Using Silviculture to Sustain Wildlife Habitat: Assessing Changes and Trade-offs in Forest Habitats Using a Habitat Evaluation Procedure within the Landscape Management System

By

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This is to certify that I have examined this copy of a master's thesis by

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And have found that it is complete and satisfactory in all respects,
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Introduction and Objectives

The public has become increasingly concerned over the past three decades about potential negative effects on wildlife caused by development and other modifications of wildlife habitat. Conversion of naturally regenerated mature and old-growth forests to intensively managed plantations for timber production has raised concerns about habitat for species that are associated with these forest structures. As a result of the concerns, regulatory pressures on forest management to provide habitat has resulted in a shift away from harvesting mature and old-growth forests to creating a system of reserves for wildlife habitat. With the reduction of the mature and old-growth forests, concerns have been raised about the ability of species associated with these forests to survive in the remaining mature forests. Consequently, there is much interest in applying alternative silvicultural regimes to produce mature and old-growth forest structures in managed forests, with the hope of providing an increased amount of habitat for species associated with mature forests.

The fields of forest management and wildlife biology often have competing objectives for the use and management of forests and often disagree on the best way to manage the forests. The common area is in forests where both timber products and wildlife habitats are provided. The management perspectives from each field vary, but the results are not necessarily mutually exclusive.

Tools exist in the forest management and wildlife biology fields to model both forest growth and wildlife habitat suitability. The tools that each field has at their disposal have common features, although they are not frequently used together. Habitat models for forest wildlife species often require tree-based measures – such as tree species, sizes, and densities – for calculating habitat values or species abundance. Forest growth and yield models use current forest inventory to predict forest growth and potential outputs in the future by using a set of tree-based measures that include tree species, sizes, and densities. With these commonalities it may be possible to integrate these tools and estimate forest outputs of timber production and wildlife habitats for the same forest. The result would be a new tool that allows both forest managers and wildlife managers to analyze and communicate proposed forest management in new ways.

This project has two dual objectives:

- Integrates these tools by implementing a habitat evaluation procedure (HEP) for Satsop Forest using the Landscape Management System. This LMS procedure parallels the original HEP that was performed on Satsop Forest in the early 1990's:
- Demonstrates how the tool can be used to analyze projected outputs from both proposed landscape management plans and from several, alternative silvicultural pathways that are proposed for creating wildlife habitats.

When assessing the performance of landscape level management plans, only a single ownership will be considered as a landscape. The term "landscape" can be defined at many scales, from an entire region to an individual watershed or a single ownership. For the analyses in this project the landscape will be limited to the Satsop Forest ownership.

Silvicultural pathways are discussed throughout this paper. These pathways are similar to management regimes but are at the stand level. A silvicultural pathway consists of a set of silvicultural treatments that will be performed on a stand during the analysis period. A pathway can include harvesting, thinning, fertilizing, pruning, and planting as well as performing no silvicultural treatments. These pathways will set the stand on a specific development trajectory based on the initial conditions and the types and timings of silvicultural treatments.

Background

Original Habitat Evaluation Procedure

During the early 1990's a habitat evaluation procedure (HEP) was performed on Satsop Forest (at the time the Satsop Nuclear Site) to assess changes in wildlife habitat to be caused by the construction of Washington Public Power Supply System (WPPSS) Nuclear Projects Nos. 3 and 5 (USDI 1980a; USDI 1980b; WSEFSEC 1990; WPPSS 1994a) as part of the Site Certification Agreement (WSEFSEC 1990). The result of the HEP was a 50-year wildlife plan to mitigate the effects of the construction of the Projects (WPPSS 1994e).

Performing the HEP involved several steps. First a vegetation cover type inventory of the area was undertaken using aerial photographs with associated criteria for determining cover types. Next, a set of species for the analysis was selected, followed by habitat suitability index (HSI) model selections and a habitat attribute inventory. Several potential management scenarios were then drafted for the area, with forest changes estimated. Habitat suitability index values were then calculated for each cover type that was expected to be found on Satsop Forest at specific future target years. These target years were 1976 (the pre-project year), 1978 (the beginning of plant construction), 1989 (the end of passive land management period), 2015 (the mid-point of the active land management period), and 2040 (the end of the analysis period). For each target year, cover type acreages and HSI and habitat unit (HU) values for each species were calculated. For the life of each alternative, annual average habitat unit (AAHU) values were calculated to estimate average available habitat quantities. The AAHU values were then compared for selection of the preferred management alternative.

Twenty-one cover types were found on Satsop forest including "Developed" and "Barren" ground that are not considered as wildlife habitat. There are three riparian cover types as well as ponds, grass, and brush. Non-riparian forested areas that can be managed fit into thirteen cover type classifications. All of which are classified by tree-based measures (Table 2.1). If a stands meets all the criteria for a cover type, it is given that cover type classification.

Five species and associated HSI models were selected for the HEP analysis: Cooper's hawk (*Accipiter cooperii*; (USDI 1980c), southern red-backed vole (*Clethrionomys gapperi*;(Allen 1983), pileated woodpecker (*Dryocopus pileatus*; (Schroeder 1983), spotted towhee (*Pipilo erythrophthalmus*; (USDI 1978), and black-tailed deer (*Odocoileus hemionus columbianus*; (WDFW 1991). Each species was chosen for a specific reason(WPPSS 1994a). Cooper's hawks tend to prefer hardwood and mixed conifer-hardwood forests in both upland and riparian habitats. Southern red-backed voles were chosen to represent small forest rodents. They prefer mature and older forest structures and are a prey species for forest raptors and owls. Pileated woodpeckers were selected to represent cavity nesters. They are the largest of the woodpeckers and require larger snags than other cavity nesters; and they are listed as a Washington State species of concern. If habitat exists for pileated woodpeckers, it is assumed that smaller cavity users such as nuthatches, flying squirrels and bats will have habitat as well. Spotted towhees prefer open structures with dense shrub layers, such as brush lands and young forests. Black-tailed deer use multiple habitats and are of concern to the public and wildlife management agencies as a game species.

Three basic management scenarios were compared: "without project", "with project without mitigation" and "with project with mitigation." "Without project" assumed industrial forest management for wood production would continue on the site without constriction of the power plants. "With project without mitigation" assumed that industrial management for wood production would continue on the buffer lands surrounding the developed site. "With project with mitigation" included four potential mitigation alternatives. These alternatives included varying levels road closures and habitat enhancing measures.

Based on average habitat attribute values measured during the 1991 habitat attribute inventory, HSI values were calculated for each species for each cover type on Satsop Forest. Cover types acreages were calculated for all the target years based on estimated forest changes caused by growth and potential management alternatives. These acreages were used with the HSI values to calculate HU values, which were then used to calculate AAHU values for each species. Changes in AAHU values between alternatives were used as the deciding factor in selecting the preferred mitigation alternative for the mitigation agreement.

Other Approaches To Habitat Evaluation

Several other methods have been used for assess changes in quality and quantity of wildlife habitat caused by forest management and disturbances. These have included HSI models implemented within a GIS, optimization systems, and population density models.

GIS-based approaches integrate HSI models with the spatial analysis power if GIS. In one example, Rempel, *et al.* (1997) used a GIS-based HSI model to examine the effects of past natural disturbance and timber management on populations of moose (*Alses alses*) in southern Quebec, Canada. Similarly Kliskey, *et al.* (1999) used GIS-based HSI models for woodland caribou (*Rangifer tarandus*) and pine marten (*Martes americana*) in the North Columbia Mountains of British Columbia, Canada. Kilskey *et al.* examined changes in habitat quality and quantity for both species as well as harvested volume under four simulated forest management scenarios to assess amounts of habitat generated by each scenario, tradeoffs of habitats among species for each scenario, and tradeoffs between habitat quantity and harvested volume.

A second approach is optimization of habitat or an aspect of habitat. Moore *et al.* (2000) used a genetic algorithm to optimize harvest scheduling on a simulated landscape based on bird populations derived from population models for hypothetical species. Beavers and Hof (1999) took a different approach by spatially optimizing the amount of edge habitat to maintain populations of both edge and interior habitat species.

A third approach was taken by Hansen, *et al.* (1995). They constructed population density models for sixteen species of birds in the Central Oregon Cascades by using density of trees in specific diameter classes to estimate population densities. With these models several silvicultural pathways were simulated with the ZELIG growth model (Urban 1992) and the outputs were used to estimate the resulting population densities.

Proposed Pathways

As a response to of the growing concern over the perceived negative effects of forest management on wildlife habitat, several silvicultural pathways have been proposed to create mature and late-successional forest structures in managed landscapes. These typically involve multiple thinnings at different stand ages and at different intensities than typically applied in commercial wood production. In many cases these pathways have been simulated using various growth models with varying degrees of success.

Hansen, et al. (1995) used data from a “typical” old-growth stand in the Central Oregon Cascades and simulated thirty-six pathways. These varied in retention of zero to sixty trees per acre with rotation lengths of 40, 80, 120 and 240 years. Simulations were done using the gap model ZELIG (Urban 1992) and relied on simulated natural seeding to regenerate the stands. Thinnings were simulated on the regenerating stands at 15 and 30 years, leaving 220 trees per acre with no preference toward species.

DeBell and Curtis (1993) highlight the Demonstrating Ecosystem Management Options (DEMO) harvests that have occurred in mature forests, Retention in these harvests ranges from 10% to 100% (control) in clumped and dispersed retentions.

Barbour, et al. (1997) simulated several pathways on young stands in central Oregon to examine the effects on wood quality and production under alternative silvicultural regimes. Beginning with stands stocked at 300 trees per acre at 15 years total age, stands were thinned to 30 or 60 trees per acre from below at 15 years, to 30 trees per acre from below at 30 years, to 60 trees per acre at 30 years leaving the 30 largest and 30 smallest trees per acre, and to 100 trees per acre from below at 30 years and the control stand was left at 300 trees per acre. These were all projected using the ORGANON (Hann, Olsen et al. 1994) growth model with output analyzed using a spreadsheet bucking algorithm and product grading simulation software.

McComb, et al. (1993) simulated four pathways using data from a 115-year old naturally regenerated stand in central Oregon using the ORGANON growth model. A clearcut pathway, leaving no remnants form the original cohort, was planted and then thinning at 35 and 60 years, with clearcutting at 70 years. This pathway was used to simulate industrial forestry silviculture. To simulate the potential of managing for both wood products and wildlife habitat, single-storied, few-storied, and multiple-storied pathways were simulated. The single-storied approach left two remnant trees over 30" DBH per acre and six snags per acre with DBH >25" followed by planting. At 45 years 30% of the trees in the 8-20" DBH class were removed and 2 mbf/ac were designated for creation of snags and downed wood. The few-storied approach left six remnant trees over 30" DBH per acre and four snags with DBH >25" per acre followed by planting. At 35-years, three more snags per acre were created. At 45 years, the regenerated stand was thinned to 50 tpa and underplanted with dominantly shade tolerant species. At 55 years, one more snag per acre was created; at 70 years, the understory was thinned to 70 % of the trees remaining.

With the multiple-storied approach, a 25-year cutting cycle was simulated. The initial harvest removed 76% of the standing volume and was followed by planting dominantly shade tolerant species and allotting 4% of the volume to snag and log creation with the remaining 20% for growing stock. Entries at 25 and 50 years removed 17% and 16% of the volume, respectively, followed by thinning the understory to 50-60% and underplanting dominantly shade tolerant species.

Along with these pathways a plantation restoration pathway was simulated, also using ORGANON. This pathway began with a 40-year old plantation in central Oregon stocked at 319 trees per acre. The initial harvest was thinned to 81 trees per acre at 40 years, followed by creating 2 mbf/ac of snags and planting dominantly shade tolerant species. Snags were then created at 45, 75 and 110 years at 1, 2, and 2 mbf/ac, respectively. At 90 years, trees <30" DBH were thinned to 60%.

