut zone to provide for continuous shade and bank stability. One of three prescriptions was applied in this zone: no action, no entry after the thin to 60 TPA (60-hold), or no entry after the thin to 25 TPA (25-hold). Beyond this bank stability zone, either 25-hold or the full 100-year rotation was applied. There were three total buffer widths used: 50, 80, and 113 feet. These widths corresponded to divisions between buffer zones for site class II under the Washington regulations. The total width of the riparian zone was 170 feet, and was based on the site potential tree height for site class II, pursuant to the Washington regulations. The portion of the riparian zone beyond the buffer was assumed to be managed with the upland areas (50-year rotation). Specific prescriptions for the 18 alternatives are listed in *Table 2*.

The 18 riparian management alternatives were simulated using the Landscape Management System (LMS). LMS is a program that integrates growth, treatment, and visualization models under a single, user-friendly interface (McCarter et al. 1998). LMS includes a number of regional variants of publicly available single-tree growth models. The Stand Management Cooperative

(SMC) variant of the ORGANON growth model was used to simulate the template options (Hann et al. 1997). The simulations were based on an actual inventory from a 20-year-old Douglas-fir plantation in southwest Washington that is representative of a dense plantation approaching its first commercial thinning (*Figure 3*). The plantation had 472 TPA and a 50-year site index of 120 feet. The simulation length was 140 years for all prescriptions. For prescriptions that included a regeneration harvest (the 100-year rotation and the 50-year upland rotation), replanting was done to 435 TPA and the rotation repeated as necessary. The simulations included only the overstory trees and did not incorporate natural ingrowth that would be expected to occur given the heavy biodiversity thinnings.

Table 2: 18 potential template alternatives. Each alternative had a 25-foot no clear-cut bank stability zone that was thinned to 60 TPA, 25 TPA, or left unthinned. The remaining portion of the buffer varied in width and was either thinned to 25 TPA or managed on a 100-year clear-cut rotation.

Alternative	Bank stability zone prescription	Remaining buffer prescription	Total buffer width (feet)
1	No action	25-hold	113
2	No action	100-year	113
3	No action	25-hold	80
4	No action	100-year	80
5	No action	25-hold	50
6	No action	100-year	50
7	60-hold	25-hold	113
8	60-hold	100-year	113
9	60-hold	25-hold	80
10	60-hold	100-year	80
11	60-hold	25-hold	50
12	60-hold	100-year	50
13	25-hold	25-hold	113
14	25-hold	100-year	113
15	25-hold	25-hold	80
16	25-hold	100-year	80
17	25-hold	25-hold	50
18	25-hold	100-year	50

Using LMS projections, stand structure relative to the target conditions were assessed over time. Each management segment of the riparian area (the bank stability zone, remaining buffer, and the riparian area outside the buffer) was assessed independently, and a weighted average was used to obtain an assessment score. Recognizing that the portions of the riparian area closest to the stream are more critical for key riparian functions such as LWD recruitment, greater weight was given for closer proximity to the stream. To calculate the weights, potential LWD recruitment volume was simulated for the DFC dataset using a model that estimates the expected values for potentially available LWD[3] (Gehringer 2005). The average percent of the cumulative potentially available LWD volume derived using the DFC dataset was then plotted by distance from the stream out to the site potential tree height of 170 feet where 100% of the potential LWD

[3] Potential LWD is a measure of the volume (or piece count) of trees that could intersect the stream if they were to fall. It provides a management-sensitive surrogate for the volume that can physically reach the stream.

volume was included (Meleason et al. 2003) (*Figure 4*). The weights used for a management segment of a given width and distance from the stream were computed as the proportion of the cumulative potential LWD volume recruitment for the corresponding segment of the cumulative curve.

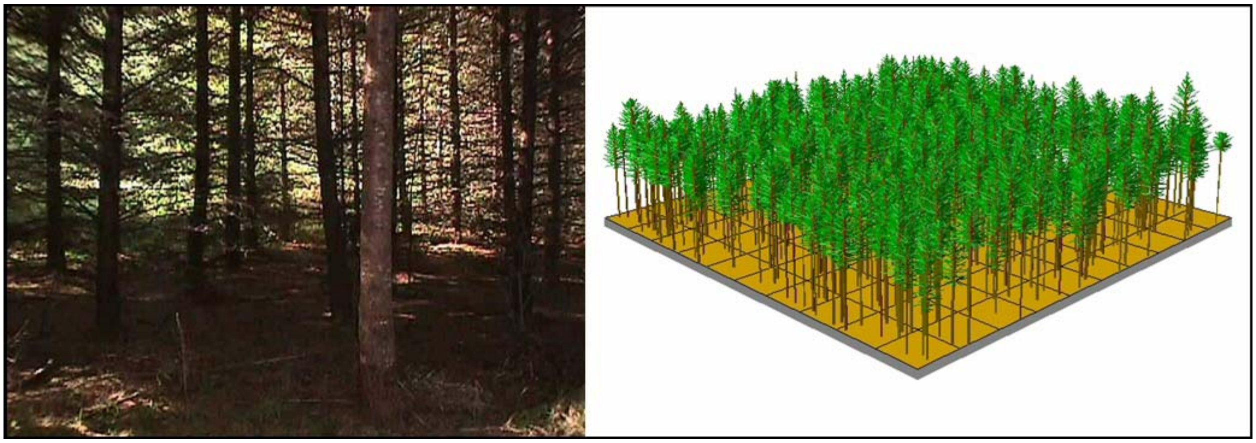

Figure 3: Photo and SVS visualization of the representative inventory used to simulate potential template alternatives. The inventory is from a Douglas-fir plantation in southwest Washington. Photograph taken by Kevin Zobrist.

To assess economic performance, LMS includes an integrated economic analysis program called Economatic. An imbedded bucking algorithm is used to divide harvested trees into different log sorts based on user-defined parameters. User-defined log prices are then applied, and revenue calculations are imported into Economatic. Economatic then applies additional user-defined costs and revenues (such as planting and pre-commercial thinning costs) and calculates both SEV and FV. For our simulations, average Puget Sound region delivered log prices for 2000 were used (Log Lines 2001). Logging and hauling costs (*Table 3*) used values from Lippke et al. (1996) and varied by the average DBH of the harvested trees and whether the harvest was a clear-cut or thinning operation. Other cost assumptions were based on input from local foresters and landowners. The early commercial thinning at age 20 was assumed to break even, with no net cost or revenue. Planting costs were assumed to be \$0.55/seedling (\$239/acre for 435 TPA). Since this template was developed with smaller, non-industrial landowners in mind, relatively high annual overhead costs of \$40/acre were used. For larger or industrial landowners, these costs would likely be much lower. All financial calculations were done before taxes. It should be noted that any of these assumed values can be changed in the model as they change or as landowner goals change.

SEV and FV were calculated independently for each management segment of the riparian area. A weighted average was then computed based on the proportion of the riparian zone width accounted for by each management segment. Economic performance was only assessed for the 170-foot riparian area. The overall economic performance of a stand depends on the combined performance of the riparian and upland areas. However, identifying management alternatives that achieve viable economic returns for the riparian area ensures that riparian areas do not cause a loss of economic viability, even when they comprise a high proportion of a stand.

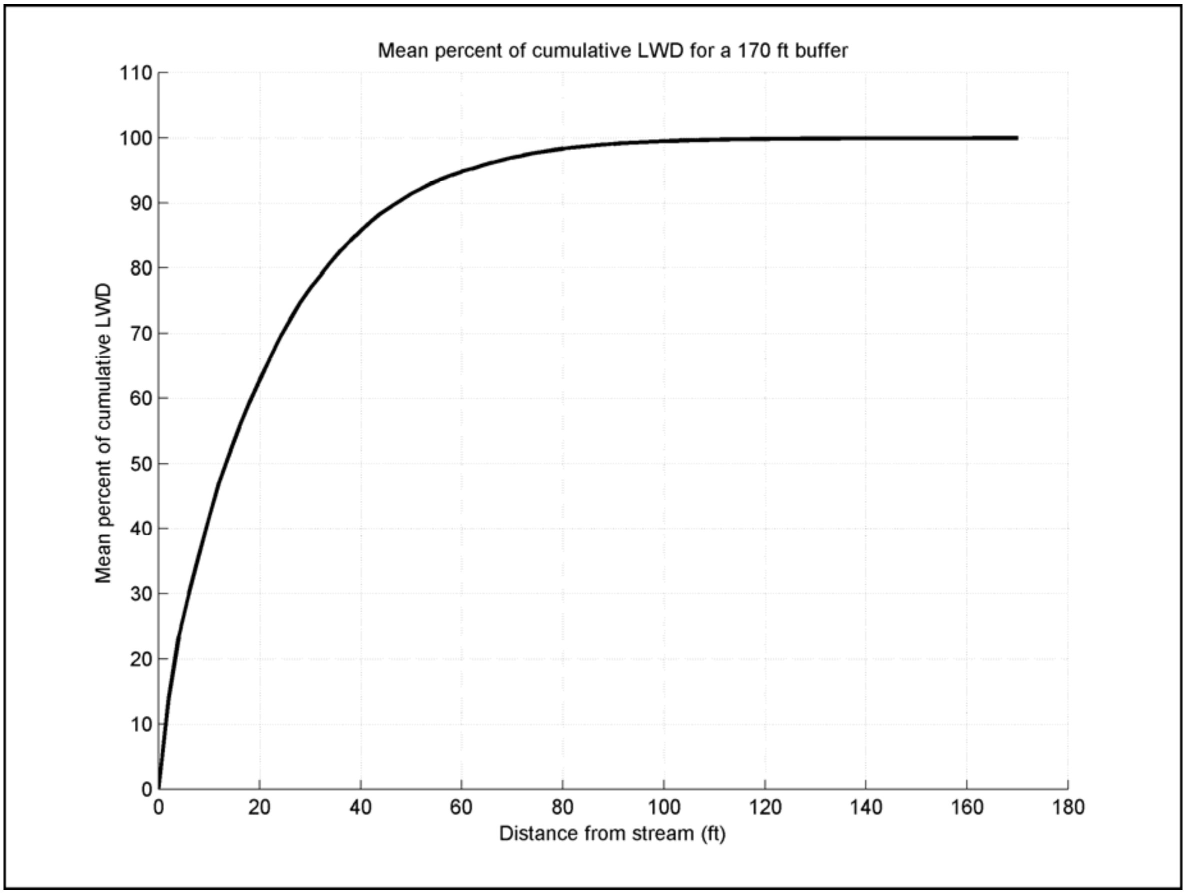

Figure 4: The average percent of the cumulative potential LWD volume recruitment by distance from the stream based on simulations of potentially available LWD using the DFC dataset.

Table 3: Logging and hauling costs (per mbf) by average DBH of harvested trees and harvest type (Lippke et al. 1996).

Average DBH (inches)	Thinning cost	Clear-cut cost
6	$250	$215
8	$226	$195
10	$202	$175
12	$182	$150
14	$166	$130
16	$150	$120
18	$140	$114
20	$130	$110
22	$128	$108
24	$126	$106

IV. Identifying preferred template alternatives

The percent time in target over a 140-year assessment period, along with SEV and FV per riparian acre, are summarized in *Table 4* for the 18 potential template alternatives. The two primary template criteria, time in target and SEV, are plotted together in *Figure 5* to compare the performance of each alternative. The default prescription under the Washington regulations[4] and a no riparian harvest alternative are included in *Table 4* and *Figure 5* as reference points. For riparian templates to be implemented in Washington, the performance of the default regulatory option could be considered as a threshold for acceptance, as the Washington regulations require that all alternate riparian management plans provide riparian protection at least as well as the default prescription.[5]

Table 4: Percent time in target over a 140-year assessment period, along with SEV and FV per riparian acre for the no harvest alternative, default regulatory prescription, and 18 potential template alternatives.

Alternative	Time in Target	SEV/acre	FV/acre
WA Regulations	32.1%	($215)	$804
No Harvest	31.0%	($800)	($800)
Alt 1	40.1%	($322)	$1,323
Alt 2	46.1%	$106	$1,521
Alt 3	40.1%	($45)	$1,633
Alt 4	45.8%	$222	$1,757
Alt 5	39.9%	$207	$1,915
Alt 6	44.1%	$329	$1,971
Alt 7	64.5%	($322)	$1,502
Alt 8	70.5%	$106	$1,699
Alt 9	64.5%	($45)	$1,812
Alt 10	70.2%	$222	$1,935
Alt 11	64.2%	$207	$2,093
Alt 12	68.5%	$329	$2,150
Alt 13	62.1%	($322)	$1,597
Alt 14	68.1%	$106	$1,795
Alt 15	62.0%	($45)	$1,907
Alt 16	67.7%	$222	$2,031
Alt 17	61.8%	$207	$2,189
Alt 18	66.1%	$329	$2,245

The no harvest alternative performed the worst relative to both the DFC and economic criteria. Maintaining a dense stand with no thinning delayed the achievement of the DFC, resulting in a low time in target score. The lack of harvest revenue resulted in a net economic cost per acre, as the only cash flows were the annual overhead costs, which are assumed to apply regardless of whether a harvest occurs. This resulted in a negative SEV (-$800). The regulatory prescription only had a marginally higher time in target score than the no harvest alternative, as the regulatory prescription called for no harvest within 80 feet of the stream–this is the portion of the riparian zone which provides the majority of the potential LWD volume and has a score weight of almost

[4] Washington regulations allow several management options. It is assumed that the default option for a clear-cut harvest is "Option 2," which requires a minimum 80-foot no harvest area, followed by retention of 20 conifers per acre greater than 12 inches in DBH out to edge of the riparian zone at 170 feet.
[5] The regulations do not specify a performance standard for riparian protection, but given that the stated intent of the regulations is to develop the DFC, time in target was assumed to be a reasonable criterion.

100% (*Figure 4*). The SEV for the regulatory prescription was negative, as there was not enough harvest revenue to achieve the 5% target rate of return.

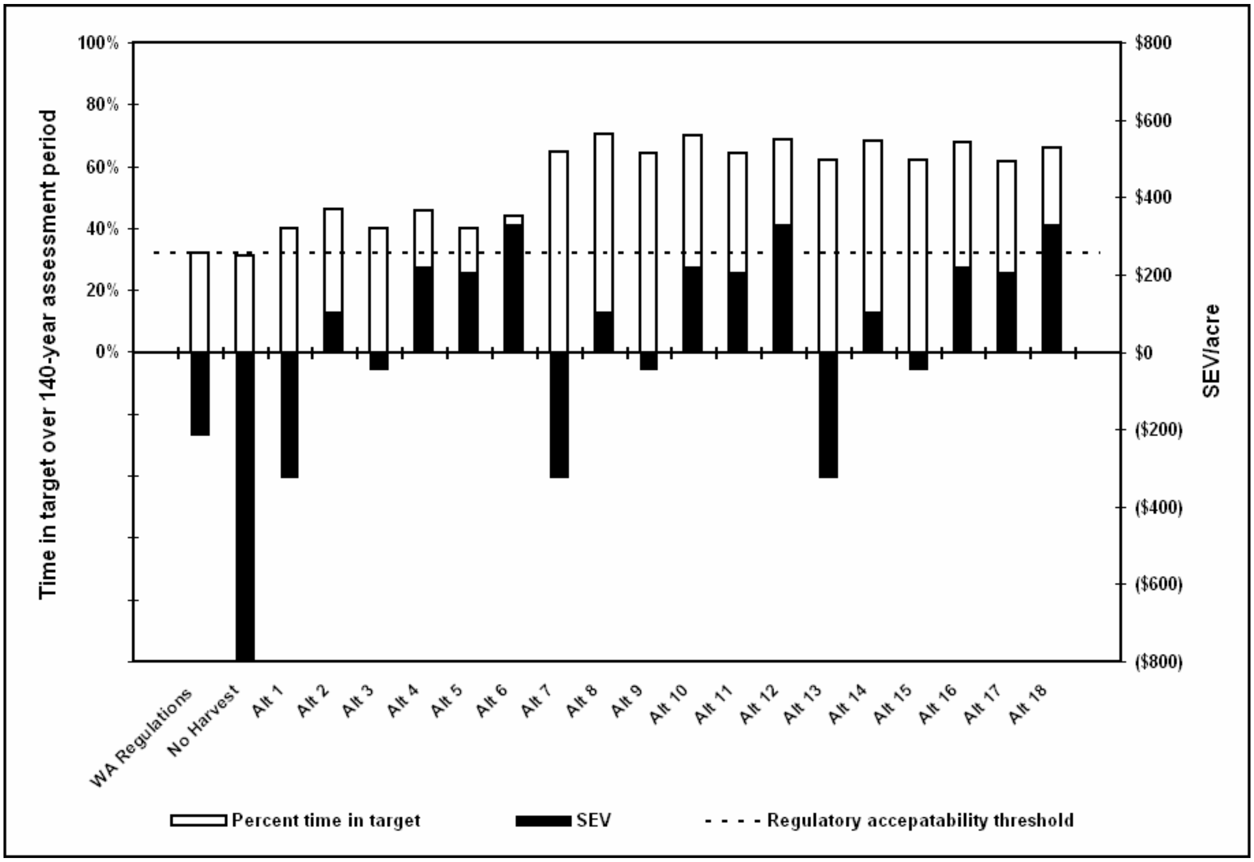

Figure 5: Performance of the18 potential template alternatives, along with the WA regulatory prescription and a no harvest alternative, relative to the two primary template criteria: percent time in target over 140 years and SEV/acre. The time in target for the WA regulatory prescription sets the acceptability threshold for alternate plans in that state.