Carey, et al. (1996) simulated biodiversity pathways on using the SNAP II harvest scheduling program and data from the Washington State Department of Natural Resources Clallam Block. Beginning with young managed stands the biodiversity pathways thinned the stands to 300 trees per acre from below at 15 years, favoring multiple species. At 30 years the stands were commercially thinned to 100 dominant trees per acre with three trees per acre inoculated with top rot fungi. A second commercial thinning was performed between 50 and 60 years with 75 dominants, hardwood and non-merchantable trees, and sufficient downed wood >20" diameter left to assure 15% ground cover and one snag per acre. Between 70 and 90 years, a third commercial thinning was performed, leaving 36 dominant and co-dominant trees per acre while leaving sufficient downed wood to assure 15 – 20% cover and creating one snag per acre.

The Cascade Center for Ecosystem Management (1993) began a study in the early 1990's to examine the effect of thinning on the development of young stands. Proposed thinning for 30 –

50 year old stands stocked at approximately 250 trees per acre are a light thinning leaving 100 – 120 tpa, a heavy thinning leaving 50 tpa, with underplanting, and thinning to 100 – 120 tpa with gaps where all trees are removed.

The Landscape Management System

The Landscape Management System (LMS) is an integrated forest management simulation and decision analysis software package developed as a cooperative effort between the Silviculture Laboratory, College of Forest Resources, University of Washington, and the USDA Forest Service (McCarter, Wilson et al. 1998). LMS is an evolving application designed to assist in stand and landscape ecosystem analyses by coordinating the processes of forest growth and management simulations, tabular data summarization, and stand and landscape visualization. Implemented as a Microsoft Windows™ application, many separate programs integrate these tasks. These programs include forest growth models, harvest simulation programs, and data summary programs, as well as stand and landscape level visualization software.

Underlying data for LMS are consolidated into a landscape portfolio. These data include forest inventory data; stand level data (e.g. site index and age), and topographic data (slope aspect and elevation), as well as geographic information system (GIS) data in the form of a digital terrain model (DTM), ESRI (Environmental Systems Research Institute, Inc., Redlands, CA) shapefiles of stand boundaries, and other features such as streams and roads. This assemblage of data is then used by LMS to simulate, analyze, and communicate the effects of forest management on the landscape.

Summary output tables from LMS range from standard inventory tables, to stand structural stages, to harvested and standing volumes. All tables are summaries of current and projected inventories for analyses of predicted future conditions and forest outputs. The large array of tables allows analyses of proposed forest management from many perspectives.

Table 2.1: Timbered cover type thresholds for Satsop Forest from the original HEP

Cover Type	Description	Canopy Closure	Percent conifer	Percent deciduous	TPA	TPA >21" DBH	Avg. DBH	Avg. height	Canopy Layers
C4	Conifer late-successional	>70%	>75%			20	≥21in	>40 ft	3
C4T	Conifer late-successional, thinned	<70%	>75%				≥21 in	>40 ft	
C3	Mature conifer	>70%	>75%				12-21 in		
C3T	Mature conifer, thinned	<70%	>75%				12-21 in		
C2	Conifer pole/sapling	>50%	>75%				4-12 in		
C1	Early-successional conifer	>50%	>75%		≥150		1-4 in		
M3	Mature mixed	>70%	<75%	<75%			12-21 in	>40 ft	
M2	Mixed pole/sapling	>50%	<75%	<75%			4-12 in		
M1	Early-successional mixed	>50%	<75%	<75%			1-4 in		
H3	Mature deciduous	>50%		>75%			12-21 in	>40 ft	
H2	Deciduous pole/sapling	>50%		>75%			4-12 in		
H1	Early-successional deciduous	>50%		>75%			1-4 in		
B	Brush	<50%							

Methods

Study Area

The Satsop Forest consists of approximately 1,281 acres just south of the Chehalis River in southwest Washington in Sections 7, 8, 17 and 18 of Township 17 North Range 6 East (Figure 3.1). The area has been divided into 163 polygons in ten cover types: Timbered, palustrine forest, palustrine shrub, palustrine emergent, grass, brush, developed, roads (including rights-of-way), barren, and ponds (Table 3.1, Figures 3.2 & 3.3).

Topographically, Satsop Forest has an average stand elevation range from 130 – 512 feet above sea level, with forested lands well distributed through all aspects and flats. "Flat" areas have an average slope of less than 8% and comprise approximately 200-ac of the Forest. Satsop Forest contains approximately 40% of the acreage on slopes less then 30%. These areas are acceptable for harvesting with ground-based systems (i.e. harvester/forwarder, skidder, bulldozer, shovel). The remaining 60% is on slopes greater than 30% and requires cable systems.

Site productivity can be classified in many ways. One standard method is based on tree growth on the particular site. Based on tree height and age, a base site productivity value is generated known as Site Index. A common standard for Douglas-fir is the 50-year base age Site Index curves developed by King (1966). Using this method, tree height at any age can be adjusted to a Site Index at 50 years of age so that productivity of sites can be compared equally. Site Index values classified into Site Classes are shown in table 3.2.

The majority (92%) of the Satsop Forest consists of highly productive soils, Site Classes 1 and 2, with the remaining 8% in Site Class 3 and 4. Geographically these sites are evenly distributed throughout Satsop Forest (figure 3.4).

Satsop Forest has stands ranging in age from 2 to 190 years. Many of the stands are in the 15-yr and younger classes and the 65-yr and older age classes. The <20-year age classes are a result of development and logging on the Satsop Forest since its acquisition in the mid-1970's. Much of this area is in the southern portion of the area (figure 3.5). Poor regeneration in this area has resulted in some extremely variable species compositions in the stands. The 60 - 100-yr age classes are the result of the first round of logging in this area. Many of these stands are in the northern portion of the Site and contain many large trees of high timber value.

Satsop Forest contains seven primary tree species: red alder (*Alnus rubra* Bong.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western hemlock (*Tsuga heterophylla* (Rafn.) Sarg.), bigleaf maple (*Acer macrophyllum* Pursh), black cottonwood (*Populus tricocarpa* Torr. & Gray), and western redcedar (*Thuja plicata* Donn). Approximately one half of the Satsop Forest is dominated by "pure" stands of red alder, Douglas-fir, bigleaf maple, or western hemlock. These stands have at least 75% of their basal area in that species. The remainder of the area is in one of a variety of conifer or hardwood dominated mixes (figure 3.6).

Field Procedures

Habitat Parameter Measurement

Field sampling was undertaken during the winter (February 20-26, 1991) and spring (May 3-15, 1991) to measure habitat parameters for each of the evaluation species for input into the HSI models. The following information comes from the original HEP documentation (WPPSS 1994a).

Winter Sampling

Winter sampling was done on the largest six blocks in each cover type. If there were fewer than six blocks in a cover type, all blocks were sampled. In each chosen block, transects of subplots were run beginning 50 feet from the edge of the cover type in the direction of the center of the cover type.

Habitat characteristics measured during the winter sampling were:

- Percent tree canopy cover
- Number of forest canopy layers
- Percent palatable (to deer) shrub cover
- Percent canopy cover of all herbaceous cover
- Percent canopy cover of all grasses
- Percent cover of all dead woody material on the forest floor >3 inches in diameter
- Depth of slash

Subplots were clustered at 100-foot intervals. Each subplot consisted of a tree plot, two shrub plots, and three herbaceous plots. Tree plots had a 37.2-foot radius with ocular estimates of tree canopy cover (for trees taller than 20 feet) and percent ground cover of dead and downed woody material greater than 3 inches. Shrub plots were 4-foot in radius at the outer edge of the tree plots with shrub canopy less than 6.6 feet tall ocularly estimated. Herbaceous plots were 2-feet in radius at the center and outer edges of the tree plot with the green grass and palatable green forb cover ocularly estimated. A total of 59 transects resulted in 177 tree plots, 354 shrub plots, and 531 herbaceous plots.

Spring Sampling

Spring sampling was done on a grid running on a north-south and east-west orientation throughout the project area. Plots were located at the intersections of the grid, every 435 feet.

Habitat characteristics measured in the spring sampling were:

- Overstory canopy – The DBH was taken of all overstory trees in the dominant, codominant, and intermediate layers. This layer was indicated by a break between the highest layer and lowest layers. If >30 percent of the intermediate or suppressed tree crowns were within the highest dominant/codominant tree layer, then those were considered part of the overstory layer.
- Shrub distribution – Shrubs included all woody vegetation less than 6.6 feet in height. Tree boles were not included in this assessment; however, tree branches were included.
- Herbaceous ground cover – Ground cover included all grasses, forbs, ferns, and moss. Grass cover was recorded as a separate characteristic.
- Snags –The DBH's of all snags >4 inches DBH were recorded. The approximate height (within 5 feet) of these was measured to a 4-inch top.
- Stumps – The number of stumps between 1 and 4.5 feet in height and >7 inches diameter were recorded.

Each plot actually consisted of "plot clusters." A 37.2-foot radius tree plot was centered at each grid intersection. The diameter, number and type, either conifer or deciduous, of live overstory trees were recorded as well as an estimate of the shrub distribution. Three herbaceous plots of 2-foot radius were centered at the plot center and at the points where the tree plot met the north-south or east-west transect line. Snags were inventoried in strip transects 33 feet wide that extended for 200 feet, typically 100 feet on either side of the plot center along north-south or east-west transects.

Data Summary

Data for each habitat characteristic were averaged and reported for each cover type. Only means were reported with no accompanying descriptive statistics. Consequently, the variability of each attribute within the cover types cannot be determined. The exception was the shrub cover class, which was converted to an average suitability index for each cover type.

1998 Forest Inventory

To develop a Satsop Forest portfolio for use in LMS, timber inventory and landscape attribute data were needed. Neither of these existed in a form usable by LMS when the project was begun in 1998. A timber inventory conducted in the summer of 1998 obtained the necessary data.

Forest Inventory

A forest inventory was conducted on Satsop Forest during the summer of 1998 to collect stand level data on trees, snags, and downed wood. The first step of the inventory was to delineate the cover type polygons. Using a combination of the 1994 HEP cover type map and aerial photographs taken in August 1997. All cover type polygons were the same except for five polygons that contained a distinct cover type break. These were split into two polygons, resulting in five new polygons. Since this inventory intended to take tree data, only forested polygons were inventoried. The result was an inventory of 101 polygons totaling 796.7 acres with polygons ranging in size from 0.5 acres to 42.1 acres. A total of 248 plots were measured with an average of 2.46 plots per polygon and an over all intensity of one plot per 3.2 acres. The number of plots per polygon ranged from one for the smallest polygons to 12 for the largest.

The Satsop Forest inventory followed USFS inventory protocol for plot layout. Initially a 100-meter grid was overlaid on Satsop Forest; however, because of the number of small polygons, some polygons were missed using the grid. Consequently, a "representative" inventory was done requiring at least one plot per polygon.

Plots consisted of two nested plots: a variable radius plot and a fixed radius plot. In the variable radius plot a basal area factor (BAF) of 20 or 40 was used depending on tree size. The goal was to have approximately eight trees per plot. The fixed radius plot was 1/300th acre where all trees with a DBH of 5 inches or less were measured. For all trees, species and DBH were recorded and height, age, crown ratio and crown class were taken for the tallest dominant tree, (a.k.a. site tree), in each plot. Site tree information was used for site index and stand age. Snags were measured in the variable radius plot if the were counted as "in" using the appropriate BAF. Downed wood was measured if it was all or partially within the fixed radius plot.

Lab Procedures

LMS Portfolio Creation

To apply LMS to a forest, a landscape portfolio must be created. This requires forest inventory data, topographic and site data, as well as Geographic Information System (GIS) data.

Two types of GIS data are needed to create a fully functioning portfolio:

- ESRI shapefiles of stand boundaries and another features that may be of interest
- A digital terrain model (DTM).

For the Satsop Forest portfolio, shapefiles of stand boundaries, road rights-of-way, and streams were created from the AutoCAD files created during the original HEP. ArcView 3.2 and ArcInfo

8.0 were used for this process. A shapefile of the roads on Satsop Forest was digitized from a 1993 USGS digital orthoquad (DOQ) using ESRI ArcInfo 8.0. Buffers of 200-feet from all streams were created and added to the “stands” shapefile. The DTM was created from a USGS digital elevation model (DEM) using the conversion program included with EnVision. Since the DEM is in UTM10 coordinates, all shapefiles were created in the same UTM10 projection.