All 18 of the potential template alternatives performed better than the regulatory prescription, as the biodiversity thinnings accelerated the development of the DFC, achieving greater time in target scores. Alternatives 1-6 had the lowest time in target scores of the 18 alternatives, as these alternatives did not include any thinning in the first 25 feet, which carries a scoring weight of 0.71 (*Figure 4*). Economic performance was driven by the total buffer width and whether or not a regeneration harvest was allowed in the area outside the bank stability zone. For the alternatives that did not have a regeneration harvest outside the bank stability zone (25-hold instead of 100-year), no further harvest was done after the third thinning to 25 TPA, which was assumed to preclude subsequent rotations. As with the no harvest prescription, this resulted in a negative SEV (-$800) for those segments, as the only perpetual cash flows beyond the current rotation were the annual overhead costs. The economic value of thinning the existing timber is reflected in the FV figures.

A total of 12 out of the 18 potential alternatives could be considered as viable template options, having achieved both increased time in target values and the 5% target rate of return (SEV > $0).

Alternatives 10, 12, 16, and 18 performed particularly well relative to both criteria. To narrow the potential template choices further, however, an additional selection criterion was needed. The economic and time in target assessments were used as a "coarse filter" analysis to identify viable alternatives, and adding an additional criterion served as a "fine filter" analysis to refine the set of viable options down to one or two preferred alternatives.

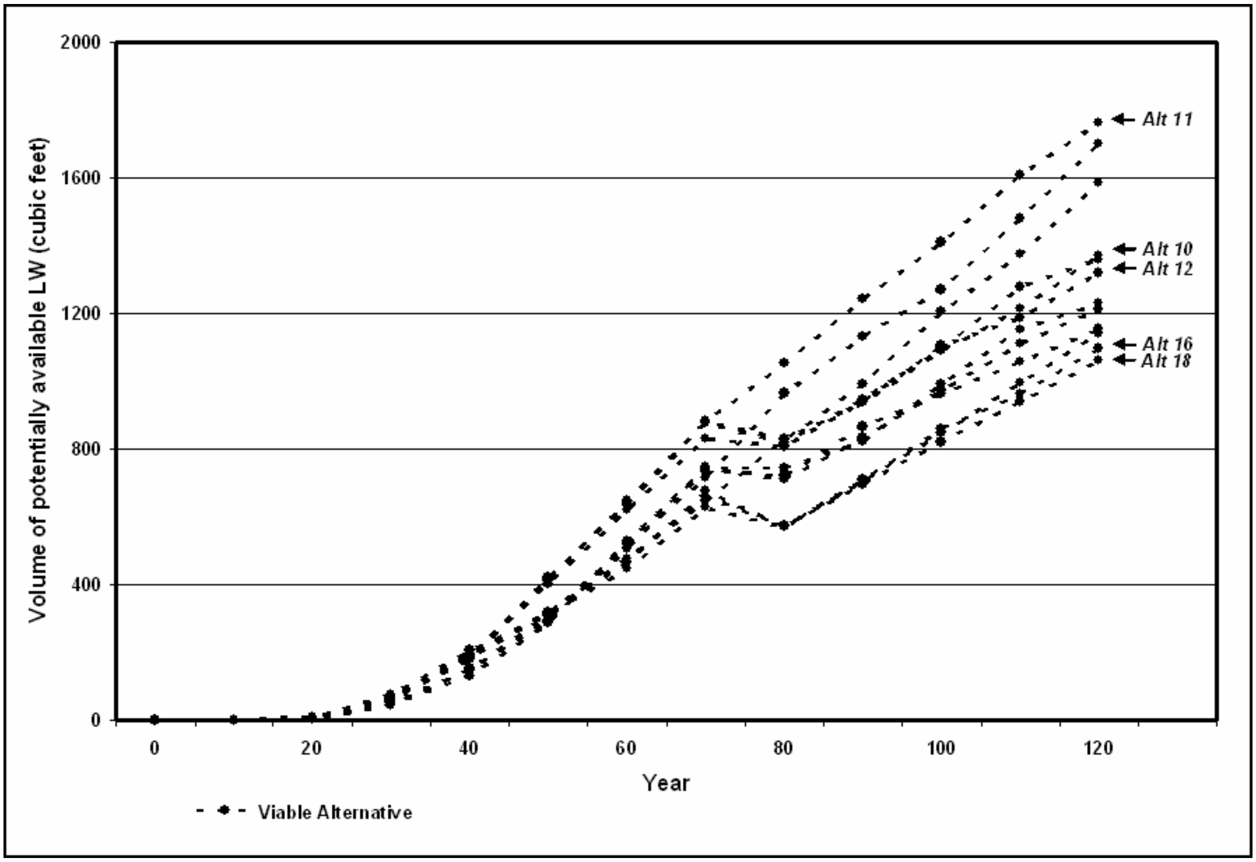

Figure 6: Potentially available LWD volume over time for the 12 viable template alternatives. Alternative 10 had the largest final volume of the four alternatives that performed best in the coarse filter assessment, and alternative 11 had the largest final volume of all viable alternatives.

Potentially available LWD volume was chosen as a fine filter criterion. LWD provides important in-stream functions, and long-term sources of LWD are typically lacking in areas of intensive management (Bilby and Bisson 1998). Conditions that provide for a long-term source of LWD recruitment are also likely to provide for other important functions such as shade, bank stability, and organic inputs, as well as streamside habitat. The potential LWD volume was simulated for the 12 viable template alternatives using a potentially available LWD model (Gehringer 2005). The potentially available LWD volume for each alternative is plotted in *Figure 6*. Of the four alternatives that performed best in the coarse filter assessment, alternative 10 provided the largest level of potentially available LWD volume at the end of the 120-year simulation, with a value of 1,369 cubic feet. Alternative 11 also warranted consideration, as it provided the largest level of potentially available LWD at the end of the 120-year simulation of all of the viable alternatives, with a value of 1,761 cubic feet. While this alternative did not perform as well as others in the coarse filter assessment, it still met the minimum criteria, and its higher LWD volume made it a desirable second option.

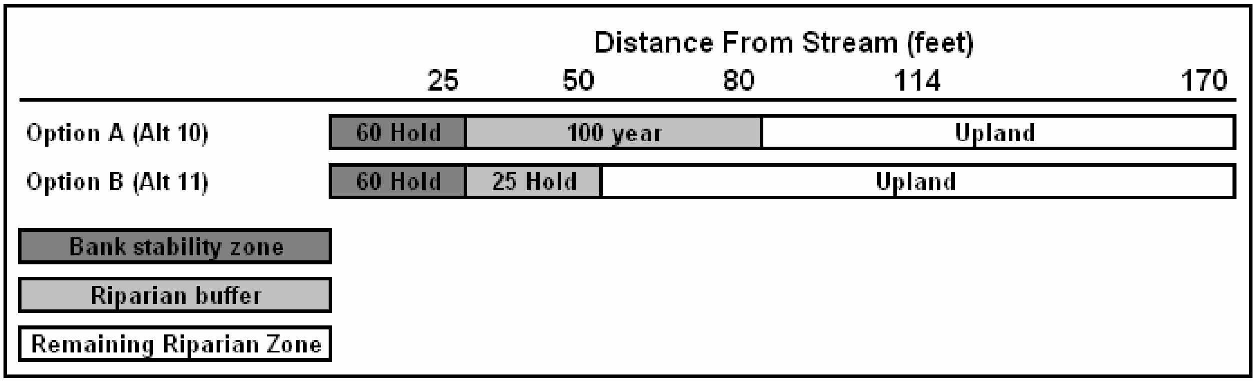

Figure 7: Using the fine filter criterion, two preferred alternatives emerged: alternative 10 and alternative 11. These became Option A and Option B respectively for the template. Option A had a wider buffer but allowed a regeneration harvest outside the bank stability zone, whereas Option B had a narrower buffer but allowed no further entries after the third thinning.

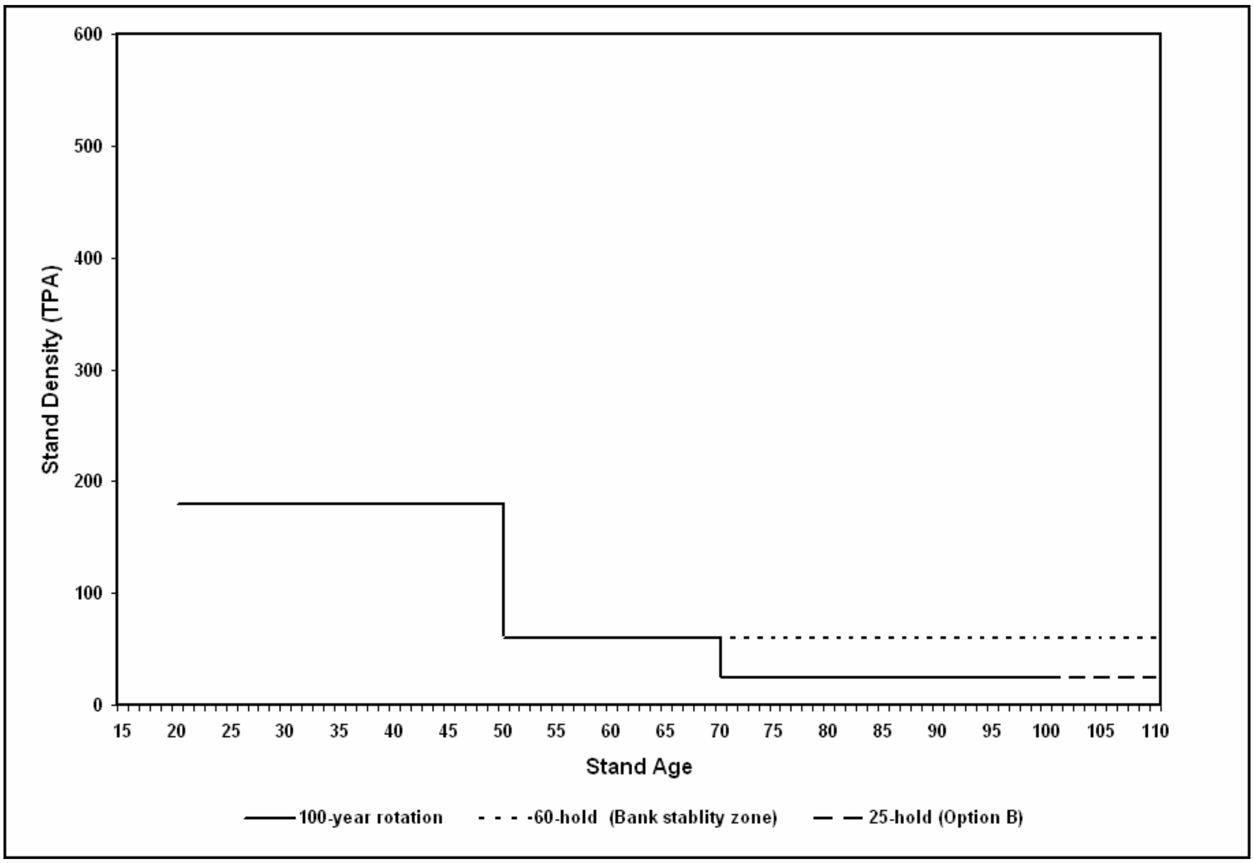

Figure 8: Management diagram for the two template options showing target stand density by stand age. The solid lines show the trajectory of the 100-year rotation, while the dashed lines show the 60-hold density floor for the bank stability zone and the 25-hold density floor for the remainder of the buffer under Option B.

Two preferred options emerged from the fine filter assessment: alternatives 10 and 11. Both alternatives called for the 60-hold prescription in the 25-foot bank stability zone. Alternative 10 had a wider total buffer width of 80 feet, but allowed a regeneration harvest outside the bank stability zone (100-year prescription). Alternative 11 had a narrower total buffer width of 50 feet but did not allow additional entries after the third commercial thin (25-hold prescription). These alternatives then became Option A and Option B, respectively, in a template that gives landowners a choice between two different approaches (*Figure 7*).

Stand density targets were plotted by stand age for the two template options in *Figure 7* to provide a density management diagram (*Figure 8*). The solid line shows the management trajectory for the 100-year rotation, with the dashed lines showing the 60-hold density floor for the bank stability zone and the 25-hold density floor for the remainder of the buffer under Option B. The specific timing and density prescriptions in *Figure 8* did not allow for much operational flexibility. A density range of plus or minus 20 percent added some operational flexibility. Likewise, a 10-year thinning window of plus or minus 5 years provided some timing flexibility to coordinate with market conditions or other operations. Incorporating this flexibility into the density management diagram resulted in a template specifying desired management ranges (*Figure 9*).

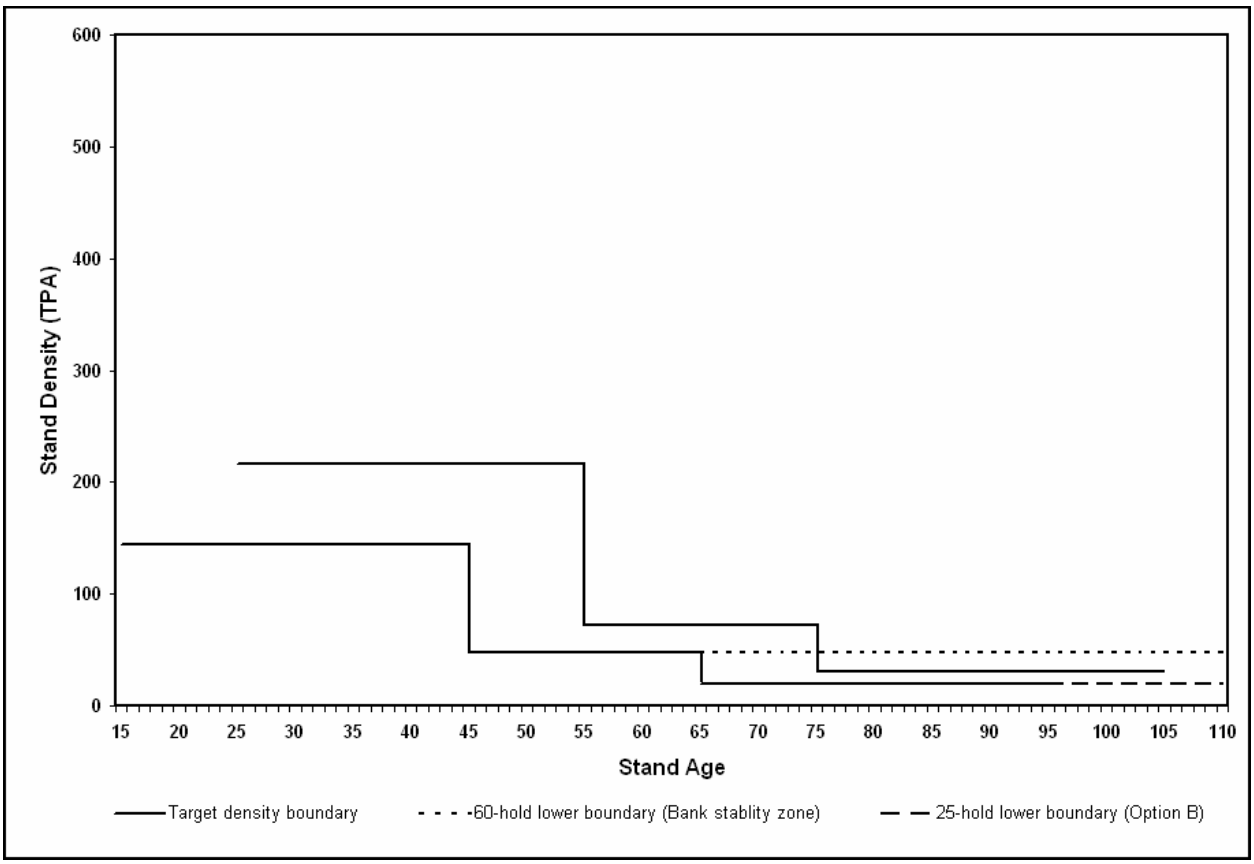

Figure 9: A density range of ± 20% and a thinning window of ±5 years created a more flexible management range allowing for operational and timing flexibility.

V. Template refinement and validation

The management diagram in *Figure 9* was considered to be a draft template, and we performed some additional analysis for refinement and validation. To help refine the template, density curves for crown closure, imminent competition mortality, and the maximum size-density relationship (3/2 thinning law) from Drew and Flewelling's (1979) density management diagram for Douglas-fir were estimated by age for site class II and overlaid on the management diagram (*Figure 10*). These curves suggested that the upper boundary of the acceptable management region allowed too high a stand density, particularly near the time of the second thinning at age 45-55 where the upper boundary came close to the maximum size-density limit.