LMS uses a stand database file for static stand information such as topographic and site information. Topographic information, average slope, aspect, and elevation, and stand acreages, were calculated from the USGS DEM of Satsop using ArcInfo AML programs developed by Phil Hurvitz (GIS Scientist / Auxiliary Faculty, College of Forest Resources, University of Washington). Initial age and site index were taken from the 1998 forest inventory of Satsop Forest.

Inventory information was summarized on a per acre basis from the 1998 forest inventory data. These data include tree species, diameter at breast height (dbh), height, crown ratio and expansion factor. The expansion factor defines how many trees per acre the tree record represents. Many heights and crown ratios were not measured. These data were calculated using the Pacific Northwest (PN) variant of the USDA Forest Service Forest Vegetation Simulator (FVS; (Donnelley 1997). A portfolio was then created from the data files using the Portfolio Builder wizard in LMS.

Habitat Evaluation Procedure (HEP) Implementation

Implementation of a HEP with LMS required the creation of two files: satsophsi.py and hsi.ini. Together these two files are the Satsop Forest HSI and HEP Cover Type analysis modules in Landscape Management System. These modules allow the user to create all tables necessary to assess changes in available wildlife habitat for Cooper’s hawk, southern red-backed vole, pileated woodpecker, and spotted towhee, as well as forest cover types. Output is available in several tabular forms. Included in these are tables are output tables that can be imported into ArcView for mapping of forest cover types and available habitat qualities. These can then be summarized to calculate quantities of habitats of different qualities.

Program File

The program that performs all the calculations is satophsi.py. Full satsophsi.py code and associated documentation are available in Appendix B. It was developed using the Python programming language to become an integral module in LMS. With the Satsop HSI and HEP modules installed in LMS, either module can be run from the Analysis / Tables menu in the LMS cockpit.

Satsophsi.py contains four HSI models that were originally used for the Satsop HEP (WPPSS 1994a). Their habitats were defined as follows:

- Pileated woodpecker (Schroeder 1983): forests with: >75% canopy closure, >30 tpa with >30 inch dbh, >10 stumps per acre >one foot tall and 7 inches in diameter or logs > 7 inches in diameter, >0.17 snags >20 inches in dbh per acre, and snag average dbh of >30 inches.
- Cooper's hawk (USDI 1980c): forests with: >60% canopy cover, >20 inches average dbh,, and 10-30% conifer canopy closure.
- Southern red-backed vole (Allen 1983): sites containing >12 inches average dbh, >20% ground cover of downfall > 3 inches in diameter, <80% grass cover, and >50% evergreen canopy closure.
- Spotted towhee (USDI 1978): 60-90% total ground cover, scattered groups of shrubs and 60-75% canopy closure.

The HSI model for black-tailed deer was not implemented in this analysis.

Each model contains variables that are both tree-based measures (i.e. canopy closure, canopy layers, and dbh) and non tree-based measures (i.e. grass cover, downed wood, and snags). Tree based measures are calculated by several algorithms within LMS. These include an algorithm that calculated the number of canopy layers (Baker and Wilson 2000) as well as an implementation of a canopy closure equation published by Crookston and Stage (1999).

Non-tree-based measures are related to stands by their cover type classification. Cover type classifications are calculated using an algorithm based on the thresholds from the original HEP cover type classification system (Table 2.1) with one change to the classification thresholds: the maximum height imposed on the C1 classification was removed. This was removed because several stands failed to be classified because the average heights were over 15 feet while the average dbh was less than the four inches required by the C2 classification. Once the stand has been given a cover type classification, that classification is used to look up the non-tree-based data in the configuration file. When all the necessary values have been calculated and retrieved the values are used to calculate HSI values for all species designated in the configuration file.

Configuration File

Hsi.ini contains all values needed to control the functionality of satophsi.py. The full configuration file and associated documentation are available in Appendix B. Application of models, calculation methods, cover type thresholds, static habitat attribute data, and output table type can be set in the configuration file. Eleven sections are available to be set by the user to configure HEP calculations, input data types and values, and output types. His.ini is a text file that can be edited using any text editor.

Data Analysis

To ensure the outputs from the coded HSI models, as implemented as an LMS extension, would be comparable with the original calculations from the Satsop HEP (model validation) and to test the silvicultural pathways, several LMS runs using the Satsop Forest portfolio were made. These ranged from a projection with no silvicultural manipulations, to pathways published in the literature that were proposed for creating mature forest structure, to pathways for managing mature and old stands for timber production and wildlife habitat simultaneously (CCEM 1993; DeBell and Curtis 1993; McComb, Spies et al. 1993; Hansen, Garman et al. 1995; Carey, Elliot et al. 1996; Barbour, Johnston et al. 1997).

LMS Simulations

All simulations were done for 80 years using LMS with the Pacific Northwest variant of the Forest Vegetation Simulator (FVS). A keyword file (Van Dyck 2001) is used to simulated natural regeneration and in-growth during all simulations. The keyword file first instructed FVS to calculate Reineke's Stand Density Index (SDI; (Reineke 1933). If the SDI is less than 150, 47 western hemlocks, 22 Douglas-firs, and 25 western redcedars are planted per acre. If the SDI is less than 50, 60 Douglas-firs, 30 red alders, 15 western hemlocks, and 15 western redcedars are planted per acre. The resulting inventory data was then processed using the satsophsi.py program inside LMS to estimate habitat quality and quantity.

Validation

For validation purposes, an LMS projection with no harvesting or silvicultural manipulation was performed. This was to assure that at least one stand of each cover type was examined at some point during the projection. HSI calculations were then done using the original cover type data used for the original HSI calculations (WPPSS 1994d). Using these data, instead of the LMS inventory data allowed the same results from the HSI models for each species and cover type. If LMS inventory data had been used, it would introduce deviations caused by variations in HSI variable values within each cover type.

Calculating the HSI value for each species and comparing it to the value published in the original HEP (WPPSS 1994d) produced good results. Two equations needed to be modified: Variable 1 and Variable 3 of the spotted towhee model. These curves are complex and difficult to interpret into a piecewise function with any accuracy. Equations were then solved again and the proper values placed in the HSI equation code. The models then predicted with quite consistently for each cover type using the original HEP data.

Landscape Simulations

Forest and wildlife management activities occur on large spatial and temporal scales. Often these are “broad-brush” approaches where the same management activities are applied over large areas. Simulating this type of management using an assemblage of individual stands, that will be collectively called a “landscape”, changes in overall wildlife habitat quality quantity as well as changes in harvested volume can be assessed.

No Action

All stands were allowed to grow without silvicultural treatments for 80 years.

Intensive Management for Timber Production

An “industry standard” (Michaelis 2000), 45-year rotation was modeled by pre-commercially thinning dense stands to 300 tpa at age 15 years, clearcutting (retaining five trees per acre to meet WA Forest Practices Rules) at age 45 years, and planting 450 tpa of Douglas-fir. This scenario was selected to maximize revenue generated by timber harvest.

Moderate Management to Enhance Mature Forest Structures

Any conifer stands in the 25-40 year range were thinned from below to 150 tpa between 2018 and 2038, leaving the biggest trees. The stands were then underplanted with 50 tpa of western hemlock and western redcedar. This scenario was chosen to simulate management on Satsop Forest during the life of the mitigation agreement (WPPSS 1994f). These thinnings are a method of accelerating multi-layered canopy development in younger planted stands with minimal silvicultural activities and consequent potential disturbances to wildlife.

Intensive Management to Enhance Mature Forest Structures

Stand-specific pathways were designed to manipulate each stand through a series of thinnings to promote the development of late-successional structural characteristics (multiple canopy layers and large diameter trees). Each thinning was designed to open the stand enough to allow understory development and canopy regeneration, while maintaining residual trees from each canopy layer that was present prior to the treatment. Multiple species, including Douglas-fir, western hemlock, and western redcedar, were planted to promote species diversity and structural development. Stands were divided into six groups according to age and species composition:

- Group 1: conifer stands < 40 years old ["young"];
- Group 2: conifer stands >40 years old ["old"];
- Group 3: young deciduous stands;
- Group 4: old deciduous stands;
- Group 5: young mixed conifer/deciduous stands; and
- Group 6: old mixed conifer/deciduous stands.

Stands in Group 1 were pre-commercially thinned to 250 tpa between 1998 and 2008, and then allowed to grow for twenty years. Between 2018 and 2038 the stands were commercially thinned, leaving the 750 largest diameter trees per acre followed by underplanting with 100 tpa each of Douglas-fir, western hemlock, and western redcedar. A third entry was made in each stand from 2058 to 2078, thinning the older cohort to 25 tpa and the younger cohort to 25 tpa followed by underplanting with 300 tpa of Douglas-fir, western hemlock, and western redcedar. These multiple thinnings and plantings were intended to develop a multi-layer canopy on these young planted stands sooner than would occur by letting the stands develop without any treatment.

Stands in Group 2 were commercially thinned between 1998 and 2018 to maintain the existing canopy layers, promote the release of advanced regeneration, and establish regeneration of shade tolerant species. Since two canopy layers already existed in these stands, the thinning prescription was designed to retain trees from each layer and to underplant to create a stands with three or more layers. Between 1998 and 2013 the stands were commercially thinned to 50 tpa. In the ≥20 inches size class the 62 tallest trees were left, and the largest 25 tpa with diameters <20 inches were also left, followed by underplanting with 300 tpa of Douglas-fir, western hemlock and western redcedar. Between 2038 and 2053, stands were commercially thinned to a diameter limit prescription by leaving 25 tpa in the 8 – 20 inches dbh range and retaining all trees above and below these limits, followed by underplanting with 300 tpa of Douglas-fir, western hemlock and, western redcedar.

Group 3 contained many dense hardwood stands that established through natural seeding. This scenario was designed to convert these stands into conifer stands that would be thinned and underplanted several times to promote the development of multiple canopy layers. Between 1998 and 2038 the stands were clearcut and planted with 450 tpa of Douglas-fir. At age 20 these stands were precommercially thinned to 250 tpa from below. At age 40 these stands were then thinned to 25 tpa, followed by underplanting with 300 tpa of Douglas-fir, western hemlock and western redcedar.

Group 4 contained hardwood stands with mature forest structures. This scenario was designed to maintain the mature forest structures while increasing the conifer component in the stands. Between 2018 and 2033 the stands were thinned removing all trees less than 20 inches dbh and leaving all trees greater than 20 inches dbh, followed by planting 300 tpa of Douglas-fir, western hemlock, and western redcedar. A second thinning was performed between 2058 and 2073 that retained 25 tpa ≥20 inches dbh and 35 tpa between 15 and 20 inches dbh, while the remaining trees were retained. Following the thinning the stands were underplanted with 300 tpa of Douglas-fir, western hemlock, and western redcedar.

Group 5 contains dense mixed conifer/ hardwood stands that resulted from planting conifers after earlier clearcutting, combined with natural seeding of more conifers and hardwoods. This scenario was designed to move the stands to pure conifer and encourage a multi-layered canopy. Between 1998 and 2008 the stands were thinned, removing all hardwoods. Between 2038 and 2053 the stands were thinned to 25 tpa from below and underplanted with 300 tpa of Douglas-fir, western hemlock, and western redcedar.

Group 6 contained older mixed stands that had some mature forest characteristics. This scenario was designed to maintain older forest structures while still allowing silvicultural activities. Between 2018 and 2033 the stands were harvested, leaving the largest 25 tpa followed by underplanting with 300 tpa of Douglas-fir, western hemlock, and western redcedar. A second "diameter limit" thinning was undertaken between 2058 and 2073. For diameters ranging from 6 – 20 inches the largest 25 tpa were retained, as were the largest 25 tpa in the >20 inches diameter range. Following the thinning 300 tpa of Douglas-fir, western hemlock, and western redcedar were planted.