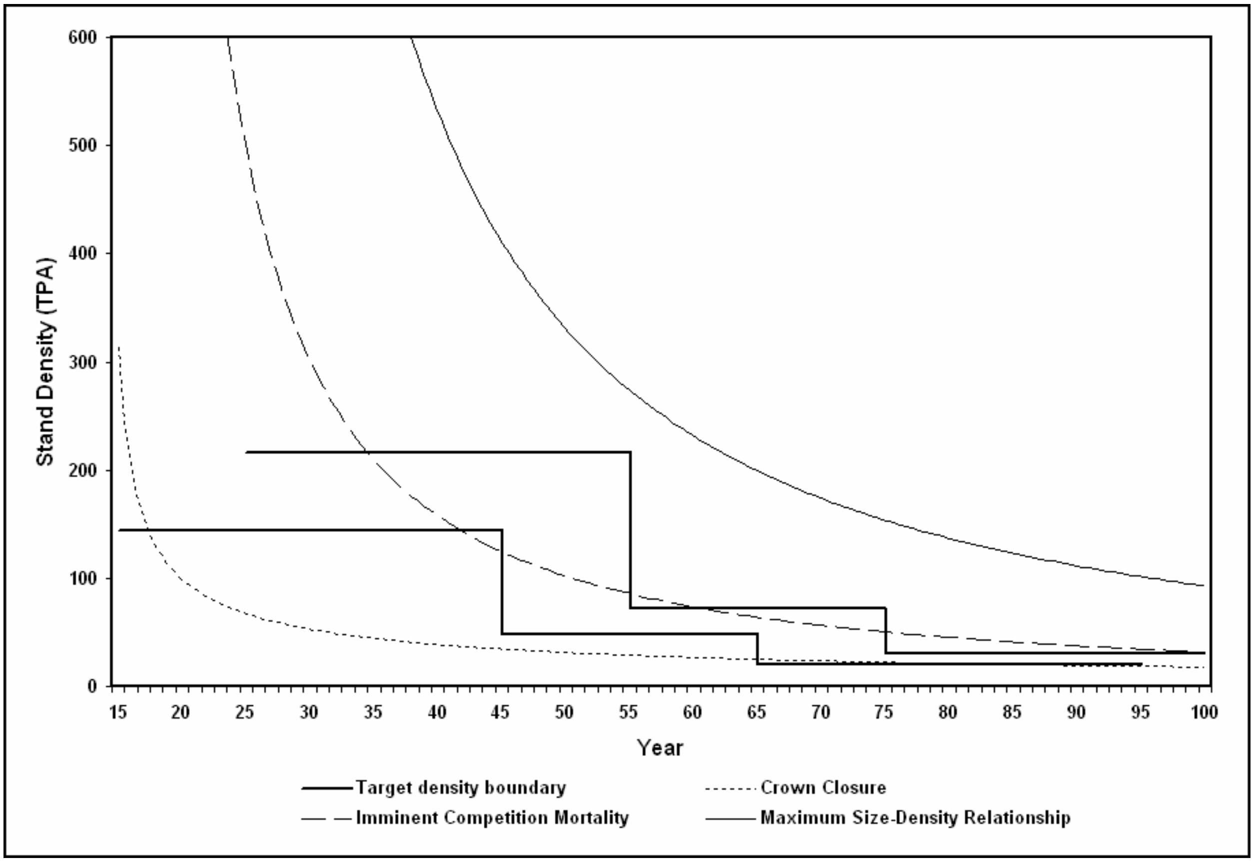

Figure 10: Overlaying density curves for crown closure, imminent competition mortality, and the maximum size-density relationship (Drew and Flewelling 1979) suggested that the upper management boundary allowed too high a stand density around the time of the second thinning.

The template was refined by reducing the acceptable density range from plus or minus 20 percent to plus or minus 10 percent to prevent the maximum allowable stand density from becoming too extreme. The target density for the third thinning was also increased to 35 TPA, as there was concern that thinning to 25 TPA may have been too heavy. The management diagram for this refined template is illustrated in *Figure 11*. The shaded area, which is bordered by the imminent competition mortality curve, suggests stand conditions which are likely to respond well to the template prescription. Stands that have been growing at high densities for too long may become unstable (Wilson and Oliver 2000) or may not have the capacity produce a growth response if thinned heavily. The imminent competition mortality curve establishes a threshold beyond which additional factors, such as height/diameter ratio or live crown ratio, should be considered before applying the template prescription.

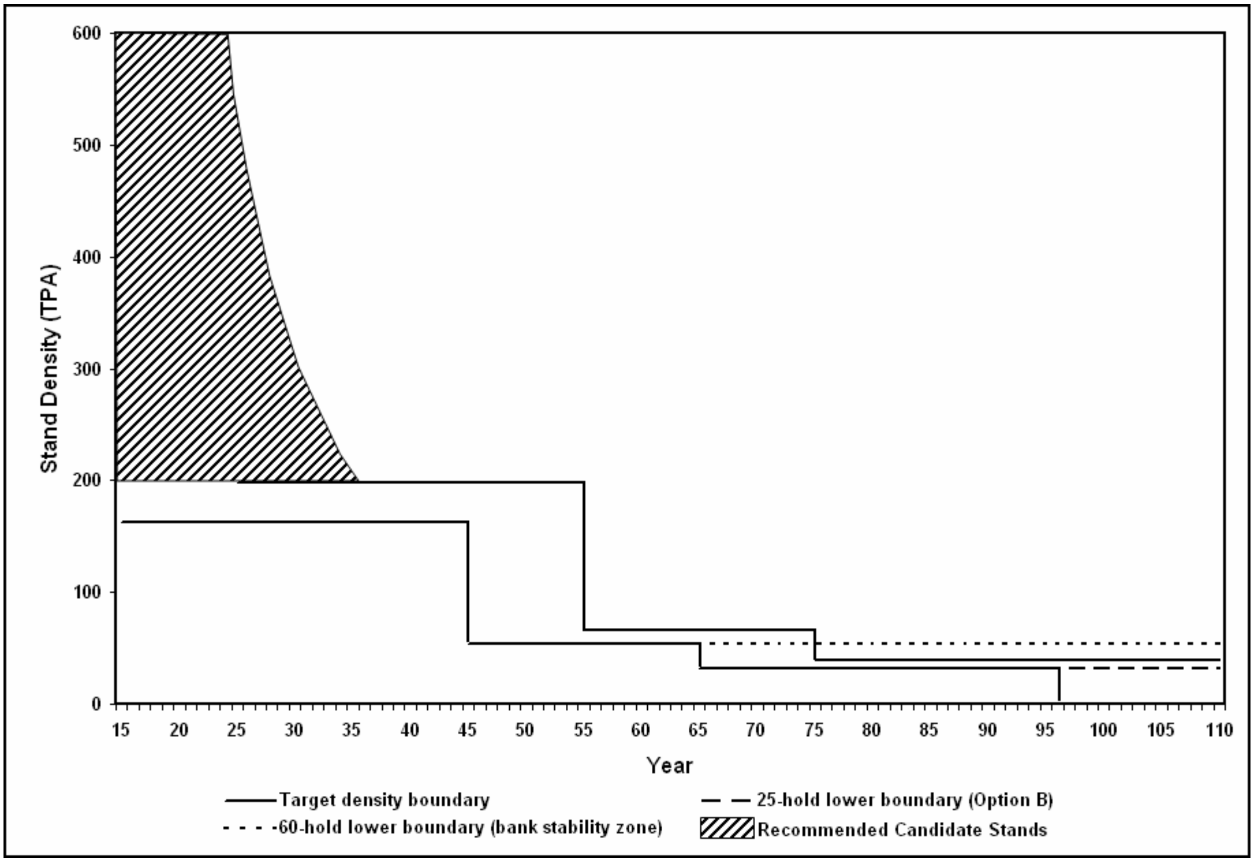

Figure 11: The revised template, with a candidate stand region defined by the imminent competition mortality curve. Stands whose density conditions fall within this region are good candidates for the templates. For stands outside of this region, other factors should be considered before applying the template prescription.

The final step in developing the template was to verify that the template produced desirable results for the full range of conditions for which it was developed. Additional simulations were run to evaluate the results of prescriptions that thinned to the upper or lower boundary of the acceptable stand density range instead of the midpoint. The differences in DFC performance and economic performance between thinning to the boundaries and thinning to the midpoints were negligible for both Option A and Option B (*Figure 12*). This verified that the template produces consistent results within the suggested range while meeting all critical thresholds.

Simulations were also run using two additional test stands representing different starting conditions within the candidate region illustrated in *Figure 11*. Like the first test stand, "Test Stand 2" and "Test Stand 3" were actual inventories from Douglas-fir plantations in southwest Washington. Test Stand 2 was a 35-year-old plantation with 258 TPA of Douglas-fir, 24 TPA of red alder (*Alnus rubra*), 21 TPA of western redcedar (*Thuja plicata*), and a 50-year site index of 126 feet. Test Stand 3 was a 15-year-old plantation with 300 TPA of Douglas-fir, 25 TPA of red alder, and a 50-year site index of 135 feet. As with the original test stand, template simulations using the additional test stands resulted in significantly improved DFC and economic performance compared to the regulatory prescription, validating that the template can produce acceptable results for a range of starting conditions (*Figure 13*).

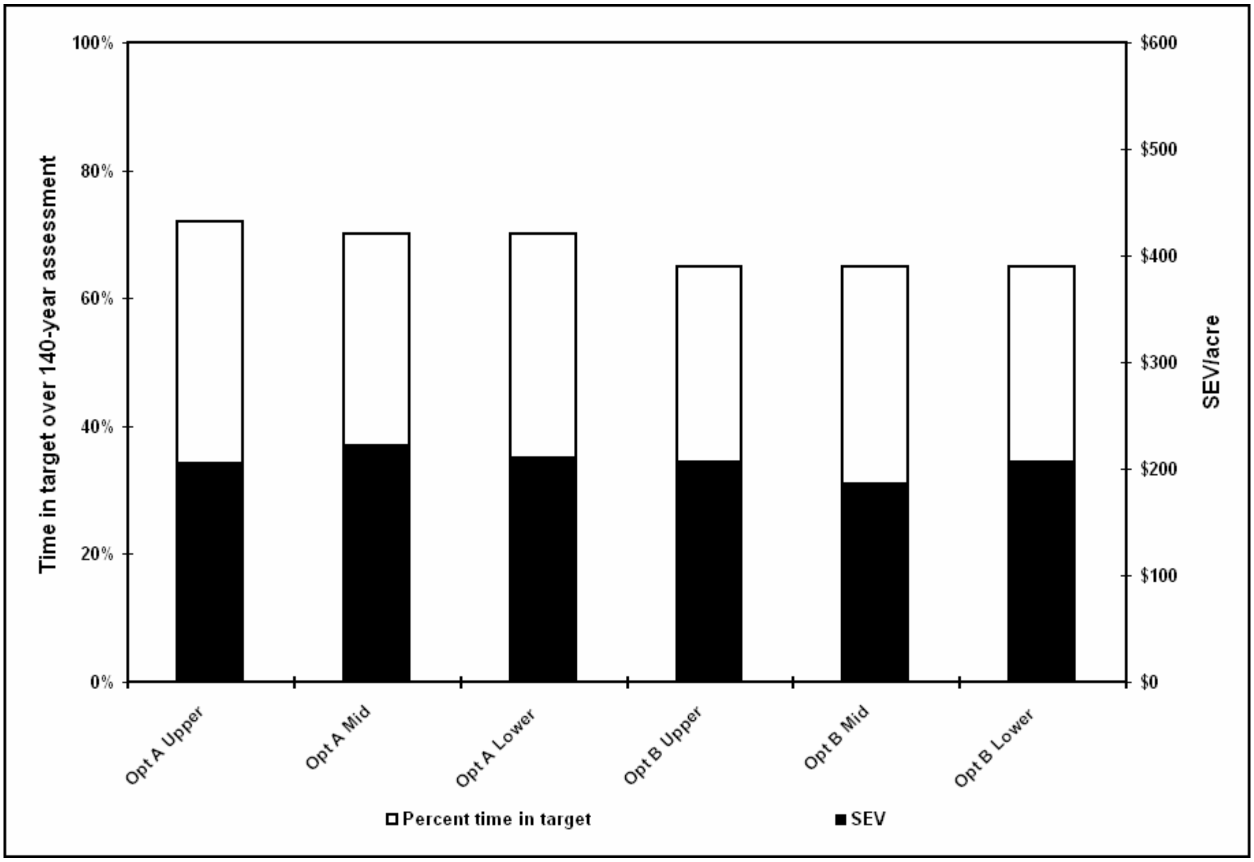

Figure 12: A comparison of the template results for thinning to the upper or lower boundaries of the acceptable stand density range versus the midpoint. Negligible differences indicated that even management along the template boundaries will produce acceptable results.

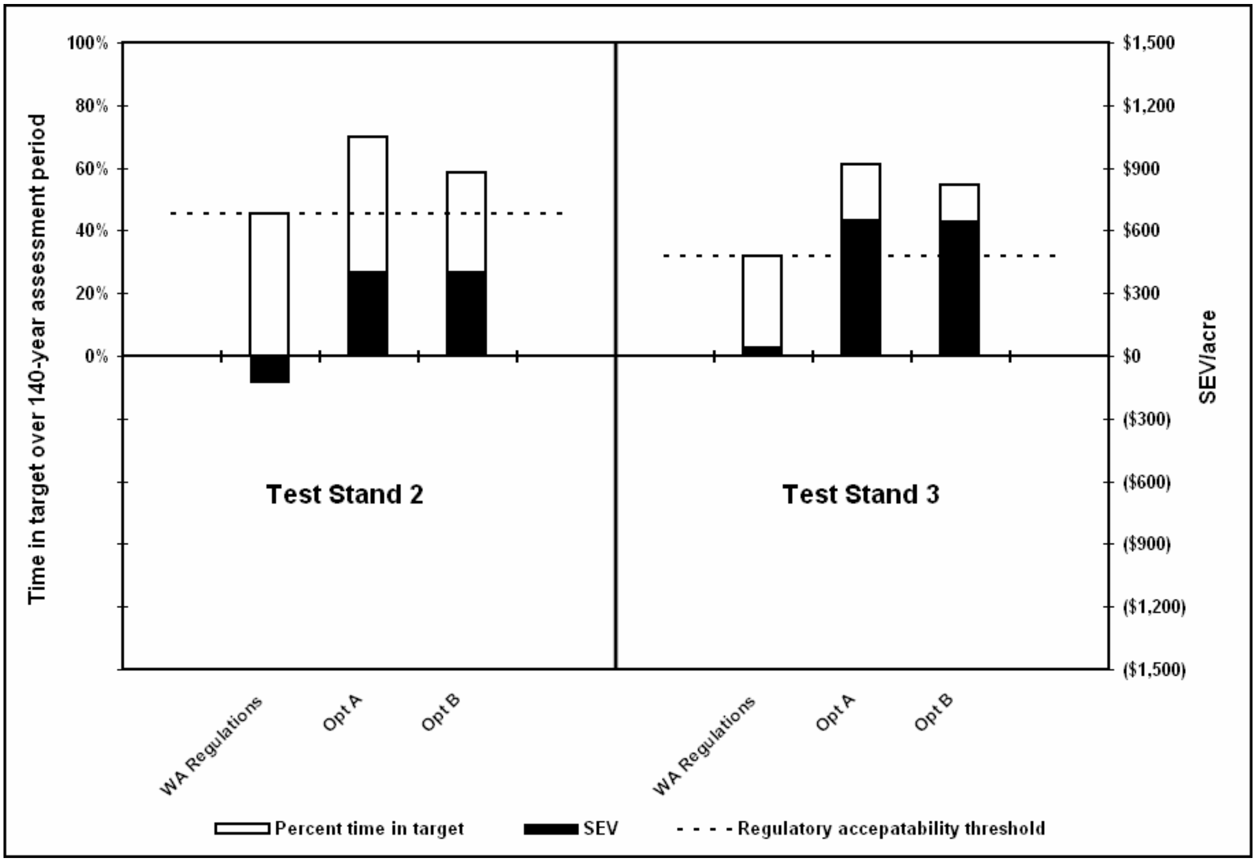

Figure 13: Simulations of additional test stands resulted in significantly improved DFC and economic performance compared to the regulatory prescription, validating that the template can produce acceptable results for a range of starting conditions

VI. Template applications

The final riparian management template described in this report provides useful guidance for landowners in Washington and Oregon who have overstocked riparian stands and wish to pursue an alternative management plan. For site class II stands with conditions that are within the candidate region illustrated in *Figure 11*, our analysis suggests that either of the template options could significantly increase the structural similarity to the DFC over a 140-year time period while also providing an acceptable economic return. It should be cautioned, however, that this template has not yet received regulatory approval. Landowners who wish to implement this template should work with the appropriate agencies to ensure that all regulatory requirements are met. Longer-term permits may also be needed to fully implement the template as a long-term riparian management plan.

The template described in this report also serves as an important demonstration of an objective, data-driven process that can be used to develop templates for situations in which desired outcomes can be quantified. Additional templates can be developed for overstocked riparian stands on different site classes or for hardwood riparian stands. A number of upland applications also exist for templates, including their use to increase biodiversity in intensively managed plantations. It is important to recognize that no single template can provide all biodiversity needs. Rather, a range of different template options is needed for application across a landscape, as applying the same management prescription over a broad region will ultimately decrease the landscape heterogeneity, with a subsequent decrease in diversity (Bunnell and Huggard 1999). An effective template should be broadly applicable in order to be useful over a significant number of acres, while at the same time the range of appropriate template application should be limited, recognizing that one size does not fit all. Finally, a degree of template flexibility will always be necessary to accommodate site-specific needs within a regulatory context

Metric equivalents

When you know:	Multiply by:	To find:
Cubic feet (ft^3)	0.0283	Cubic meters
Dollars per acre ($/acre)	2.471	Dollars per hectare
Feet (ft)	0.3048	Meters
Inches (in)	2.54	Centimeters
Trees per acre (TPA)	2.471	Trees per hectare

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Technical Report C: A literature review of management practices to support increased biodiversity in intensively managed loblolly pine plantations

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A literature review of management practices to support increased biodiversity in intensively managed loblolly pine plantations

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Technical Report C Contents

I. Introduction

When European settlers first arrived in North America, it is estimated that the South had 200 million acres in pine, mixed oak, and other forest systems. Pine savannahs and open woodlands containing longleaf (*Pinus palustris*), loblolly (*P. taeda*), shortleaf (*P. echinata*), slash (*P. elliottii*) and pond (*P. serotina*) pine dominated. Of these species, it is estimated that longleaf pine ecosystems may have covered over 60 million acres[1] (Bragg 2002, Wahlenberg 1946). Longleaf pine stands were often characterized by a single species overstory, a sparse mid-story/shrub layer, and a well-developed and species-rich ground layer. Frequent, low intensity fires, natural or anthropogenic in origin, were the primary disturbance regime (Noss 1988, Van Lear et al. 2004). These stands were also known for the diversity of wildlife, particularly game species, they harbored. Trees in these stands were often very large (*Table 1*) and ranged as old as 600 plus years. Today, there are only about 3 million acres of longleaf pine forest, of which only 12,000 are regarded as old-growth (Bragg 2002). These old growth stands are now recognized for the habitat that they provide for dozens of threatened species (Bragg 2002, Noss 1988).

Table 1. Heights and diameters of old growth pines in the south and southeast (Bragg 2002).

Species	Height (feet)	Diameter at breast height (inches)
Loblolly pine	145 -180	39 - 65
Longleaf pine	85 - 130	27 - 45
Shortleaf pine	85 - 140	35 - 50

Nearly 90% of the forestland in the South today is in private ownership (Wicker 2002), and much of it is comprised of dense plantations of fast-growing loblolly pine. The management intensity of these plantations has been increasing in recent decades (Siry 2002). At the same time, private landowners are facing an increasing demand to provide for broad, non-timber values such as biodiversity on these lands, which can lead to conflict over forest management practices.

Forest plantations have long been negatively characterized as biological “deserts” in which concern for wildlife is limited to key game species (Margolin 1970). While it is true that today’s dense loblolly pine plantations are different from the natural, open pine stands that were historically prevalent throughout the South, these intensively managed forests can still contribute to biodiversity on the landscape (Wigley et al. 2000). This contribution may fall short relative to natural forests, but it may compare favorably to other competing land uses such as agriculture or urbanization (Moore and Allen 1999).

At any rate, because of their prevalence in the region, intensively managed plantations have a significant potential impact on the level of biodiversity. Stand-level management changes can be made that can readily support increased biodiversity in these plantations. Even minor changes

[1] Estimates vary from a low of 30 to a high of 92 million acres. If one uses the low estimate, then today’s acrage of longleaf pine is only 10% of the original and of that only a very small fraction is in “old-growth.” Therefore, there is value in discussing mechanisms to increase old-growth structures in these remaining forests in the South.

can significantly improve biodiversity values (Hartley 2002, Johnson et al. 1975). Some of these changes may be complimentary with timber production and economic goals; others may involve some costs and trade-offs (Allen et al. 1996, Buongiorno et al. 2004, Hunter 1990). In this paper we review the literature to identify a spectrum of practices that support increased biodiversity in intensively managed loblolly pine plantations.

II. Management practices to support increased biodiversity

Biodiversity has several definitions, the simplest being a variety of life. Many definitions further specify that the definition includes all types of organisms as well as genotypes and even ecological processes and their inter-relationships (Hunter 1990, Oliver 1992, Reid and Miller 1989).[1] There is no single forest type or structure that maximizes biodiversity. Different species have different habitat requirements such that structures that support some species may not support others (Dickson and Wigley 2001). Even individual species require habitat diversity (Johnson et al. 1975). Thus the overall key to supporting a variety and abundance of species is to provide a diversity of structure and vegetation (Allen et al. 1996, Harris et al. 1979, Marion et al. 1986, Sharitz et al. 1992). This includes both within stand diversity and between stand diversity (Marion and Harris 1982, Thill 1990).

An important way to increase within-stand structural diversity is to maintain a lower overstory density. A more open canopy allows a diverse understory to develop, which provides forage and habitat for wildlife. Even plantations established with intensive site preparation are often very diverse in the early years as long as the canopy is open, but as the canopy closes this diversity rapidly decreases (Baker and Hunter 2002). Once the canopy closes, the stand moves into the stem exclusion stage that shades out the understory vegetation and subsequently lacks wildlife (Oliver and Larson 1990). Minimizing this stage can allow a stand to support more biodiversity over a given rotation. Maintaining an open canopy with a productive understory also makes plantations more similar to the diverse, natural pine communities that existed historically in this region (Bragg 2002, Noss 1988, Van Lear et al. 2004).

One way to maintain lower stand density for biodiversity is by planting at a lower density. A wider spacing, such as 12 feet, delays canopy closure, extending the more diverse early-successional stages (Dickson 1982, Johnson et al. 1975, Melchiors 1991). In addition to delaying canopy closure, a wider spacing between rows can also allow disking or mowing to help maintain a productive understory (Allen et al. 1996). A wider planting spacing may be undesirable, though, because of the resulting decreased wood quality. In this case a closer spacing followed by thinning may be a more desirable approach (Van Lear et al. 2004).

[1] "Biodiversity is defined by the UN as the variability among living organisms from all sources including terrestrial, marine, and other aquatic systems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems. The Global Biodiversity Strategy (WRL, IUCN, and UNEP 1992) espouses a shorter definition where biodiversity is the totality of genes, species and ecosystems in a region." (Patel-Weynand 2002)

Perhaps the most important way to establish and maintain an open, diverse structure is by thinning. Thinning has been found to benefit numerous individual wildlife species such as deer (Blair 1960, Halls 1973, Hurst and Warren 1980), quail (Dougherty 2004), small mammals (Mengak and Guynn 2003), turkeys (Mississippi State University Extension Service 2004), nuthatches (Wilson and Watts 1999), and other birds (Turner et al. 2002). Thinning early and often is widely recognized as an important component of an overall strategy to increase biodiversity (Hunter 1990, Marion et al. 1986). This minimizes the time in the stem exclusion stage and can maintain and further develop an open, diverse structure throughout the rotation. In addition to stimulating the herbaceous understory by allowing light to reach the forest floor (Harrington and Edwards 1999, Schultz 1997), thinning also facilitates additional understory management such as disking or burning (Johnson et al. 1975), and it increases the understory response to such treatments (Melchiors 1991, Tucker et al. 1998).

Van Lear et al. (2004) suggest that a commercial thinning be done by the time a plantation reaches age 15. Hurst and Warren (1980) suggest that it be done as early as age 12 if no pre-commercial thinning was done. The recommended frequency of thinning to maintain an open stand structure is usually around five years (Blair and Enghardt 1976, Conroy et al. 1982, Halls 1973, Hunter 1990, Schultz 1997). Maintaining an open stand structure requires heavier thinning than for timber production, with a target of 50-70 ft^2/acre of residual basal area (Blair and Enghardt 1976, Halls 1973, Van Lear et al. 2004). A residual basal area of 80 ft^2/acre is usually considered a minimum for timber production and economic return (Siry 2002, Siry et al. 2001).

A potential problem with thinning to open up the pine overstory is that it can allow understory hardwoods to develop into a dense midstory. Hardwoods produce heavy shade that inhibits understory vegetation (Blair and Enghardt 1976, Dickson and Wigley 2001, Schultz 1997, Tappe et al. 1993). Thinning can also increase vines and shrubs, which further shade out the herbaceous layer (Harrington and Edwards 1999). Thus, without controlling hardwoods and other woody vegetation, thinning can ultimately result in a less productive and less diverse understory (Blair and Feduccia 1977, Hunter 1990). A hardwood midstory can add vertical stratification and benefit some midstory-associated birds (Dickson 1982, Melchiors 1991, Turner et al. 2002). However, a hardwood midstory is generally undesirable for most wildlife, including deer, small mammals, and other birds (Dickson 1982, Lohr et al. 2002, Melchiors 1991, Wilson and Watts 1999).

While a dense midstory is undesirable, some hardwoods are necessary for supporting biodiversity. Mature hardwoods such as oaks provide hard mast that is important for many wildlife species (Dickson 1982, Dickson and Wigley 2001, Johnson 1987, Johnson et al. 1975). Maintaining a desirable component of hardwoods can improve wildlife habitat (Tappe et al. 1993). When controlling hardwoods, individual fruit or mast producing trees can be selectively retained (Blair 1967, Blair and Feduccia 1977). Maintaining whole areas of hardwoods is also important. An interspersion of hardwood and pine forest types provides good wildlife habitat (Shultz 1997). Hardwoods should especially be maintained in sensitive areas such as bottomlands and drainages (Halls 1973, Johnson et al. 1975). Hardwood maintenance should generally stay focused on hardwood sites (Johnson 1987).

In historic, natural pine stands, frequent low-intensity fires helped to control hardwoods and maintain an open stand structure with a productive and diverse understory (Noss 1988, Van Lear et al. 2004). Frequent low-intensity fires tend to favor growth of herbaceous vegetation by suppressing hardwoods and other woody vegetation (Reed et al. 1994). Prescribed burning can be used in conjunction with thinning in intensively managed plantations to achieve desired conditions that support increased biodiversity. Many of the plants and animals associated with southern pine communities are adapted to or even dependent on fire, and wildlife mortality from fire is generally very low (Landers 1987, Means and Campbell 1981, Moorman 2002). Regular burning improves habitat for many species, including deer (Dickson 1982, Halls 1973, Hurst et al. 1980, Marion et al. 1986), quail (Dougherty 2004), turkey (Marion et al. 1986, Mississippi State University Extension Service 2004), amphibians and reptiles (Means and Campbell 1981), and Bachman's sparrow (Tucker et al. 1998). To help provide for a broad suite of species in the short and long term, areas should not be burned evenly, but rather patches of unburned areas should be left to provide for nesting and cover (Landers 1987, Moorman 2002).

Prescribed burning is recommended when the dominant pine trees are 15 feet tall (Halls 1973, Moorman 2002). Recommended burning intervals range from 3-6 years (Blair and Enghardt 1976, Blair and Feduccia 1977, Halls 1973, Mississippi State Extension Service 2004, Schultz 1997). Marion et al. (1986) suggest 3-5 years to allow enough time for browse and cover to develop, as well as enough fuel to carry the next fire. Historically, longleaf pine communities in Florida burned naturally every 2-5 years (Noss 1988). Prescribed burning should not be overdone, or the cumulative impacts could become negative in the long term (Melchiors 1991). For example, if burning is done too frequently, such as annually, it can eliminate hardwoods altogether, (Dickson 1982, Grano 1970, Schultz 1997). Complete loss of the hardwood component would have a negative impact on biodiversity.

Many authors recommend burning in winter (Allen et al. 1986, Blair and Feduccia 1977, Halls 1973, Mississippi State Extension Service 2004, Schultz 1997). However, Robbins and Myers (1992) note that varying both the season and the frequency of burning avoids favoring only one suite of species. Adding this element of variability can increase overall stand diversity. Coordinating burning with thinning is also important. Thinning increases the effectiveness of prescribed burning for wildlife (Hurst and Warren 1982, Melchiors 1991, Tucker et al. 1998). Burning before thinning can make thinning easier (Hurst et al. 1980), and it avoids the problem of the fire burning too intensely in the slash from the thinned trees (Van Lear et al. 2004).

An alternative to prescribed burning for the control of nonpine woody vegetation is to use herbicides (Dickson and Wigley 2001, Harrington and Edwards 1999). Herbicides can be less costly than burning and may be especially desirable where burning opportunities are limited (Wigley et al. 2002). Normal applications of herbicides are generally not directly toxic to wildlife (McComb and Hurst 1987). Herbicides may have a longer residual effect on understory diversity than prescribed burning or mechanical vegetation control (Hunter 1990). Nonetheless, vegetation seems to recover quickly within 1-3 years (Keyser et al. 2003, Reed et al. 2004). A longer term study found no significant impact on floristic diversity 11 years after herbicide treatment (Miller et al. 1999).

The intensity and methods of site preparation for controlling vegetation at the beginning of the rotation should also be considered when managing pine plantations for increased biodiversity. More intensive site preparation favors grass and forbs, while less intensive site preparation favors vines and woody vegetation (Johnson 1975, Locascio et al. 1990). More intensive site preparation also reduces the availability of fruit for wildlife (Hunter 1990, Stransky and Roese 1984). Thus, while intensive site preparation can benefit some game species like deer, less intensive site preparation is generally better for a diversity of wildlife (Marion and Harris 1982, Marion et al. 1986). Locascio et al. (1990) found that moderate intensity site preparation produced the greatest understory biomass, and moderate intensity treatments may be the most cost effective, especially for non-industrial landowners. In terms of site preparation methods, Locascio et al. (1991) observed that mechanical site preparation (shear, chop, disk, etc.) did not seem to diminish understory plant diversity. Mechanical methods may provide for greater understory diversity and food production compared to herbicides (Fredericksen et al. 1991, Keyser et al. 2003). Burning may also be a desirable option for stimulating stored seeds (Hunter 1990).

Other management activities like fertilization and pruning can also impact biodiversity. Use of fertilization in pine plantations has increased in recent decades, though it is mostly done on industry lands (Siry 2002). The impacts of fertilization on biodiversity are somewhat mixed. Fertilization can improve understory food production for wildlife, especially in stands that have been thinned (Hunter 1990, Hurst and Warren 1982, Melchiors 1991). Fertilization can also accelerate canopy closure, though, which can offset wildlife benefits (Dickson and Wigley 2001). Thus fertilization treatments should be done in conjunction with thinning to maximize wildlife benefits. Pruning can benefit biodiversity by increasing understory vegetation (Baker and Hunter 2002, Hurst and Warren 1982) as well as creating more horizontal openings.

Another way to support increased biodiversity in pine plantations is by retaining key structural features such as snags, coarse woody debris, and mature live trees. These elements add additional structural complexity that benefits a wide range of wildlife (Allen et al. 1996, Baker and Hunter 2002, Dickson and Wigley 2001, Lohr et al. 2002, Marion et al. 1986, Sharitz et al. 1992). Maintaining riparian buffers, or streamside management zones, can provide for some of these elements (Dickson and Wigley 2001, Thill 1990). Riparian buffers further contribute to biodiversity by providing for aquatic species and water quality (Baker and Hunter 2002) and by providing habitat connectivity (Dickson and Wigley 2001, Johnson 1987).

All of the management practices described above will be most effective if done in conjunction with longer rotations. Pulpwood rotations can be as short as 20 years (Biblis et al. 1998, Melchiors 1991). Short rotation management limits pine plantations to early successional structures and does not provide for species needing older seral stages (Johnson et al. 1975). Because of the dominance of short rotations, older seral stages are becoming rare in the region (Allen et al. 1996). Managing for longer rotations can increase diversity (Sharitz et al. 1992). Rotations of 40-100 years can provide for long-term wildlife forage as well as key habitat elements such as hardwood mast, snags, and cavities (Melchiors 1991).

Longer rotations can impact economic returns. Because future revenues are discounted, longer rotations must produce significantly more revenue to be economically competitive with shorter rotations. Dean and Chang (2002) found that economic performance decreased with increasing rotation length. In contrast, Biblis et al. (1998) noted that 50-year sawtimber rotations performed better economically than 20-year pulpwood rotations if the target rate of return was 7% or less. Ultimately it depends on the relative prices of pulpwood and sawtimber and the rate of return that is acceptable to the landowner.