Mixed Management for Wildlife and Timber Values

Young stands on the most productive soils (50-year site index of >140 feet; Figure 1A) were managed for intensive timber production as in scenario 2, but the remaining forest was left as an untreated reserve for wildlife habitat. This resulted in 34 stands totaling 290 acres being managed for timber, with the remaining 506 acres without active management. In the wildlife simulations, mature forest was the preferred habitat for three of the four species modeled; therefore, these stands were designated as wildlife habitat reserves and not silvicultually treated. This scenario was selected to simulate intensive timber production along with reserves on a small landscape.

Individual Pathway Simulations

"Broad-brush" approaches may not provide habitat for all desired species. Since a landscape is an assemblage of stands "gaming", individual representative stands can be used to test several alternative management regimes and assess the potential of providing habitat for individual species. When the pathways have been simulated and habitat values assessed an assemblage of pathways, which can then be applied to stands in a landscape, can then be created to provide habitat for multiple species across a landscape.

LMS scenarios were created based on the publications mentioned in the Proposed Pathways section earlier in this paper. These pathways were simulated for 80 years using both young and old stands. Pathways that required clumped retention or gap or strip harvesting were not simulated, since LMS cannot perform spatially explicit harvesting methods. To supplement these pathways and to assess trade-offs with industrial wood production pathways, rotations of 40, 60 and 80 years were simulated, with thinning to 300 tpa at 15 years. At 40 years the 60 and 80-year rotation stands were thinned to 140ft^2 of basal area. At 60 years the 80-year rotation stand was thinned to 75 tpa. At rotation ages, the stands were clearcut (leaving 5 tpa to comply with Washington State forest practice regulations), and planted with 400 tpa of Douglas-fir.

The stands used for pathway simulations are actual stands on Satsop Forest. The young stands are both approximately 10 years old, Douglas-fir dominated, and stocked at approximately 435 and 1300 tpa, respectively. The old stands are both approximately 90 years old, one with a relatively open single-storied canopy and the second with a multiple layered canopy. The young stands were chosen to simulate young plantations while the older stands were chosen to examine potentials for managing older stands for habitat development and wood products production.

Young Stand Pathways

Separating out the pathways that preliminarily appeared best suited for young stand management resulted in 21 individual pathways that were simulated using LMS:

1. 0_NA: No silvicultural manipulation
2. Barbour15-150: Thinned at 15 years to 60 tpa
3. Barbour15-75: Thinned at 15 years to 30 tpa
4. Barbour30-150: Thinned at 30 yeas to 60 tpa
5. Barbour30-150HL: Thinned at 30 years to 60 tpa leaving smallest and largest
6. Barbour30-250: Thinning at 30 years to 100 tpa
7. Barbour30-75: Thinning at 30 years to 30 tpa
8. BarbourNT: Thin to 300 tpa at 10 years
9. CareyBDPF: PCT at 15 to 300 tpa, CT at 30 to 100 tpa, CT at 50 to 75 tpa, CT at 70 to 36 tpa
10. CareyBDPS: PCT at 15 to 300 tpa, CT at 30 to 100 tpa, CT at 60 to 75 tpa, CT at 90 to 36 tpa
11. CC40_PCT: PCT at 15 to 300 tpa, clearcut at 40 leaving 5 tpa, plant 400 Douglas-fir

12. CC60_PCT_CT: PCT at 15 to 300 tpa, commercial thin at 30 to 140ft^2 of basal area, clearcut at 60 leaving 5 tpa, plant 400 Douglas-fir.
13. CC80_PCT_CT: PCT at 15 to 300 tpa, commercial thin at 30 to 140ft^2 of basal area, commercial thin at 60 to 75 tpa, clearcut at 80 leaving 5 tpa, plant 400 Douglas-fir
14. Hansen0-40: Thin to 220 tpa at 15 and 30, clearcut at 40 leaving 5 tpa, plant 400 Douglas-fir
15. Hansen0-80: Thin to 220 tpa at 15 and 30, clearcut at 80 leaving 5 tpa, plant 400 Douglas-fir
16. Hansen0-120: Thin to 220 tpa at 15 and 30
17. McCombCC: PCT at 15 to 300 tpa, commercial thin at 35 to 140ft^2 of basal area, commercial thin at 60 to 75 tpa, , clearcut at 80 leaving 5 tpa, plant 400 Douglas-fir
18. McCombPR: Thin to 81 tpa at 40 years, planting 75 tpa of Douglas-fir and 190 tpa of western hemlock, thin trees <30” to 60% at 90 years
19. Mit_SOP: Thin to 150 tpa from below at 50 years, plant 50 tpa of western hemlock and western redcedar
20. YSTD-Heavy: Thin to 50 tpa at 40 years, plant 16 tpa Douglas-fir and 104 tpa western hemlock
21. YSTD-Light: Thin to 110 tpa at 40 years.

Old Stand Pathways

Several remaining pathways were used for old stands. This resulted in a set of 30 pathways simulated using LMS:

1. 0_NA: No silvicultural manipulation

2. CC40_PCT: Clearcut, leaving 5 tpa, in the initial year followed by planting 400 Douglas-fir per acre. Thin to 300 tpa at 15 years. Clearcut and plant again at 40 years.
3. CC60_PCT_CT: Clearcut, leaving 5 tpa, in the initial year followed by planting 400 Douglas-fir per acre, commercial thin at 30 to 140ft^2 of basal area, clearcut and plant again at 60 years leaving 5 tpa, plant 400 Douglas-fir.
4. CC80_PCT_2CT: Clearcut, leaving 5 tpa, in the initial year followed by planting 400 Douglas-fir per acre, commercial thin at 30 to 140ft^2 of basal area, commercial thin at 80 years to 75 tpa, clearcut and plant again at 80 years leaving 5 tpa, plant 400 Douglas-fir.
5. DEMO20: Thin from below in the initial year leaving 20% of the trees.
6. DEMO40: Thin from below in the initial year leaving 40% of the trees.
7. Hansen5-40: Clearcut in the initial year leaving 2 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years, clearcut at 40 years leaving 2 tpa and planting 400 Douglas-fir per acre. Repeat this for a second rotation.
8. Hansen5-80: Clearcut in the initial year leaving 2 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years, clearcut at 80 years leaving 2 tpa and planting 400 Douglas-fir per acre.
9. Hansen5-120: Clearcut in the initial year leaving 2 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years.
10. Hansen10-40: Clearcut in the initial year leaving 4 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years, clearcut at 40 years leaving 4 tpa and planting 400 Douglas-fir per acre. Repeat this for a second rotation.
11. Hansen10-80: Clearcut in the initial year leaving 4 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years, clearcut at 80 years leaving 4 tpa and planting 400 Douglas-fir per acre.

12. Hansen10-120: Clearcut in the initial year leaving 4 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years
13. Hansen15-40: Clearcut in the initial year leaving 6 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years, clearcut at 40 years leaving 6 tpa and planting 400 Douglas-fir per acre. Repeat this for a second rotation.
14. Hansen15-80: Clearcut in the initial year leaving 6 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years, clearcut at 80 years leaving 6 tpa and planting 400 Douglas-fir per acre.
15. Hansen15-120: Clearcut in the initial year leaving 6 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years
16. Hansen20-40: Clearcut in the initial year leaving 8 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years, clearcut at 40 years leaving 8 tpa and planting 400 Douglas-fir per acre. Repeat this for a second rotation.
17. Hansen20-80: Clearcut in the initial year leaving 8 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years, clearcut at 80 years leaving 8 tpa and planting 400 Douglas-fir per acre.
18. Hansen20-120: Clearcut in the initial year leaving 8 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years
19. Hansen30-40: Clearcut in the initial year leaving 12 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years, clearcut at 40 years leaving 12 tpa and planting 400 Douglas-fir per acre. Repeat this for a second rotation.
20. Hansen30-80: Clearcut in the initial year leaving 12 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years, clearcut at 80 years leaving 12 tpa and planting 400 Douglas-fir per acre.

21. Hansen30-120: Clearcut in the initial year leaving 12 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years
22. Hansen50-40: Clearcut in the initial year leaving 20 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years, clearcut at 40 years leaving 20 tpa and planting 400 Douglas-fir per acre. Repeat this for a second rotation.
23. Hansen50-80: Clearcut in the initial year leaving 20 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years, clearcut at 80 years leaving 20 tpa and planting 400 Douglas-fir per acre.
24. Hansen50-120: Clearcut in the initial year leaving 20 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years
25. Hansen150-40: Clearcut in the initial year leaving 60 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years, clearcut at 40 years leaving 60 tpa and planting 400 Douglas-fir per acre. Repeat this for a second rotation.
26. Hansen150-80: Clearcut in the initial year leaving 60 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years, clearcut at 80 years leaving 60 tpa and planting 400 Douglas-fir per acre.
27. Hansen150-120: Clearcut in the initial year leaving 60 tpa followed by planting 400 tpa of Douglas-fir, thin understory to 220 tpa at 15 and 30 years
28. McCombSS: Clearcut in the initial years leaving 2 tpa, at 45 years thin the understory to 70%, at 70 years clearcut leaving 2 tpa
29. McComdFS: Clearcut in the initial year leaving 6 tpa, at 45 years thin the understory from below to 50 tpa followed by planting 60 tpa of Douglas-fir and 205 tpa of western hemlock, at 70 years thin understory from below to 70%

30. McCombMS: Thin from below to 24% in the initial year followed by planting 16 tpa of Douglas-fir and 140 tpa of western hemlock, at 25, 50 and 75 years remove 16% of the overstory from below, remove 45% of the understory from below, and plant 16 tpa of Douglas-fir and 140 tpa of western hemlock

For all projections, tables and charts were created to compare habitat quality and quantity, standing volume, and cut volume. Habitat values are reported as average HSI, habitat units (HU) and average annual habitat units (AAHU). LMS reports both standing timber volume and harvested timber volume through time. Standing volume is calculated as the total standing volume at the end of each growth period. Cut volume is the amount of timber harvest that occurred during each 5-year growth period. Volumes are calculated by FVS based on Scribner 32-foot log rule with a minimum top diameter outside bark of 4.5 inches. These values are reported for each five-year interval separately for three size classes:

- "Poles": tree <12 inch dbh that are used for low-grade lumber or pulp.
- "Small sawlogs": tree 12 – 24 inch dbh trees that produce average quality lumber.
- "Large sawlogs": trees >24 inch dbh that provide high quality wood for lumber including specialty, clear, tight-grained woods used in boat planking, siding, molding, and ladders.