III. Other considerations

In looking at management practices to increase biodiversity in intensively managed loblolly pine plantations, some additional considerations should be made. The management practices described in this paper are geared towards increasing stand-level biodiversity. Ultimately, though, a landscape approach is needed. A variety of different stand structures and age classes should be present on the landscape to support the full range of biodiversity (Marion et al. 1986, Moore and Allen 1999, Oliver 1992). The size, shape, and spatial arrangement of these structures are also important (Johnson 1987). For landowners with large areas of contiguous holdings, a landscape management approach to providing for biodiversity may be feasible. When the landscape is broken up among different ownerships, landscape management requires coordination between different landowners with different needs and goals. The issues involved with such coordination are beyond the scope of this review. In any case, maintaining biodiversity at the landscape level depends on a collection of stand-level decisions. If individual landowners employ practices to increase stand level biodiversity, their practices are likely to support significantly increased biodiversity across the landscape.

Another important consideration when managing for biodiversity is land use history. Hedman et al. (2000) found that understory vegetation is driven more by previous land use than forest management practices within the past 35 years. Plantations established on old field sites do not have biological legacies such as seeds and rootstocks that are present in plantations established on cutover lands (Baker and Hunter 2002). Because of this, old field sites have low understory diversity regardless of management practices (Hedman et al. 2000, Marion and Harris 1982, Marion et al. 1986). On the other hand, old field sites have greater pine growth and yield and can produce more wood per area of land (Yin and Sedjo 2001). Thus, intensive timber management that maximizes wood production and economic return should be focused on old field sites where biodiversity is likely to be poor regardless of management practices. Likewise, practices to improve biodiversity should be targeted to cutover lands.

Finally, there should be economic considerations when examining ways to increase biodiversity. Intensively managed plantations are business enterprises for which landowners will expect some level of economic return. There are various costs associated with managing for increased biodiversity which create trade-offs between biodiversity and economic returns (Allen et al. 1996, Hunter 1990). If management practices are too costly, they are unlikely to be implemented on private lands. Management strategies that balance both biodiversity and economic objectives should be identified (Buongiorno et al. 2004).

One thing that may help offset the costs of managing for increased biodiversity is the potential for increased hunting lease revenue (McKee 1987, Melchiors 1991). Hunting leases can provide significant revenue, especially if there is quality wildlife habitat (Baker and Hunter 2002, Johnson 1995, Jones et al. 2001). Ownership size may limit these opportunities, though.

IV. Summary

There is concern about the maintenance of biodiversity in the intensively managed loblolly pine plantations that are increasingly prevalent in the southeastern United States. There are a number of stand-level management practices that can support increased biodiversity in these plantations. The overall key to providing for biodiversity is to provide structural diversity. An open stand structure with a diverse, productive grass-herb understory is more similar to the natural, fire-maintained pine communities that were historically present and can support a broad suite of plants and wildlife.

Maintaining an open canopy with a diverse understory can be achieved with heavy thinnings early and often in the rotation. This may allow a dense hardwood midstory to develop, though, which would shade out the understory and negate the benefits of thinning. Consequently, hardwood control will be necessary either by prescribed burning or with mid-rotation herbicide applications. Hardwoods should not be eliminated entirely. A mast producing component should be maintained to provide wildlife food and structural diversity.

Light to moderate site preparation is best for biodiversity, and mechanical methods may perform better in this respect than herbicides. Fertilization can benefit wildlife by increasing understory growth, but it should be done in conjunction with thinning to maximize benefits. Key structural features such as snags, coarse woody debris, and mature trees should be maintained, along with riparian buffers to protect aquatic areas and provide for habitat connectivity. Long rotations are necessary to provide a broader range of age classes, though the economic impacts may be a consideration.

Biodiversity is ultimately achieved at the landscape level, but stand-level changes can go a long way towards making improvements and can be implemented regardless of ownership pattern. Land use history is an important consideration, as old field sites are unlikely to support a diverse stand structure regardless of management practices. Economics should also be considered, as management practices to increase biodiversity need to be economically viable if they are to be successful on private lands. Opportunities for hunting lease revenue may offset some of the costs of managing for biodiversity.

Metric equivalents

When you know:	Multiply by:	To find:
Acres	0.4047	Hectares
Feet	0.3048	Meters
Inches	2.54	Centimeters
Square feet per acre (ft^2/acre)	0.229	Square meters per hectare

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Technical Report D: Management templates for increased biodiversity and economics in intensively managed loblolly pine plantations

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Management templates for increased biodiversity and economics in intensively managed loblolly pine plantations

Final Technical Report to the National Commission on Science for Sustainable Forestry (NCSSF)

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Technical Report D Contents

I. Introduction

There are a number of stand-level management practices that can support increased biodiversity in intensively managed loblolly pine (*Pinus taeda*) plantations.[1] These practices include thinning, prescribed burning, less intensive site preparation, longer rotations, and others (for a complete review see Zobrist et al. 2005b). For best results, many of these practices can be used in combination with each other, though timing is important. For landowners or managers interested in supporting greater biodiversity in their plantations, it can be useful to summarize these practices into a set of specific but flexible guidelines or management "templates."

From a private landowner's perspective, it is particularly useful to identify templates that will support increased biodiversity while maintaining an acceptable economic return. Some practices for increasing biodiversity are complimentary with timber production and economic goals, while others involve some level of trade-off (Allen et al. 1996, Hunter 1990). An approach for creating templates for achieving biodiversity and economic goals has been developed for riparian zone management in the Pacific Northwest (Zobrist et al. 2004, 2005a, 2005c). Using this approach, we have developed an example template for southern loblolly pine plantations as a demonstration of how the approach developed in the Pacific Northwest can be used to address biodiversity issues in other regions. In this report we will describe how the template approach was applied to southern conditions, examine the biodiversity and economic outcomes of the example template, and discuss additional southern applications of this template process.

II. Identifying biodiversity and economic criteria

The key to supporting biodiversity is to provide structural diversity (Allen et al. 1996, Harris et al. 1979, Marion et al. 1986, Sharitz et al. 1992). Ultimately this is best achieved at the landscape level, but structural diversity can also be increased at the stand level to provide significant benefits to biodiversity. The natural longleaf pine (*Pinus palustris*) forests that historically covered much of the South had high levels of structural diversity. These stands were characterized by open overstories that allowed light to reach the forest floor. Frequent, low-intensity fires prevented dense midstories and shrub layers from developing and stimulated the understory vegetation (Noss 1988, Van Lear et al. 2004). The resulting understories had a rich herbaceous layer that had a diversity of native plants and provided necessary food, cover, and ground-level structures for a broad suite of wildlife.

An open pine stand with a minimal midstory and a diverse understory provides a good structural target that is likely to support high levels of biodiversity on appropriate sites. In order to assess management practices relative to this structure, the structure must be quantified. Hedman et al. (2000) established a dataset of "benchmark" plots that were characteristic of historic, open longleaf pine stands (*Figure 1*). The structural attributes of these plots can be used to create a

[1] Because of the commercial importance of loblolly pine as well as the number of acres in plantations in the South, we assume that this will be this species to which our template is applied.

quantitative target of desired stand conditions.[2] Potential management plans can then be assessed based on whether or not they produce structural conditions that are statistically similar to this target (Gehringer in press). While the Hedman dataset is somewhat small to do a robust statistical analysis, it provides a reasonable target range to demonstrate an example loblolly pine template.

Figure 1: An example of the benchmark conditions measured at International Paper's Southlands Forest (stand 400-053) by Hedman et al. (2000). The open, park-like structure of this uneven-aged longleaf pine-wiregrass stand supports a rich, herbaceous understory that provides habitat for a wide range of game and non-game wildlife species. Photograph taken by Craig Hedman.

Four key structural attributes were identified from the benchmark plot dataset: the density in trees per acre (TPA) and the quadratic mean diameter (QMD) of larger trees, and the density and QMD of smaller trees. Trees with a diameter at breast height (DBH) greater than 8 inches were considered larger trees, and those less than 8 inches in DBH were considered small trees.[3] The distributions of values for these four attributes when considered at the same time may be used to create a four-dimensional target region. The four-dimensional target can be represented visually

[2] The benchmark plots included longleaf, loblolly, and slash pine (*Pinus elliottii*) stands (natural and plantation). It was assumed that the target structural attributes would be applicable multiple pine species.

[3] The gap between the upper DBH limit for the small tree sub-target and the lower DBH limit for the large tree sub-target was motivated by a consideration of the diameter distributions for the targeted benchmark stands. The distributions were typically bimodal with the trough between the modes occurring within the interval from 5 to 10 inches. The total TPA for a stand is, therefore, larger than would be obtained by combining the TPA values for small and large tree sub-targets.

by splitting the large tree and small tree density and QMD components into sub-targets that can be plotted in two dimensions (*Figure 2*). The elliptical region in each sub-target represents an approximate 95% acceptance level, and this is the region that encompasses the central 95% of the target data, assuming a normal distribution. By using only the central 95% of the target, the influence of the most extreme outlying values in the target dataset are reduced. An observed stand structure that simultaneously falls within these two elliptical sub-target regions is statistically similar to the benchmark plots.

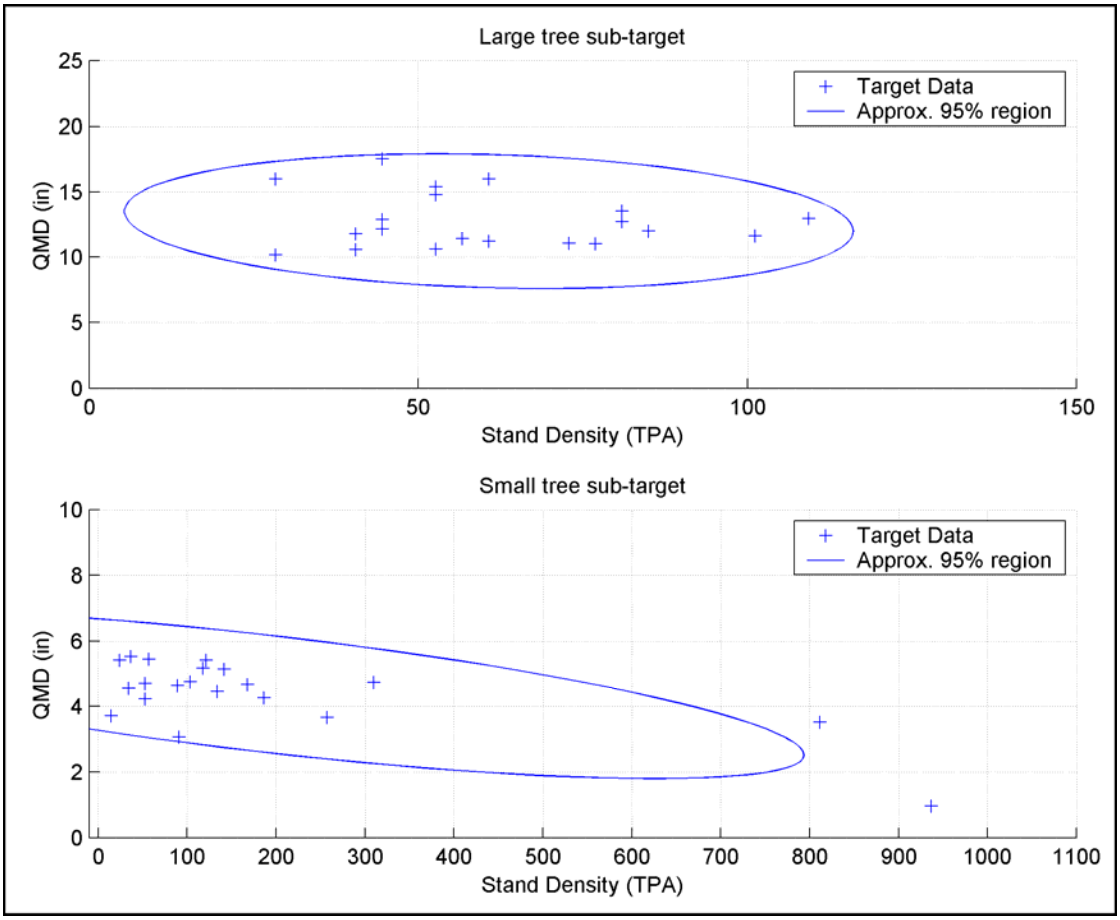

Figure 2: The 4-dimensional stand structure target is split into larger tree and smaller tree stand density and QMD sub-targets that can each be plotted visually in two dimensions. The ellipses represent approximate 95% acceptance regions for each sub-target. When comparing this target data to the one for Douglas-fir (see Zobrist et al. 2005c), the limitations of the pine dataset become clear as there are few data points outside of the 95% acceptance area.

The four-dimensional target provides a high degree of discrimination between the benchmark and non-benchmark plots. By including both a larger tree and a smaller tree component in the target, we can assess stands to make sure that they have an open pine canopy but have not developed a dense midstory. To be in the target, an observed stand must have some larger trees, but not too many or too few, while also having smaller trees in a midstory or understory, but again not too many or too few. The percent time over a 100-year simulation that predicted stand structures fall within the 95% target region was used as a specific biodiversity criterion for assessing potential template.

There are several metrics that can be used as economic performance criteria. Soil expectation value (SEV), or bare land value, is the net present value of a complete forest rotation repeated in perpetuity given a target rate of return (Klemperer 1995). This is perhaps the most important single economic criterion, as it reflects the economic performance of the initial investment in establishing a plantation given an expected management regime. This will be the metric of most relevance for landowners implementing a template that starts from bare land.

SEV is also relevant for landowners starting with mid-rotation stands, as at some point they will reach rotation end and be faced with the decision of whether or not to continue the template for additional rotations. Thus, SEV is the best indicator of long-term economic acceptability. However, landowners with mid-rotation stands may also be interested in the overall forest value (FV), which is also known as land and timber value (Klemperer 1995). FV includes SEV along with the net present value of the expected costs and revenues to hold the existing timber through the end of the current rotation, including the opportunity cost of using the land. In developing templates, we used SEV as the primary economic criterion but also considered FV for mid-rotation stands. In both cases, 5% was used as the target real rate of return, which is typical for financial analysis calculations.

III. Simulating management alternatives

The next step in developing templates is to define potential management alternatives. We established nine different alternatives that were intended to represent a range of management prescriptions that a private landowner might use if intending to harvest a minimum of some small sawtimber (chip and saw) at the end of the rotation. The first alternative was a 25-year chip and saw rotation, while the other eight were sawtimber rotations ranging from 35 to 55 years. Each alternative included a commercial thinning at age 15 in which every 5th row was removed, along with additional thinning from below to remove a total of 30% of the stand volume.

The sawtimber rotations included subsequent thinnings from below starting at age 25. To balance the frequency needed to maintain an open canopy with the economic viability of the operation, we used thinning intervals of either 10 or 15 years. We used two different thinning intensities, leaving a residual basal area (BA) of either 60 or 80 ft^2/acre. The complete list of alternatives is below. *Table 1* shows a management timeline of each alternative.

1. 25-year chip and saw rotation
2. 35-year sawtimber rotation with 10-year thinning interval to 60 ft^2/acre BA
3. 35-year sawtimber rotation with 10-year thinning interval to 80 ft^2/acre BA
4. 40-year sawtimber rotation with 15-year thinning interval to 60 ft^2/acre BA
5. 40-year sawtimber rotation with 15-year thinning interval to 80 ft^2/acre BA
6. 55-year sawtimber rotation with 10-year thinning interval to 60 ft^2/acre BA
7. 55-year sawtimber rotation with 10-year thinning interval to 80 ft^2/acre BA
8. 55-year sawtimber rotation with 15-year thinning interval to 60 ft^2/acre BA
9. 55-year sawtimber rotation with 15-year thinning interval to 80 ft^2/acre BA

Table 1: Management timeline for each alternative. Common to all alternatives is a 30% thinning at age 15. Final, clear-cut harvest occurred at 25, 35, 40 or 55 years. Mid-rotation thinning varied in timing and intensity.

Alt	Year 15	20	25	30	35	40	45	50	55
1	Thin 30%		Clear-cut						
2	Thin 30%		Thin 60 BA		Clear-cut				
3	Thin 30%		Thin 80 BA		Clear-cut				
4	Thin 30%		Thin 60 BA			Clear-cut			
5	Thin 30%		Thin 80 BA			Clear-cut			
6	Thin 30%		Thin 60 BA		Thin 60 BA		Thin 60 BA		Clear-cut
7	Thin 30%		Thin 80 BA		Thin 80 BA		Thin 80 BA		Clear-cut
8	Thin 30%		Thin 60 BA			Thin 60 BA			Clear-cut
9	Thin 30%		Thin 80 BA			Thin 80 BA			Clear-cut

Each management alternative was simulated using the Landscape Management System (LMS). LMS provides a user-friendly interface that integrates existing and publicly available growth, treatment, and visualization models (McCarter et al. 1998). One of the growth models that LMS interfaces with is the USDA Forest Service's Forest Vegetation Simulator (FVS). For our simulations we used the Southern Variant of FVS (Donnelly et al. 2001, Stage 1973, Wykoff et al. 1982).