Table 3.1: Cover type acreages and number of polygons

Cover Type	Polygons	Acres
Timbered	101	796.7
Palustrine Forest	7	5.4
Palustrine Shrub	1	1.4
Palustrine Emergent	2	0.5
Grass	14	87.1
Brush	6	29.5
Developed	15	291.9
Roads	14	46.7
Barren	1	4.6
Ponds	2	16.4
Total	**163**	**1281.2**

Table 3.2: Site Class to 50-yr Site Index

Site Class	Site Index
1	> 135 ft
2	115 – 135 ft
3	95 – 115 ft
4	75 – 95 ft
5	< 75 ft

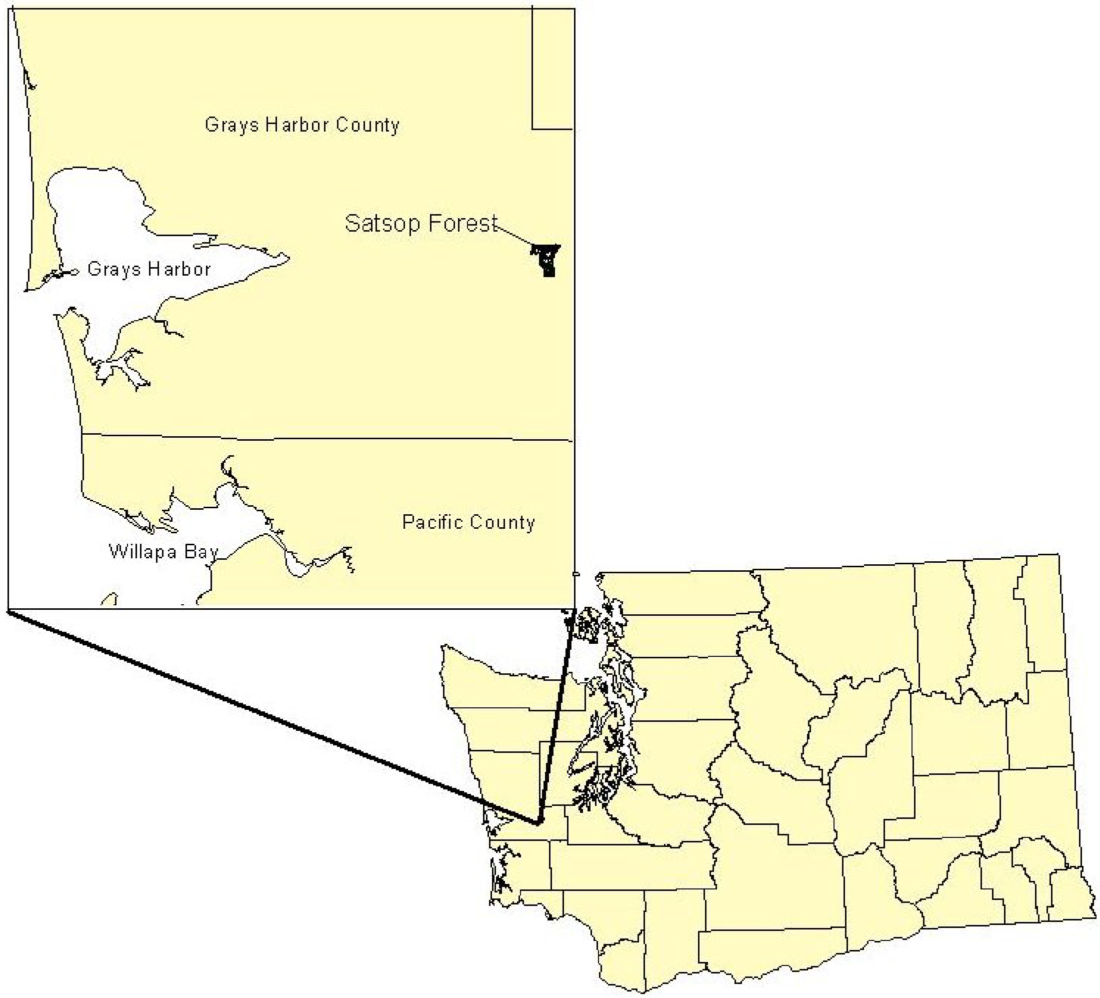


Figure 3.1: Location map of Satsop Forest in Southwest Washington

Figure 3.2: Orthophotograph of Satsop Forest with stand boundaries

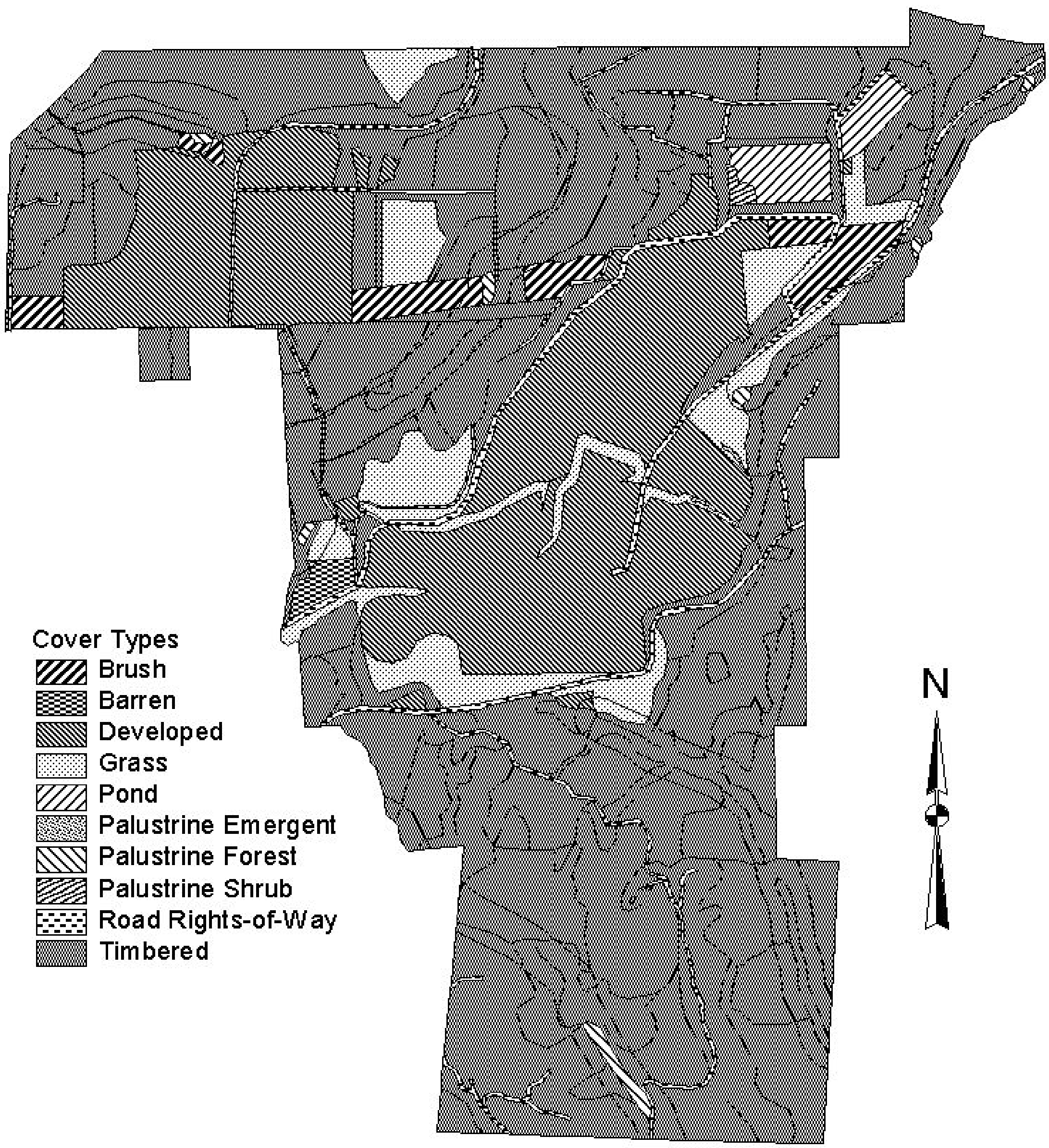


Figure 3.3: Map of Satsop Forest cover types.

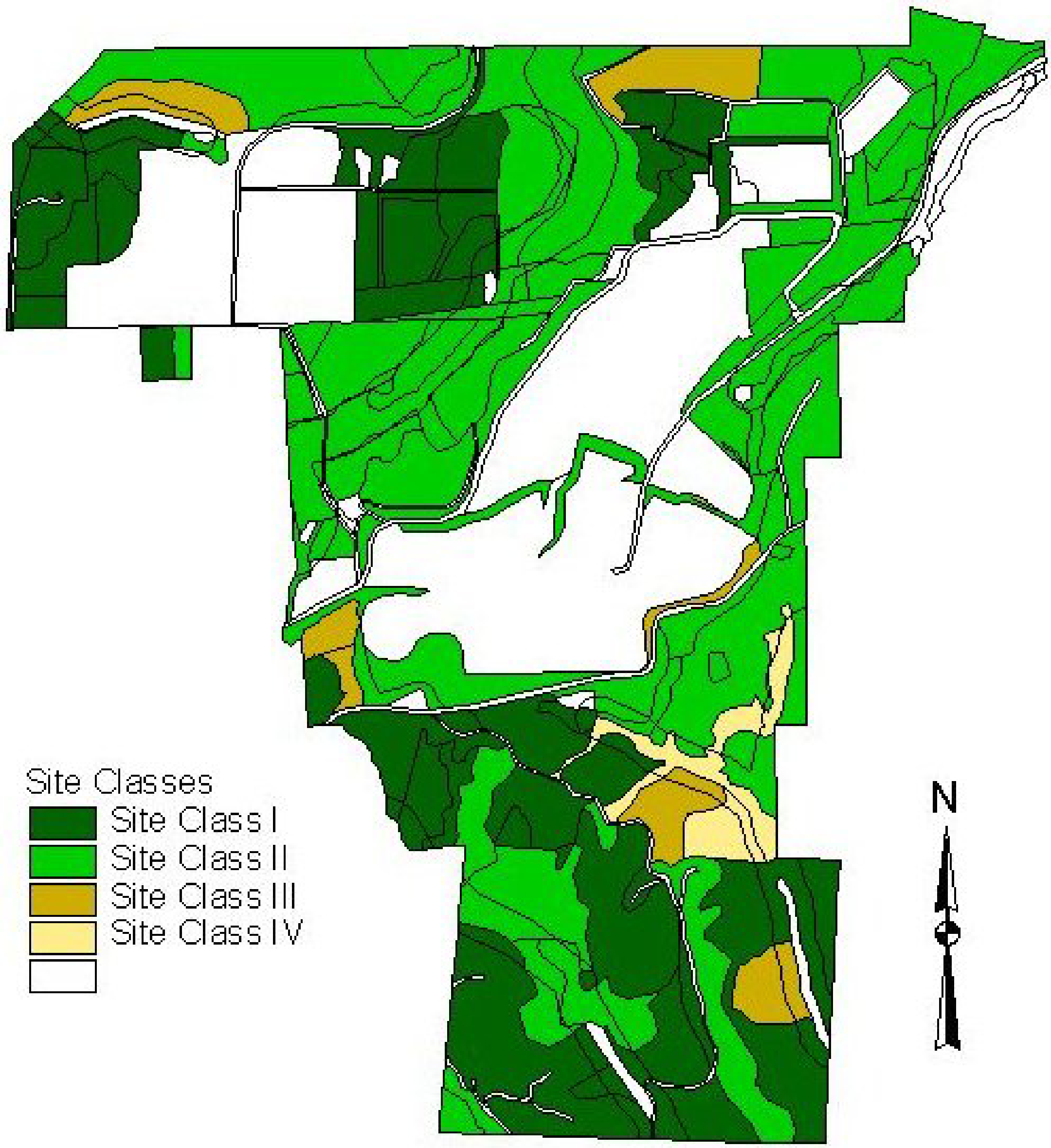


Figure 3.4: Map of Site Classes on Satsop Forest

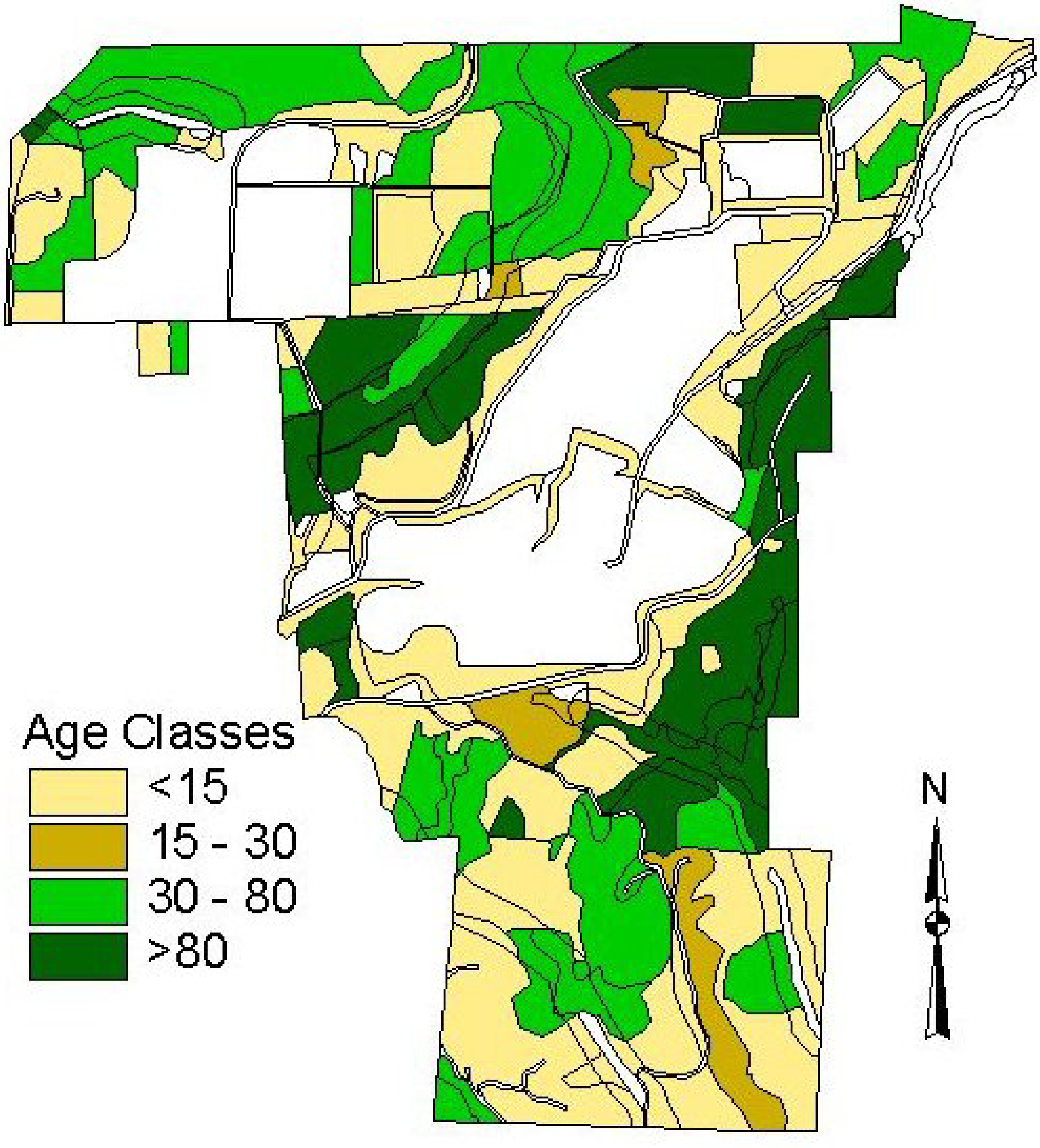


Figure 3.5: Map of age classes on Satsop Forest

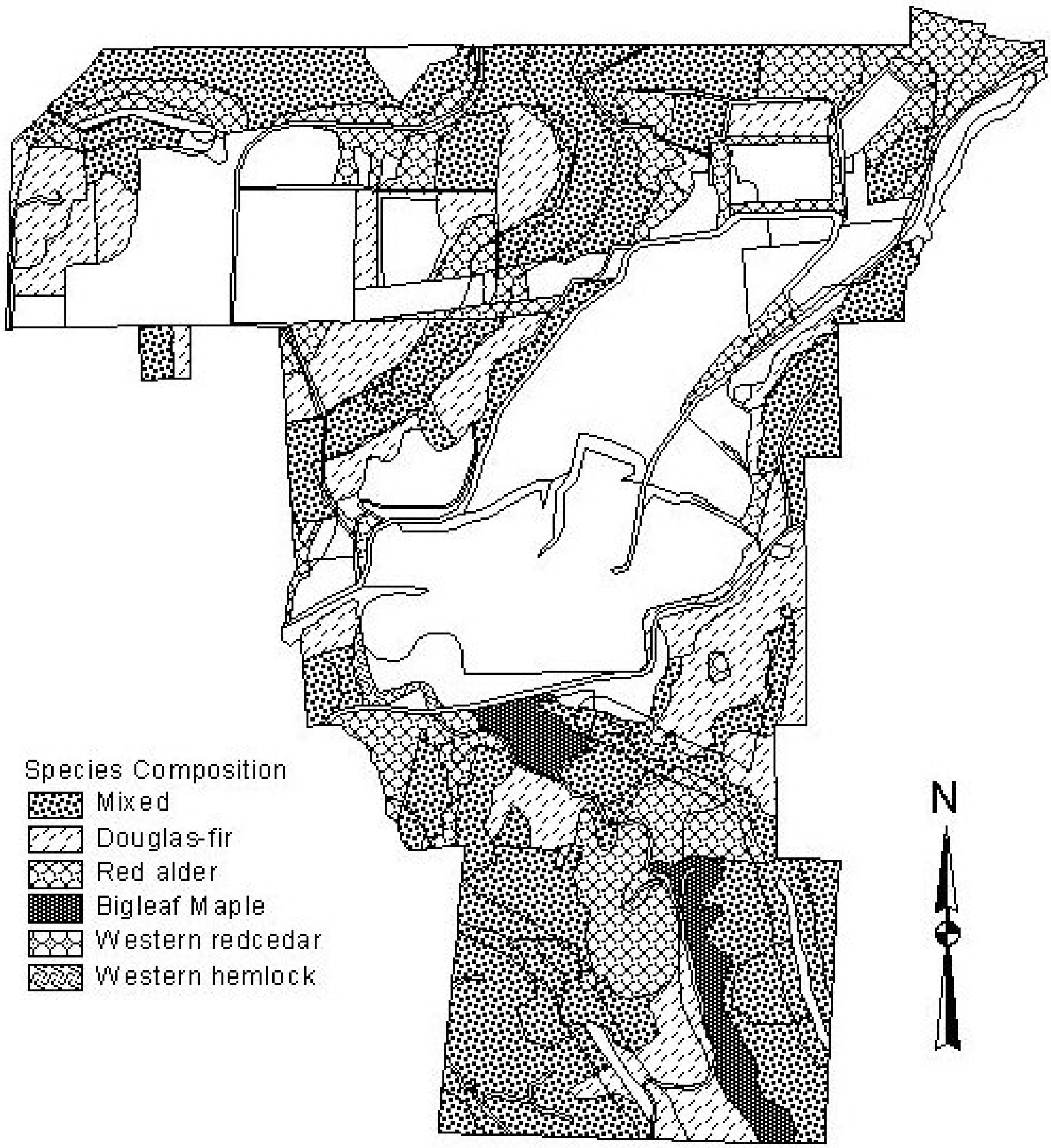


Figure 3.6: map of species distribution on Satsop Forest

Results

There are three components to the results:

- The validation of the models, comparing outputs from the HEP implemented in LMS with the original results from the original HEP.
- A set of landscape simulations.
- A set of silvicultural pathways simulated on four individual stands.

The latter are two are examples of how the HEP implemented in LMS can be used to assess changes in habitat and timber volumes caused by different silvicultural pathways from both the landscape- and stand-level perspectives.

Validation

To assess the performance of the models implemented in LMS, it was necessary to use data, both tree-based and non-tree-based, from the original HEP to calculate HSI values for the four species. When compared with the HSI values calculated during the original HEP differences range from –0.009 to 0.001. A paired t-test on the differences between HSI values reported the original HEP and those calculated with LMS using data from the original HEP was performed using the statistical analysis software package SPSS 10.0. Mean differences range from 0.000 – 0.001 with all 95% confidence intervals containing 0.0 (Figure 4.1). Results from the Cooper's hawk HSI model, using the original HEP data, could not be analyzed using the t-test because the model predicted the exact HSI values that were reported in the original HEP analysis. The resulting mean difference of 0.0 with a standard error of the mean of 0.0 does not allow the paired t-test to be used. Since all 95% confidence intervals contain 0.0 the models predict as well as the original HSI models at the 0.05 level.

A second analysis was performed using forest inventory collected in 1998. A second paired t-test was performed comparing the mean differences between the HSI values reported in the original HEP and the HSI values calculated using LMS with this updated data set. Mean differences ranged from –0.0615 to 0.1176 with all 95% confidence intervals containing 0.0 (Figure 4.2). Using the updated data made no significant difference in model outputs at the 0.05 level.

Given these results it can be said that the HSI models, as implemented in LMS, predicted HSI values as well as the original HSI models and using updated forest inventory data summarized on a per stand basis made no significant difference in HSI values for each cover type.

Landscape Simulations

Landscape simulations yielded a range of effects on both habitat values and harvested volumes. HU values for Cooper's hawk began at 343.8 or 305.7 in 1998 and declined during the simulation period. Southern red-backed vole HU values began at 308.7, 309.0 or 276.9 and increased at varying rates to 481.1 – 682.5. Spotted towhee HU values began at 122.7 – 127.9 and declined to 16.8 – 67.6. Pileated woodpecker HU values began at 266.7 – 269.9, then generally increased to 261.3 – 625.5 (Table 4.1).

Flows of these habitats may be more important than looking at individual years (Figure 4.3). Generally, Cooper's hawk and spotted towhee habitat units declined during the entire simulation period, while southern red-backed vole and pileated woodpecker habitat units increased. The exception to this is the "timber intensive" simulation where pileated woodpecker declined.

Harvested volumes varied greatly among the management alternatives simulated (Table 4.2). Total harvest ranged from 0mbf/yr in the "no action" alternative to 914.4mbf/yr with the

"45-year rotation" alternative. Sizes of trees harvested varied between alternatives as well. The greatest proportion of volume was pole timber under the "moderate enhancement" alternative (42%), while the greatest proportion of volume of sawlogs was under the "45-year rotation" alternative (67%), and the greatest proportion of volume of large sawlogs was under the "intensive enhancement" alternative (26%).

Flows of harvested volume changed between alternatives as well (Figure 4.4). With the "45-year rotation" alternative, harvested volume was greatest but the type of harvest changed from a mix of size classes in the first 45 years to predominantly small sawlogs in the last 35-years. The "moderate enhancement" alternative produced very little volume with all the volume concentrated between 2018 and 2038 in pole and small sawlogs. "Intensive enhancement" yields less total volume than the 45-year rotation, but the distribution of size classes harvested changed from predominantly pole and small sawlogs in the first half of the simulation to a majority of the harvest in large sawlogs in the second half of the simulation. "Mixed management" yielded fluctuating harvested volumes with the majority of the volume in the small sawlog size class.

Pathway Simulations

Using the set of silvicultural pathways to assess the effects on both habitat and harvested volumes on individual stands allows comparisons among pathways that may be used to promote certain types of habitat. Sets of 21 pathways applied to two 10-year-old stands, with approximately 435 and 1300tpa, respectively, and sets of 30 pathways simulated using two 90-year-old stands, one a relatively open single-storied stand and the other a multiple-storied stand were simulated to assess yields of habitat qualities and harvested volumes.

Young Stands

The set of 30 silvicultural pathways simulated using data from the two young stands results in a wide range of HSI values for each species (Tables 4.3 and 4.4). The greatest average HSI values produced are for the southern red-backed vole at 0.863 and 0.820 for dense and open stands, respectively. Silvicultural pathways that produced the highest habitat values for the vole had light thinnings, from a single thinning at 10 – 30 years to multiple thinnings during the 80-year simulation period. Similarly, pileated woodpecker HSI models respond well to light thinnings in a dense stands. In contrast, when the open stand was simulated, the woodpecker HSI model responded best to heavier thinnings at 15 years, but only slightly better than the light thinnings. In contrast to the responses of the vole and woodpecker HSI models, the Cooper's hawk HSI model responds best to heavier thinnings in both dense and open stands and the spotted towhee model responds best to 40-year rotations and pathways that simulate "traditional" industrial forest management approaches. The results from the towhee model are low HSI values ranging from 0.012 – 0.096.

Both dense and open stands produced the highest total harvest volume using silvicultural pathways with 40 – 80-year rotations with one or two intermediate thinnings that mimic "traditional" forest management practices (Table 4.7). Maximum total volumes produced were 260 and 216mbf/ac for dense and open stands, respectively. Average volumes produced by the set of silvicultural pathways were low at 96 and 80 mbf/ac for the entire simulation period. Silvicultural pathways focusing on thinnings for habitat development rather than on harvested volume caused lower average harvested volumes.