Simulations were begun on a representative inventory from a 10-year-old plantation that was one of the benchmark plots (stand 300-030). The 25-year site index was 55. To be compatible with LMS, we converted this to a 50-year site index of 73 using a factor of 1.32 (North Carolina Division of Forest Resources 1988). We further increased the site index to 80 in the growth model to account for intensive management practices (Siry et al. 2001).

For each thinning operation, it was assumed that in addition to thinning the crop trees, all non-crop trees over 5 inches DBH were removed except for a small component (13 TPA) of desirable, mast-producing hardwoods (black cherry, hickory, and various oaks). For trees under 5 inches DBH, 40% of the stems were removed at the time of thinning to simulate mortality from being crushed, etc. during the operation. In the absence of understory vegetation control, heavy, repeated thinnings can result in an undesirable hardwood midstory that inhibits the understory (Hunter 1990, Schultz 1997). For our simulations, we assumed that prescribed burning was done every 5 years starting at age 20. This was not directly represented in our simulations. Rather, the impacts of burning on understory tree composition were indirectly represented by not simulating the natural hardwood ingrowth that would be expected after thinning treatments, assuming that such ingrowth would be killed or suppressed by burning.

Using LMS projections, stand structure relative to the target conditions can be assessed over time. Economic metrics for each alternative can be computed using an integrated financial analysis program called Economatic. An imbedded bucking algorithm is used to divide harvested trees into different log sorts based on user-defined parameters. User-defined log prices are then applied, and revenue calculations are imported into Economatic. Economatic then applies additional user-defined costs and revenues (such as planting and prescribed burning costs) and calculates both SEV and FV.

For these simulations, we used 1st quarter 2005 average stumpage prices for Georgia Region 2 (Timber Mart-South 2005). Since LMS volume outputs were in cubic feet, we converted board foot prices to cubic foot prices using a factor of 5 board feet/cubic foot (North Carolina Division of Forest Resources 1988). Prices per cord were converted using a factor of 75 cubic feet/cord (Timber Mart-South 2005). Cost assumptions included $13.25/acre for prescribed burning (Dubois et al. 2003) and $8/acre annual property taxes and overhead costs (Siry 2002). SEV was calculated retrospectively by assuming a $215/acre cost for planting and site preparation (Dubois et al. 2003, Siry 2002) at the beginning of the rotation (10 years prior to the beginning of the simulations on the 10-year-old representative inventory). All financial calculations were done before income taxes.

IV. Results

The percent time in target over a 100-year simulation, along with SEV/acre and FV/acre, is summarized for each alternative in *Table 2*. Alternative 1, the 25-year chip and saw rotation, never achieved structure similar to the target; it also had the lowest economic performance. SEV for this alternative was negative, indicating that, given our assumptions, investing in this rotation would not earn the target real rate of return of 5%. Shorter rotations generally have favorable economic returns. Our results may reflect several factors. The growth model computes volume based on a minimum 4-inch top, which can underestimate the volume of small-diameter pulp and chip and saw logs. The historically low current pulp price ($18.40/cord) was also a likely factor.

FV figures are higher than SEV, as they include the existing 10-year-old inventory for which establishment costs are sunk. The 35 and 45-year rotations (Alternatives 2-5) reached the target less than 25% of the time, but tended to perform well economically, with Alternative 5 performing the best. The 55-year rotations (Alternatives 6-9) had the most time in the target and had moderate economic performance. The stumpage values used to compute SEV and FV, along with harvested volume, are summarized in *Table 3* and *Table 4* respectively.

Table 2: Comparison of time in target over 100 years, SEV/acre, and FV/acre for each alternative.

Alternative	% Time in Target	SEV/Acre	FV/Acre
1	0%	($20)	$418
2	14%	$423	$1,140
3	14%	$480	$1,233
4	24%	$466	$1,210
5	14%	$619	$1,459
6	48%	$305	$947
7	48%	$413	$1,124
8	48%	$382	$1,074
9	38%	$415	$1,127

Table 3: Total harvest revenue by year for each alternative.

Alternative	Year								
	15	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**
1	$107		$905						
2	$107		$375		$2,990				
3	$107		$263		$3,432				
4	$107		$375			$4,253			
5	$107		$263			$5,412			
6	$107		$375		$634		$755		$4,477
7	$107		$263		$746		$1,206		$5,408
8	$107		$375			$1,656			$5,004
9	$107		$263			$1,750			$5,741

Table 4: Total harvested volume (cubic feet) by year for each alternative.

Alternative	Year								
	15	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**
1	435		2,965						
2	435		1,533		2,439				
3	435		1,073		3,141				
4	435		1,533			2,973			
5	435		1,073			3,772			
6	435		1,533		721		518		2,526
7	435		1,073		896		758		3,289
8	435		1,533			1,158			2,918
9	435		1,073			1,409			3,593

For each alternative, the simulation cycles that achieved the target conditions are shaded in *Table 5*. This gives some insight as to which management strategies were most successful in producing target structures. All of the sawtimber rotations reached the target after the second commercial thinning. All of the alternatives that were thinned to 60 ft^2/acre of BA remained in the target until final harvest, as did those that were thinned to 80ft^2/acre of BA at 10-year intervals. When thinned to 80ft^2/acre at 15-year intervals (Alternative 9), the stand fell out of the target 10 years after the second thinning. This suggests that heavier or more frequent thinnings are necessary to maintain the target structure. The alternatives in which thinning was done to 80 ft^2/acre (3,5,7,9) produced a better economic return than the comparable alternatives that were thinned to 60ft^2/acre (2,4,5,8). Thus, thinning more frequently to 80 ft^2/acre might be a good way to balance objectives. In each case, the overall time in target was limited by the rotation age.

Table 5: The management timelines from Table 1 with shaded areas indicating the simulation cycles for which the target conditions were achieved.

Alt	Year 15	20	25	30	35	40	45	50	55
1	Thin 30%		Clear-cut						
2	Thin 30%		Thin 60 BA		Clear-cut				
3	Thin 30%		Thin 80 BA		Clear-cut				
4	Thin 30%		Thin 60 BA			Clear-cut			
5	Thin 30%		Thin 80 BA			Clear-cut			
6	Thin 30%		Thin 60 BA		Thin 60 BA		Thin 60 BA		Clear-cut
7	Thin 30%		Thin 80 BA		Thin 80 BA		Thin 80 BA		Clear-cut
8	Thin 30%		Thin 60 BA			Thin 60 BA			Clear-cut
9	Thin 30%		Thin 80 BA			Thin 80 BA			Clear-cut

Aside from Alternative 1, which performed the worst relative to both criteria, increasing the percent time in target will involve some level of economic trade-off relative to Alternative 5, which had the highest SEV. The performance of each alternative relative to the two primary template criteria, time in target and SEV, are plotted in *Figure 3* to show a visual comparison of the trade-offs.

As shown in *Figure 3*, maximizing the time in target (Alternatives 6-8) involves a trade-off with SEV. One way this trade-off might be minimized is through increased hunting lease revenue. Hunting leases can provide forest landowners in the South with significant supplemental revenue, especially for landowners who provide high-quality habitat (Baker and Hunter 2002, Johnson 1995, Jones et al. 2001). Using time in target as an indicator of habitat quality, landowners who provide more time in target may earn hunting lease premiums. *Figure 4* shows what the relative trade-offs for each alternative would be assuming the following hunting lease rates: $4/acre for less than 20% time in target, $8/acre for 20-40% time in target, and $12/acre for greater than 40% time in target.[4] The trade-offs still exists, but they are reduced for the alternatives that have the most time in target, which may make these costlier alternatives more acceptable to private landowners.

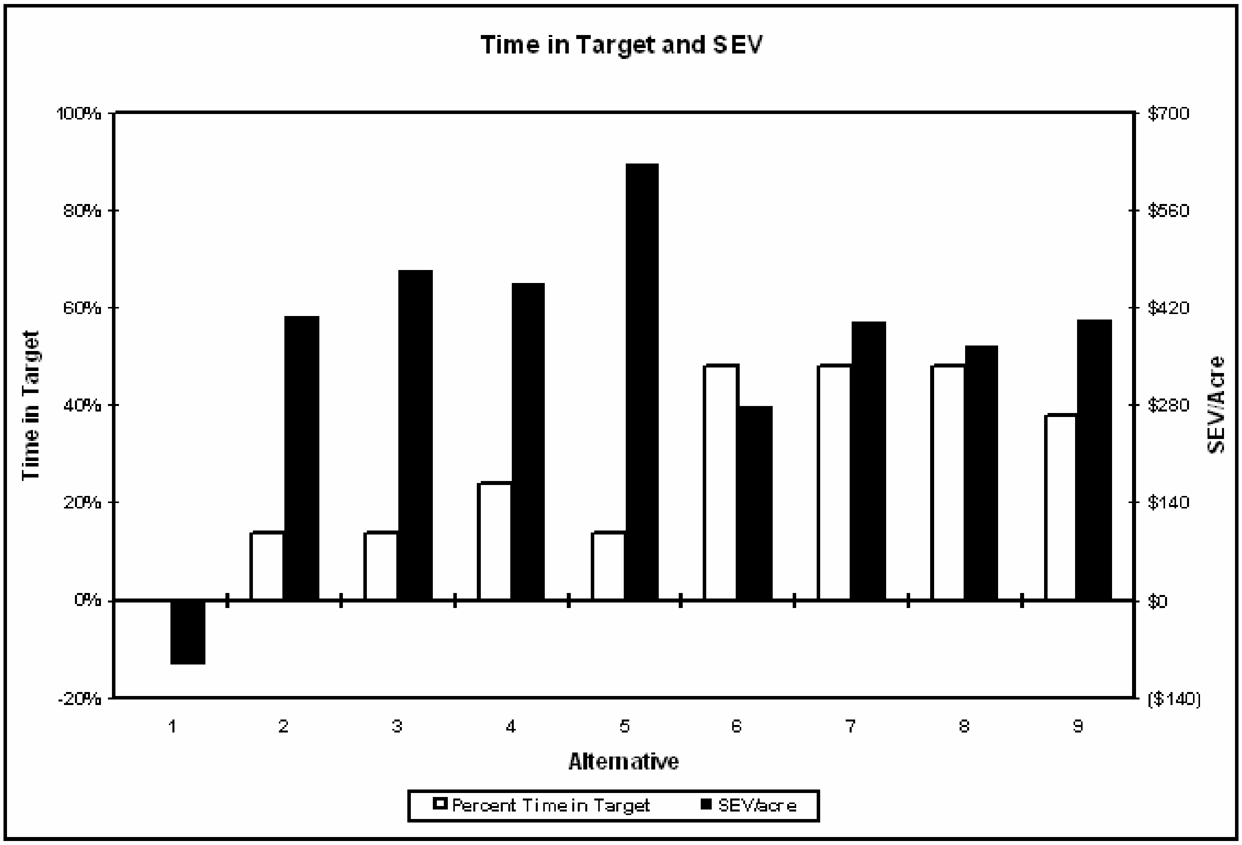

Figure 3: The percent time in target over 100 years plotted together with the SEV/acre for each alternative illustrates some of the trade-offs between biodiversity and economic return.

Quantifying the trade-offs between time in target and SEV can help identify the best template options from our 9 alternatives. *Table 6* summarizes the SEV cost (assuming hunting lease premiums) for each alternative as the difference relative to the maximum possible (Alternative 5). Both the total cost and the cost per percent time in target are given.

Three alternatives emerged from *Table 4*, illustrating a range of template options. The lowest cost template would be Alternative 5, for landowners who want to provide some level of biodiversity but not sacrifice economics. Of the alternatives that provided a higher percent of time in target, Alternative 4 was the lowest cost alternative and may be desirable for landowners who want to make a small improvement in biodiversity but cannot afford significant costs. Alternative 7 had the lowest overall cost/benefit ratio and thus produced the desired structure most efficiently. For supporting significantly increased biodiversity while maintaining a competitive economic performance, this may be the overall most desirable template option.

[4]Average net revenues for hunting lease in Mississippi were reported as $4.59/ac for 1997-98 (Jones et al. 2001). We believe that quality habitat can generate as much as $12-$15/acre.

Figure 5 illustrates the projected stand development from age 10 to 55 under Alternative 7. Complete stand development projections for each alternative are shown in the Appendix.

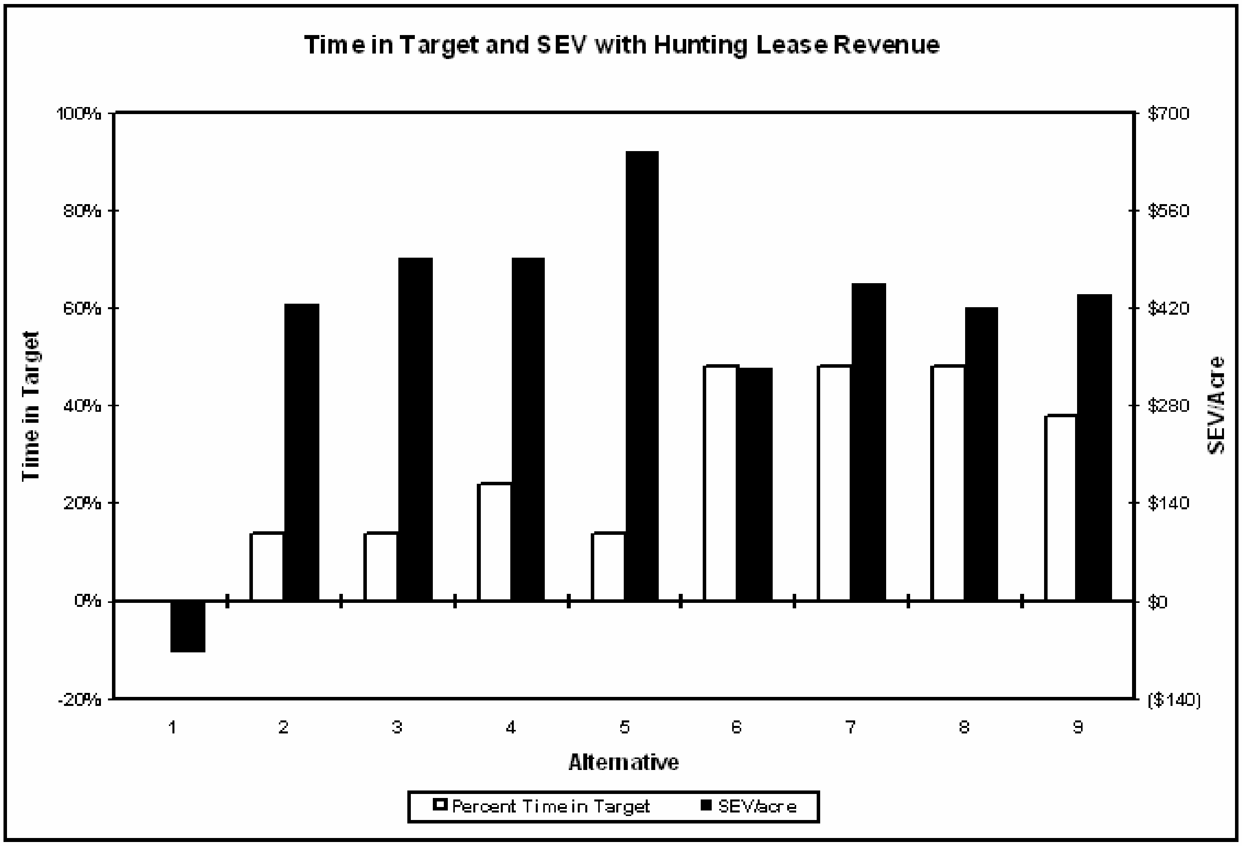

Figure 4: The percent time in target over 100 years plotted together with the SEV/acre for each alternative assuming hunting lease premiums, which can reduce economic trade-offs for alternatives with high time in target scores.

Table 6: Comparison of the SEV costs (as the difference relative to the maximum possible) and percent time in target over 100 years for each alternative.