Older Stands

The set of 21 silvicultural pathways simulated using data from the 90-year old, single and multiple-storied stands also produce a wide range of HSI values (Tables 4.5 and 468). As with the young stand simulations, the vole model produced the greatest average HSI values of 0.746

and 0.817 for single and multiple storied stands, respectively. The best model response was to very light thinnings or no action for both stand structures. The woodpecker model responded very well to pathways with light thinnings or no action as well. Pathways with heavier thinnings produced better responses from the hawk model than the vole or woodpecker models but many of the pathways that produced the best responses with the hawk model were light thinning or no action pathways. In contrast to the vole, hawk, and woodpecker models the towhee model responded best to heavier harvesting in older stands. As with the young stand simulations the overall response was low producing HSI values ranging from 0.000 – 0.105.

Highest total harvested volumes were produced with 80-year rotation pathways leaving two to eight trees per acre from the original stand (Table 4.7). Total harvest volumes were 248 and 216 mbf/ac, for single and multiple storied stands, respectively, for the full 80-year simulation period. Average harvested volumes were low at 94 and 99 mbf/ac. As with the young stands pathway simulations these volumes are low because the simulated pathways focus on multiple thinnings for habitat development rather than harvest volume.

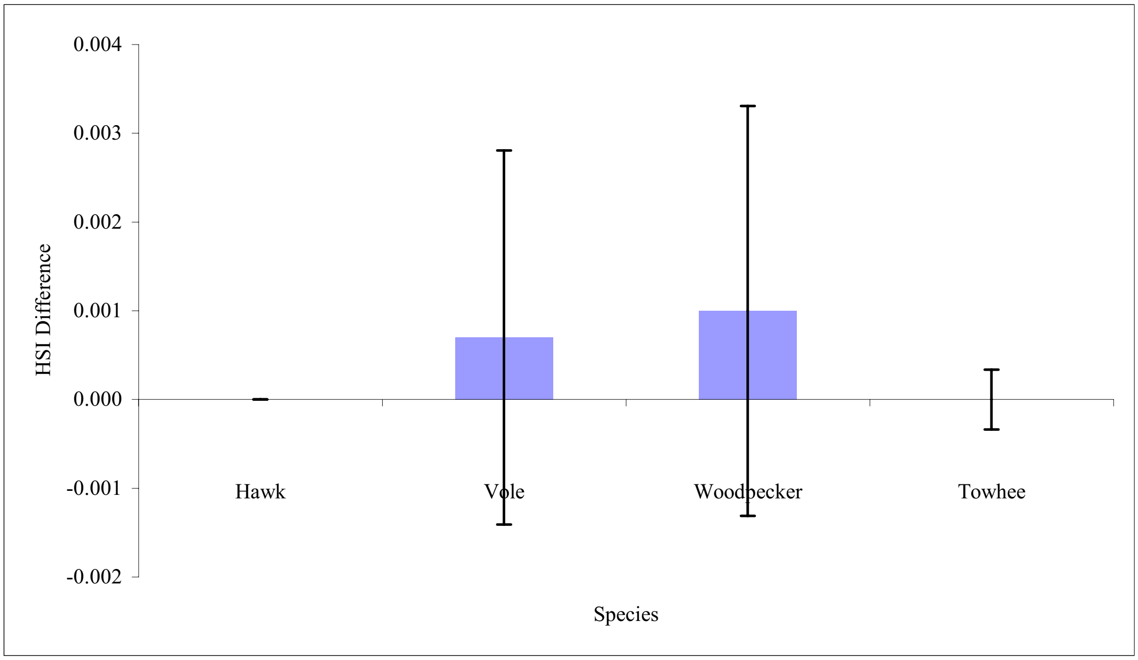


Figure 4.1: Mean difference between HSI values reported in original HEP and values calculated by LMS using original HEP data, with 95% confidence intervals.

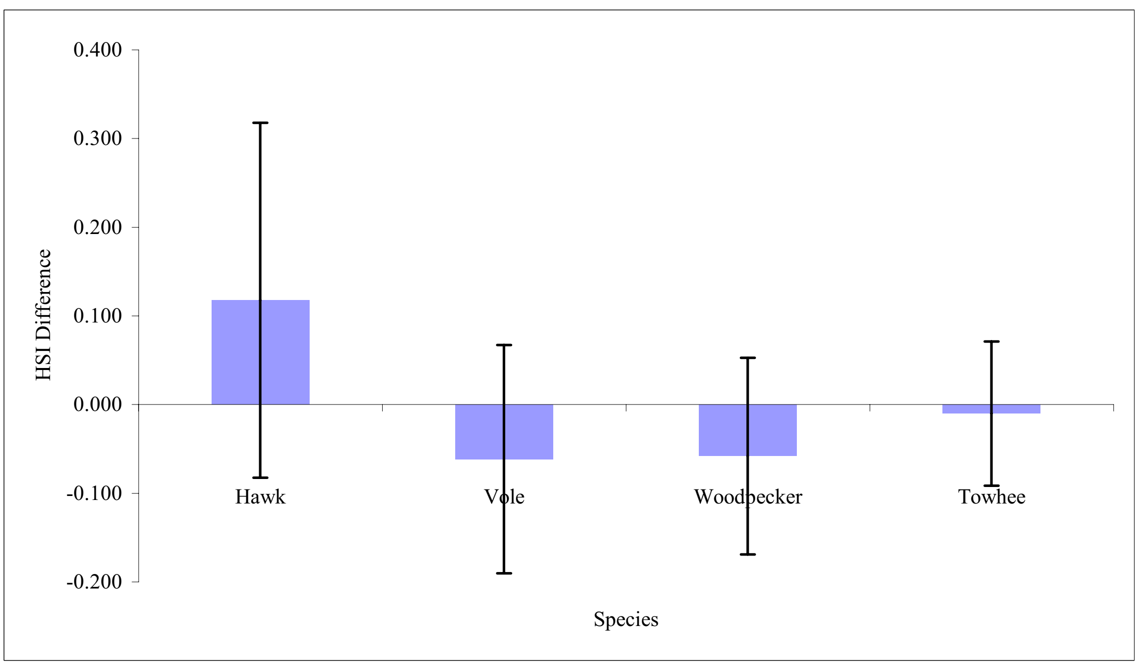


Figure 4.2: Mean difference between HSI values reported in original HEP and values calculated by LMS using 1998 Satsop Forest inventory data, with 95% confidence intervals.

Table 4.1: Habitat units for all species modeled for 1998, 2038 and 2078

	Cooper's hawk			**Southern red-backed vole**			**Spotted towhee**			**Pileated woodpecker**		
Scenario	**1998**	**2038**	**2078**	**1998**	**2038**	**2078**	**1998**	**2038**	**2078**	**1998**	**2038**	**2078**
1. No Action	343.8	309.2	277.0	308.7	507.9	540.8	127.9	25.6	17.5	269.9	519.6	571.3
2. 45-yr rotation	343.8	99.6	98.6	308.7	453.8	481.1	127.9	70.5	67.6	269.9	209.7	216.3
3. Moderate enhancement	343.8	309.2	277.0	308.7	508.4	540.8	127.9	25.6	17.5	269.9	534.5	571.5
4. Intensive enhancement	305.7	143.1	123.2	276.9	597.7	682.5	124.1	36.7	16.8	266.7	507.4	625.7
5. Mixed management	343.8	235.7	224.8	309.0	406.4	515.2	122.7	42.7	27.9	269.9	375.3	427.5

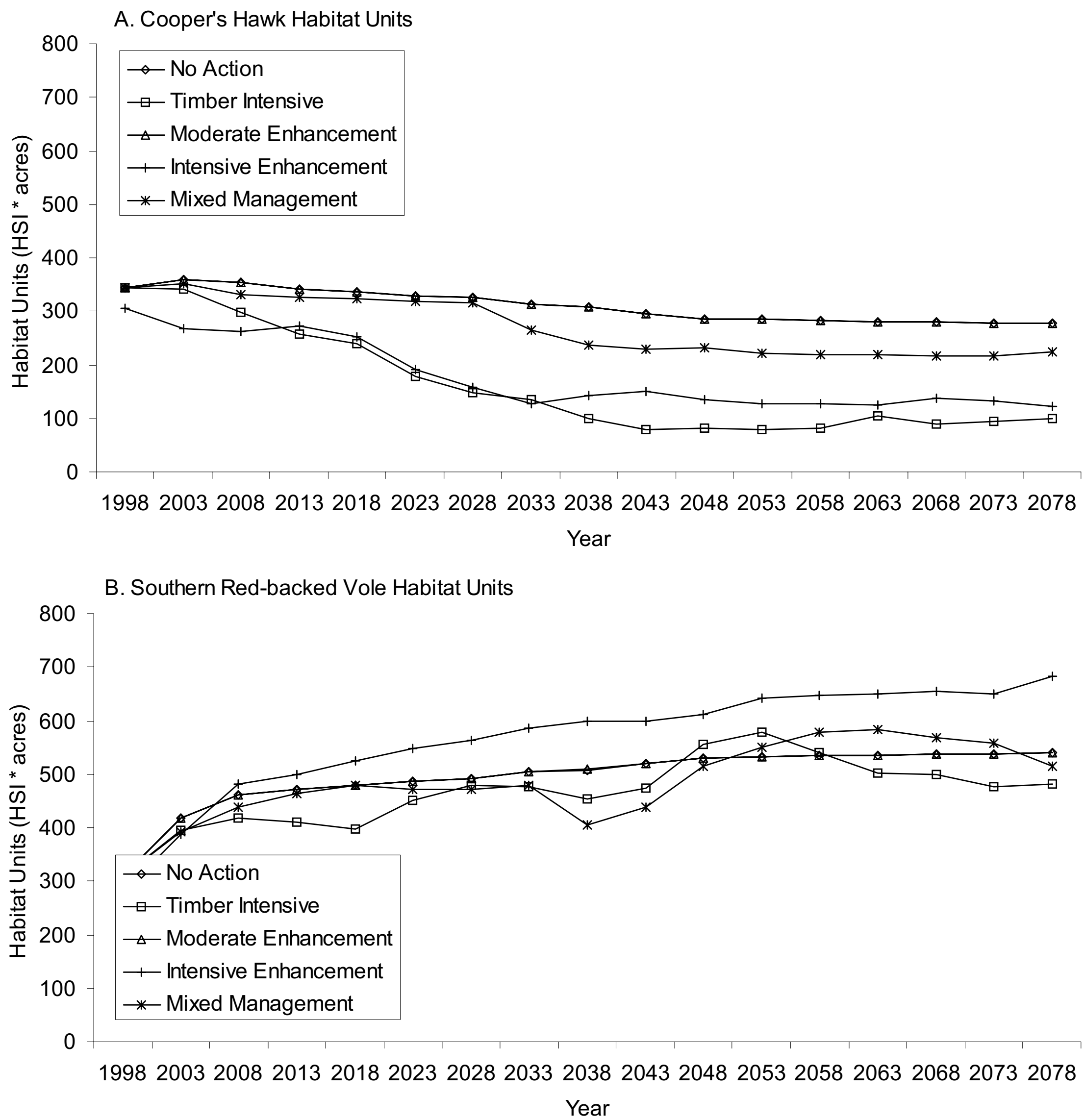
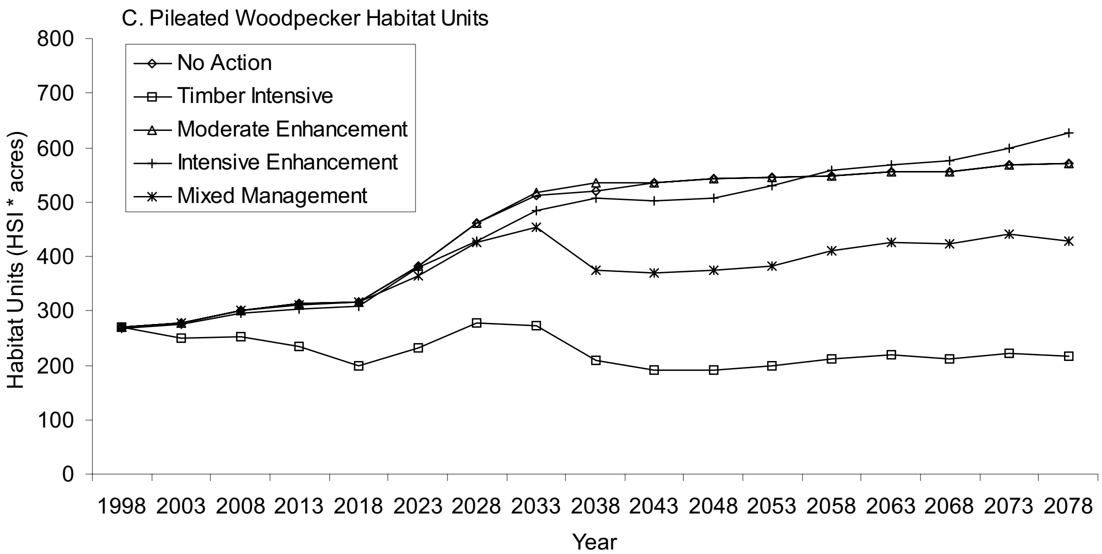