Alternative	% Time in Target	SEV/Acre	SEV Cost	Cost/% in target
1	0%	($2)	$639	N/A
2	14%	$442	$195	$13.93
3	14%	$499	$138	$9.86
4	24%	$503	$134	$5.58
5	14%	$637	$0	$0
6	48%	$360	$277	$5.77
7	48%	$469	$168	$3.50
8	48%	$438	$199	$4.15
9	38%	$452	$185	$4.87

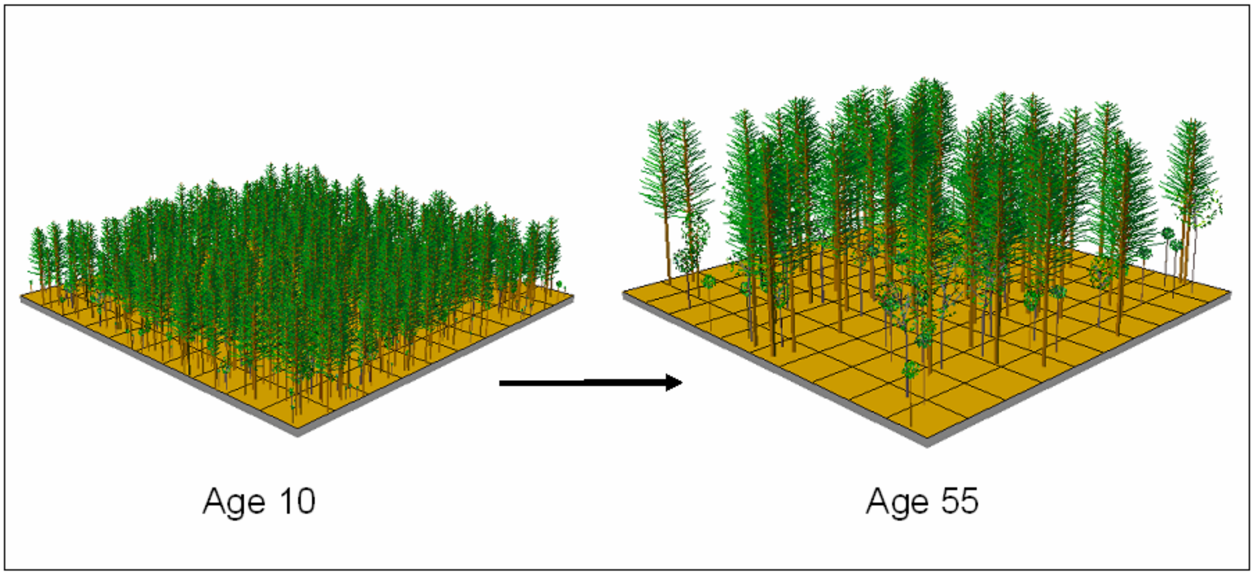

Figure 5: Projected stand development from age 10 to 55 under Alternative 7.

V. Template applications

The thinning and burning regime of Alternative 7 (*Table 7*) can potentially support significantly increased biodiversity in intensively managed loblolly pine plantations. When implementing such a template, several guidelines should be considered. One of the most important considerations is land use history. Old-field sites lack seed- and rootstock-banks (Baker and Hunter 2002). Plantations established on these sites are unlikely to develop a diverse, productive understory regardless of overstory management (Hedman et al. 2000). Thus, templates like this should only be applied to plantations established on cutover lands. Plantations on old field sites may be best managed for maximum timber production, as these sites will not likely support high levels of biodiversity.

Table 7: Thinning and burning timeline for Alternative 7.

Year	15	20	25	30	35	40	45	50	55
Alt 7	Thin 30%		Thin 80 BA		Thin 80 BA		Thin 80 BA		Clear-cut
		burn	burn	burn	burn	burn	burn	burn	burn

Additional management practices can be used in conjunction with a template like this to promote increased biodiversity. Moderate intensity site preparation may provide a reasonable balance of understory diversity and cost effectiveness (Locascio et al. 1990). Fertilization can promote biodiversity by improving understory food production in thinned stands (Hunter 1990, Hurst and Warren 1982). Snags and downed wood provide important habitat structures that should be retained as much as possible (Allen et al. 1996, Dickson and Wigley 2001, Lohr et al. 2002). Retaining riparian buffers will also promote biodiversity (Baker and Hunter 2002, Dickson and Wigley 2001).

Site specific factors should be taken into account when considering the frequency and timing of burning. Some suggest in general to burn before thinning, as it makes thinning easier (Hurst et al. 1980) and there will not be heavy fuel loads at the time of burning to cause the fire to burn too hot (Van Lear et al. 2004). When possible and practical, varying the season and frequency of prescribed burning can increase diversity and favor a broader suite of species (Robbins and Myers 1992). Likewise, leaving patches of unburned areas can favor some wildlife (Landers 1987, Moorman 2002). For both thinning and burning, mast-producing hardwoods like hickories and oaks should be retained if possible to provide food for wildlife (Johnson et al. 1975, Melchiors 1991).

The template presented above is just one example management strategy for supporting increased biodiversity while maintaining viable economics. The template incorporates some key basic principles for increasing biodiversity, such as longer rotations, early and frequent thinning, and prescribed burning. There are many possible variations of this proposed template that could achieve as good or better results. In particular, even longer rotations may provide for greater biodiversity. The time in target scores for the alternatives that we examined were ultimately limited by rotation length. SEV values for some of the 55-year alternatives were still competitive, especially if hunting lease premiums were assumed. Rotations longer than that can likely still achieve acceptable economic returns and may be desirable for landowners who are willing to incur additional costs to support higher levels of biodiversity. Earlier, more frequent, or heavier thinnings may also achieve target conditions sooner than the alternatives that we examined.

Most importantly, the template presented above successfully demonstrates an approach for developing sustainable management solutions that support increased biodiversity while maintaining economic viability. With additional data to quantify the desired conditions, a more robust target can be developed, which will be helpful for further refining this example template and generating additional templates. Ultimately a spectrum of management templates is needed to be applicable to a wide range of site conditions and to give landowners choices as they balance biodiversity and economic objectives.

Acknowledgements

The authors would like to acknowledge James McCarter, Kevin Ceder, and Larry Mason at the Rural Technology Initiative, University of Washington, for their contributions to this project in guidance and technical support.

Metric equivalents

When you know:	Multiply by:	To find:
Cubic feet (ft^3)	0.0283	Cubic meters
Feet (ft)	0.3048	Meters
Inches (in)	2.54	Centimeters
Square feet per acre (ft^2/ac)	0.229	Square meters per hectare
Trees per acre (TPA)	2.471	Trees per hectare

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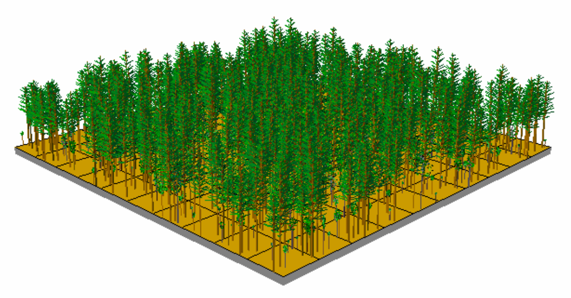
Appendix: Stand development projections

Below are projections of each management alternative over time using LMS and the Stand Visualization System (McGaughey 1997).

Alternative 1:

- 30% thin at age 15
- Clear-cut at age 25



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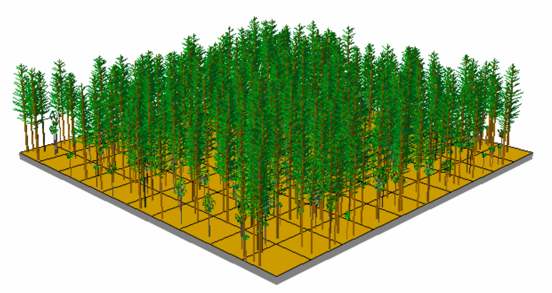

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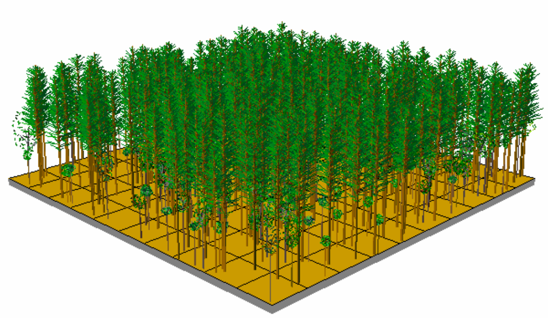
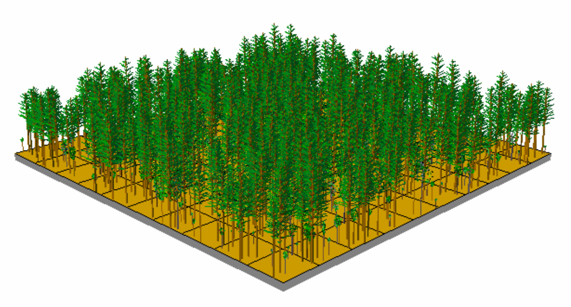


Age 25

Alternative 2:

- 30% thin at age 15
- Thin to 60 BA at age 25
- Clear-cut at age 35



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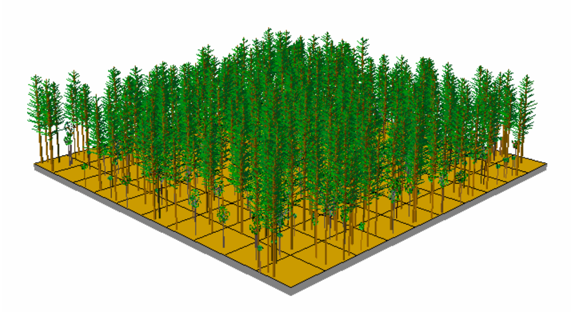

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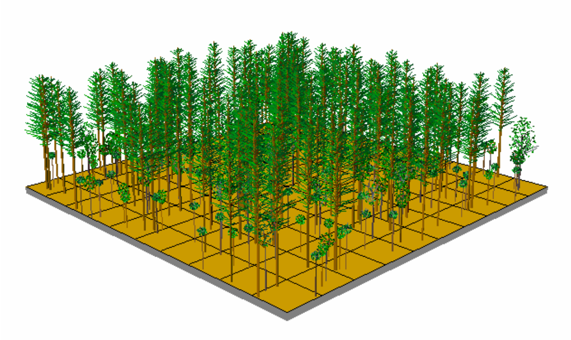

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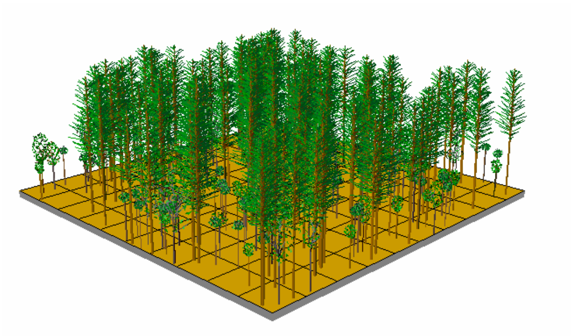
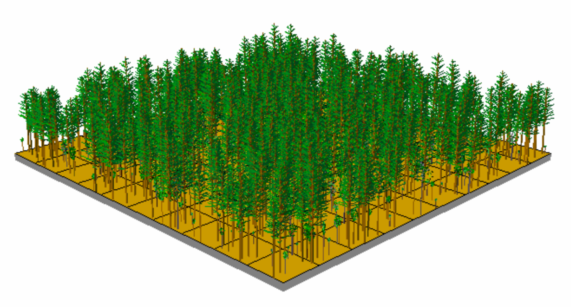


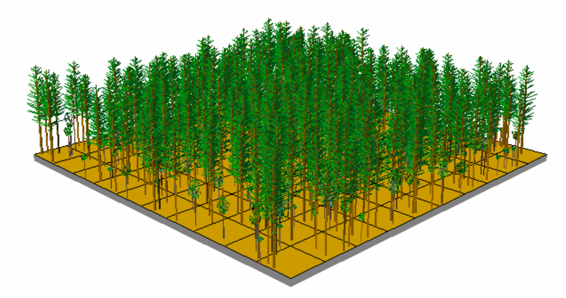
Age 35

Alternative 3:

- 30% thin at age 15
- Thin to 80 BA at age 25
- Clear-cut at age 35



Age 10



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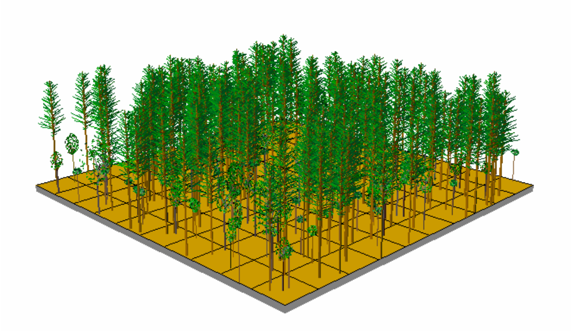

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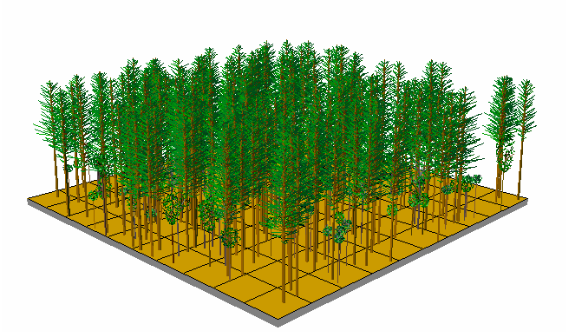
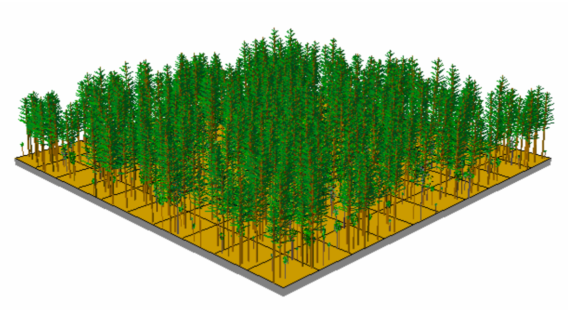


Age 35

Alternative 4:

- 30% thin at age 15
- Thin to 60 BA at age 25
- Clear-cut at age 40



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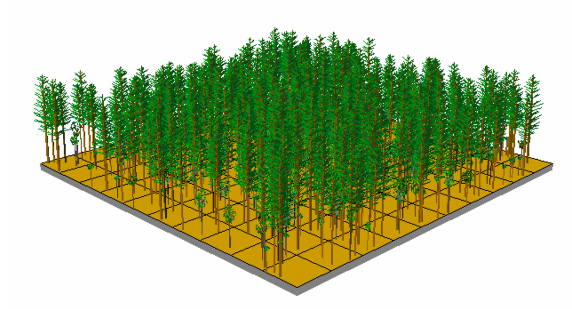

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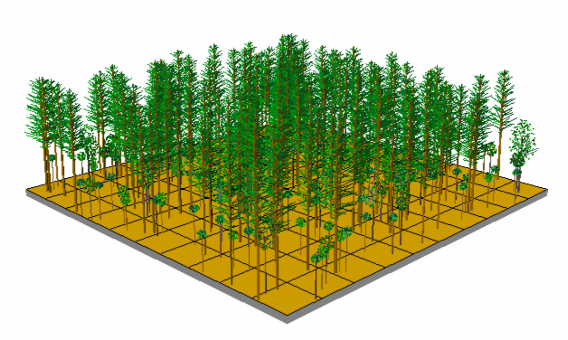

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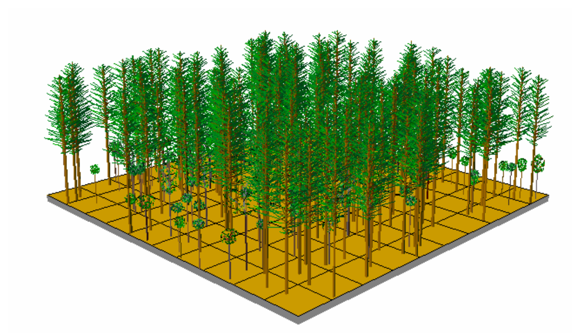
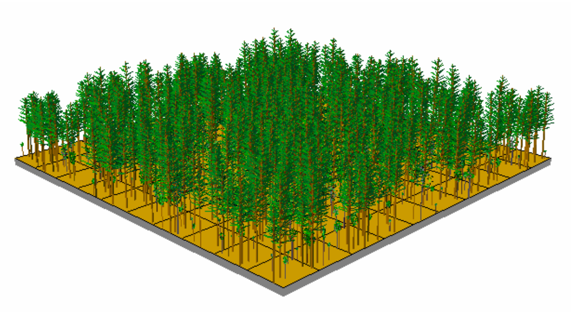


Age 40

Alternative 5:

- 30% thin at age 15
- Thin to 80 BA at age 25
- Clear-cut at age 40



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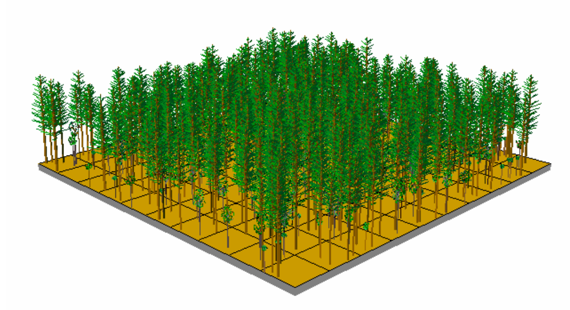

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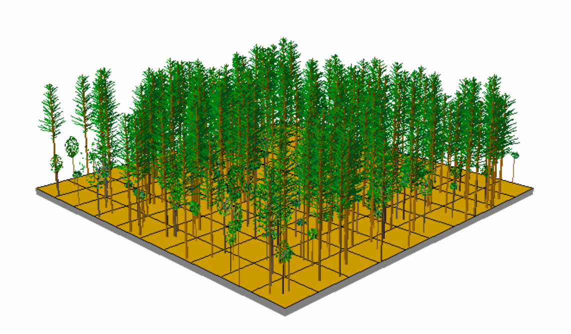

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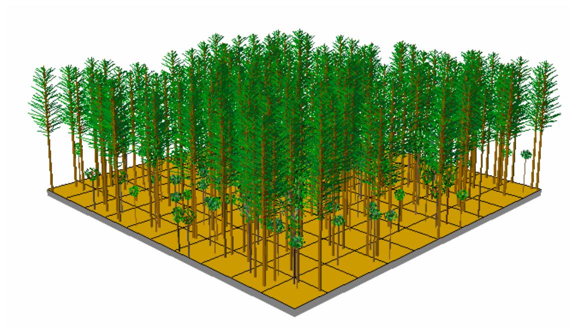
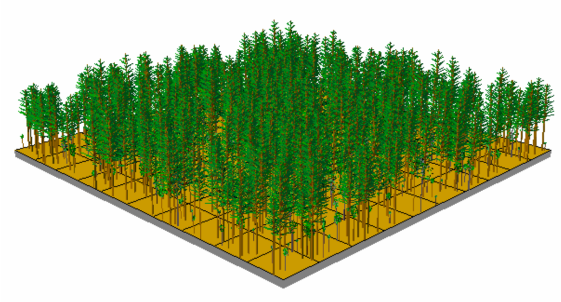


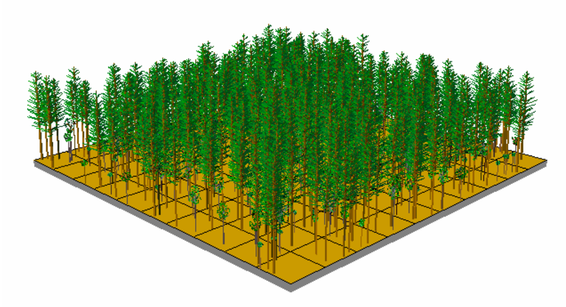
Age 40

Alternative 6:

- 30% thin at age 15
- Thin to 60 BA at age 25
- Thin to 60 BA at age 35
- Thin to 60 BA at age 45
- Clear-cut at age 55



Age 10



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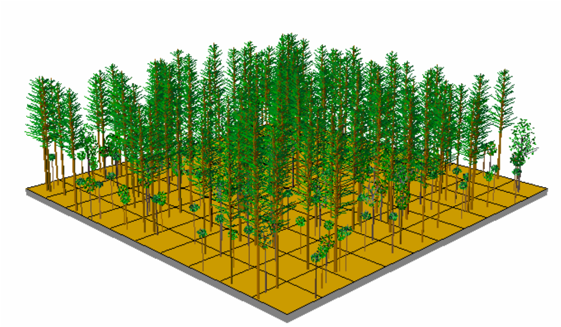

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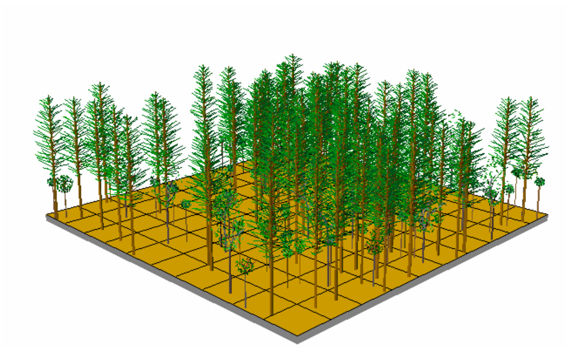
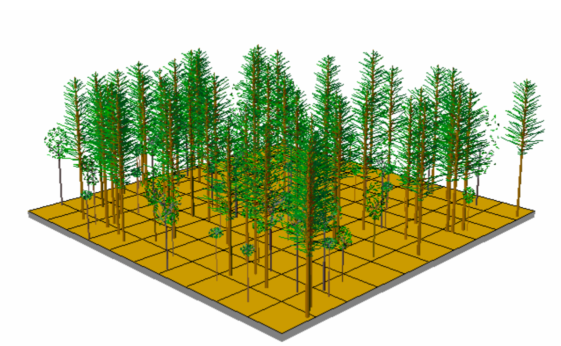
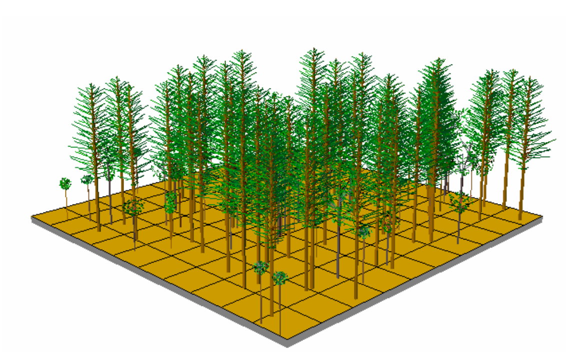


Age 35



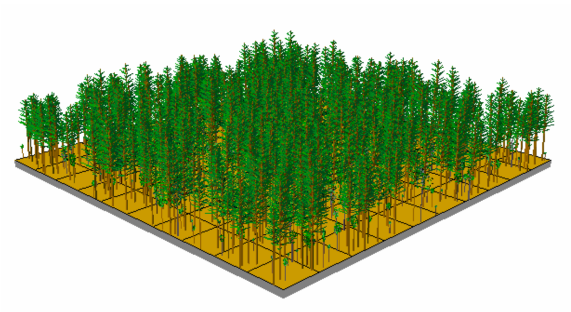
Age 45



Age 55

Alternative 7:

- 30% thin at age 15
- Thin to 80 BA at age 25
- Thin to 80 BA at age 35
- Thin to 80 BA at age 45
- Clear-cut at age 55



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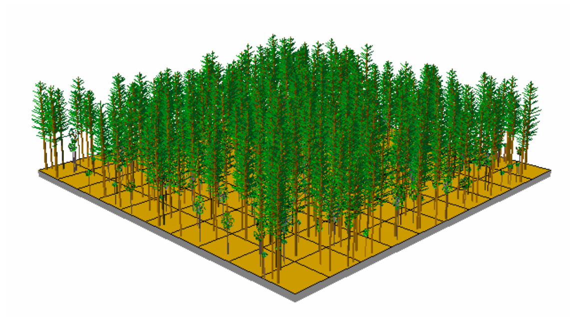

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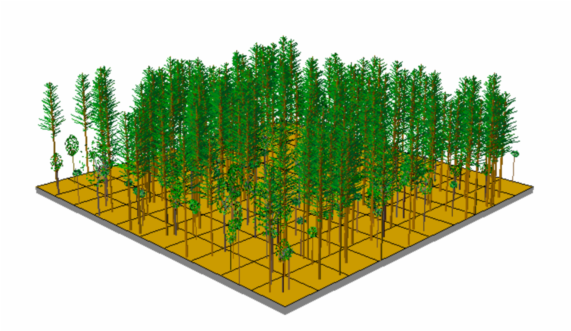

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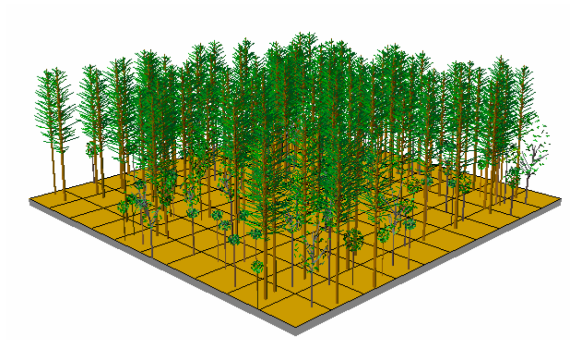

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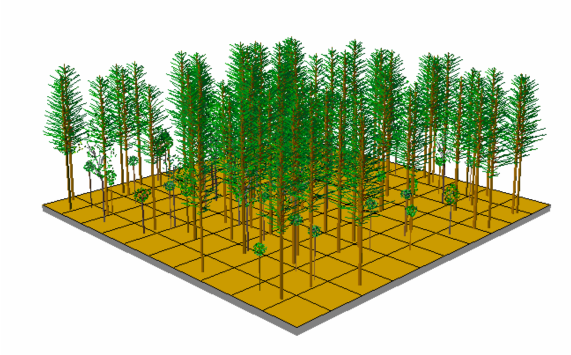

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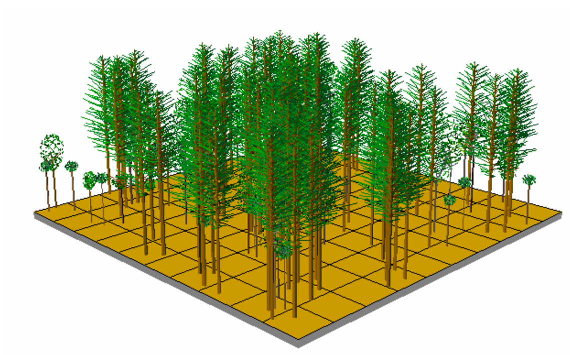
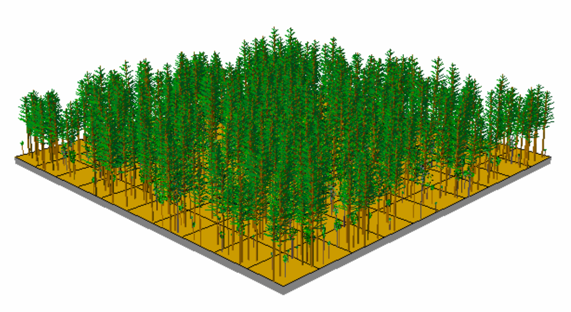


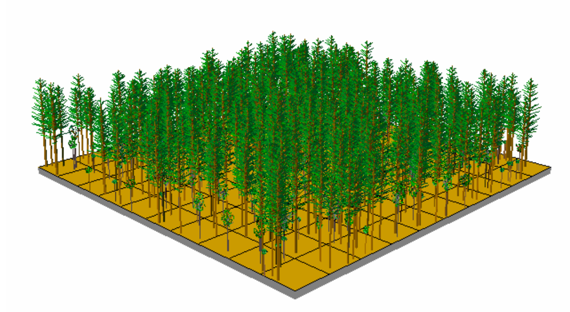
Age 55

Alternative 8:

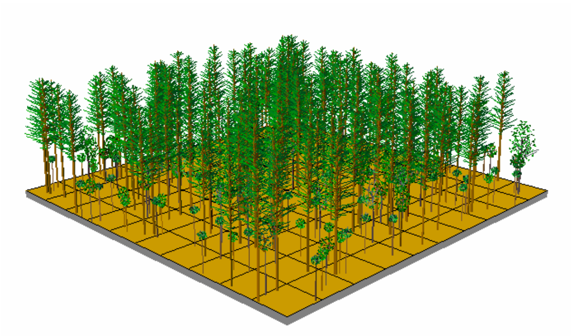
- 30% thin at age 15
- Thin to 60 BA at age 25
- Thin to 60 BA at age 40
- Clear-cut at age 55



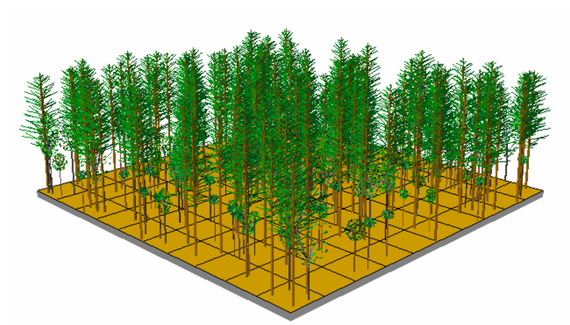
Age 10



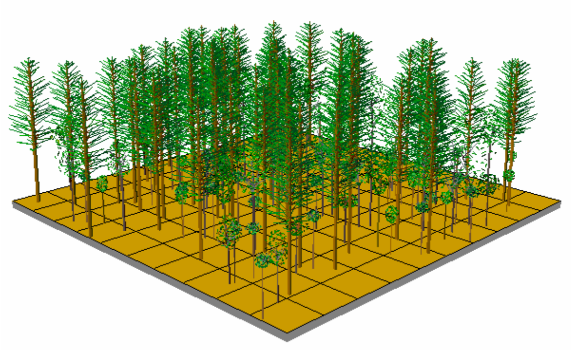
Age 15



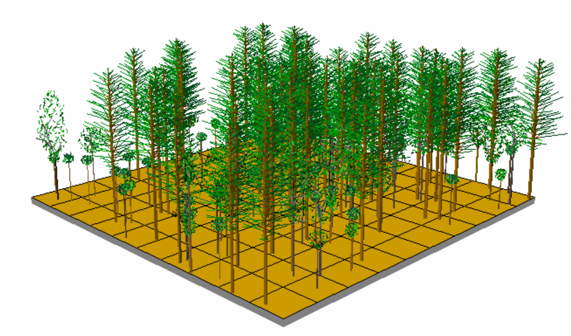
Age 25



Age 35



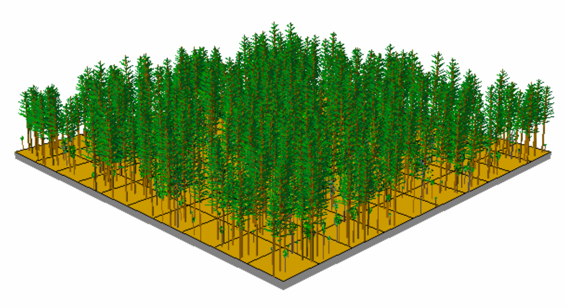
Age 45



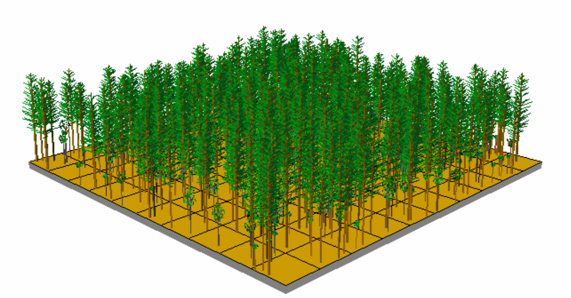
Age 55

Alternative 9:

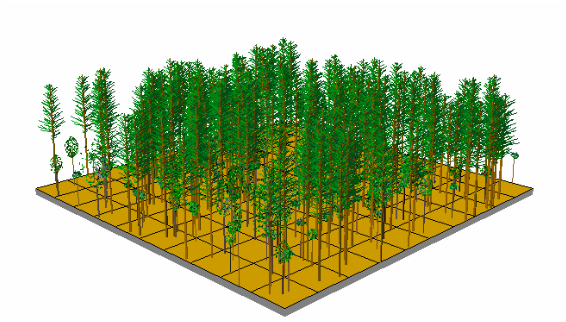
- 30% thin at age 15
- Thin to 80 BA at age 25
- Thin to 80 BA at age 40
- Clear-cut at age 55



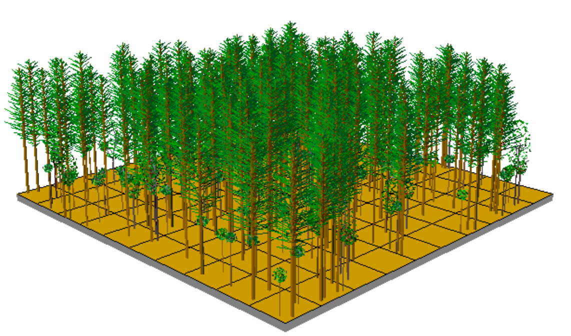
Age 10



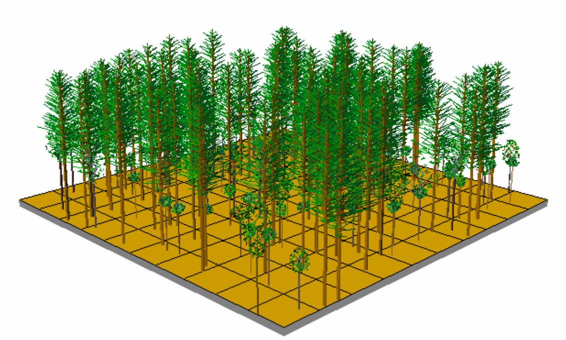
Age 15



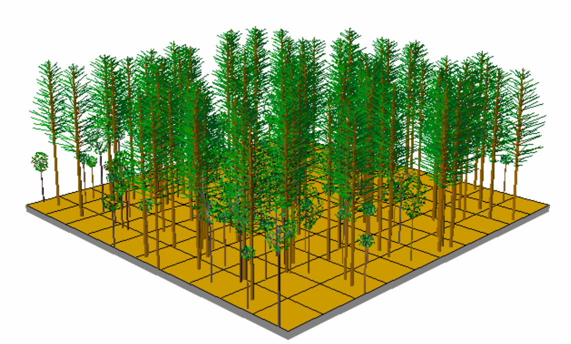
Age 25



Age 35



Age 45



Age 55