Figure 4.3: Habitat flows for landscape simulations



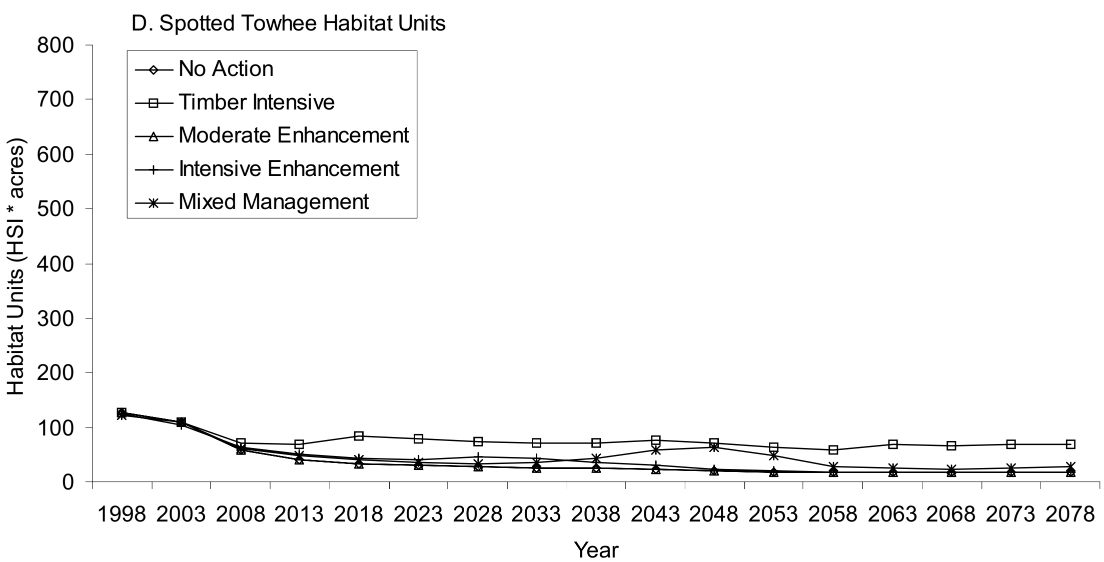


Figure 4.3 (continued): Habitat flows for landscape simulations

Table 4.2: Annual average harvested volumes (mbf/yr) and percentage in each size class from landscape simulations. Pole = <12"dbh, Sawlog = 12-24"dbh, Large Sawlog = >24"dbh

	Pole		Sawlog		Large Sawlog		Total
Scenario	**mbf/yr**	**%**	**mbf/yr**	**%**	**mbf/yr**	**%**	**mbf/yr**
1. No Action	0.0	NA	0.0	NA	0.0	NA	0.0
2. 45-yr rotation	91.8	10%	611.5	67%	211.1	23%	914.4
3. Moderate enhancement	19.7	42%	27.4	58%	0.0	0%	47.1
4. Intensive enhancement	73.3	15%	280.5	59%	124.7	26%	478.4
5. Mixed management	19.7	6%	273.8	81%	44.0	13%	337.5

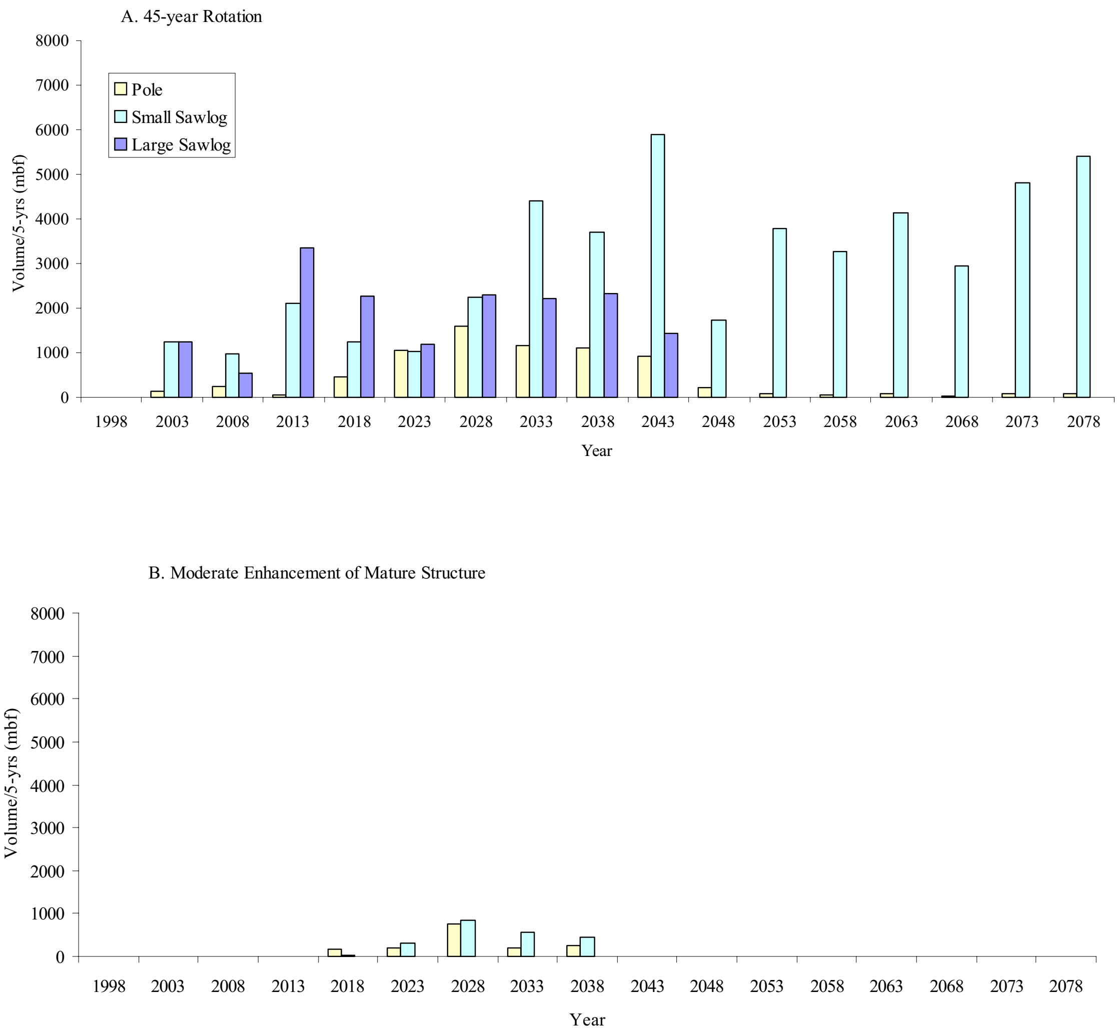
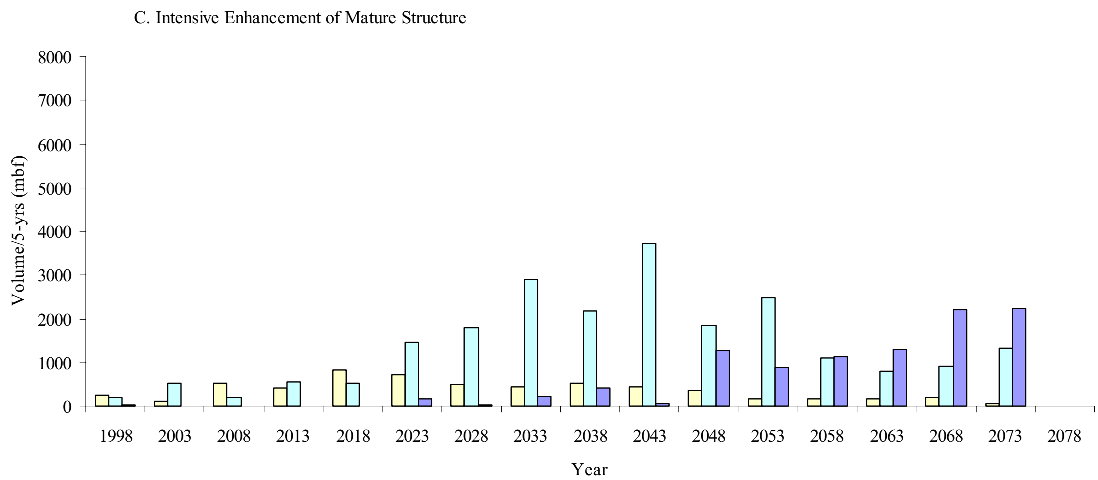


Figure 4.4: Harvested volumes by size class for five-year projection periods



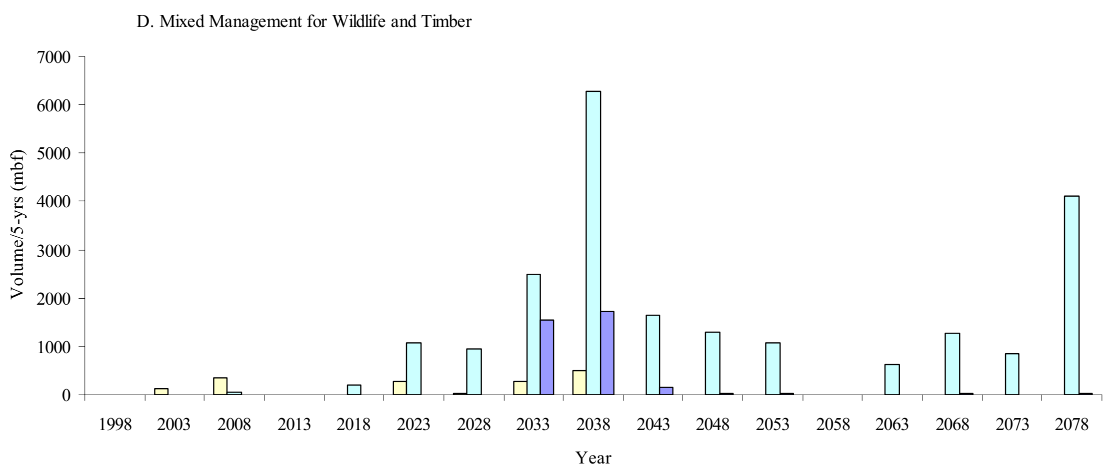


Figure 4.4 (continued): Harvested volumes by size class for five-year projection periods

Table 4.3: HSI values and top five pathways for individual pathway simulations using young dense stand

	Hawk	Vole	Woodpecker	Towhee
Max	0.614	0.968	0.651	0.078
Min	0.200	0.580	0.112	0.012
Average	0.383	0.863	0.486	0.024
Top five pathways	Barbour15-150	Barbour30-250	YSTD-Light	Hansen0-40
	Barbour30-150HL	YSTD-Light	BarbourNT	CC40_PCT
	Barbour30-75	BarbourNT	Hansen0-120	CC60_PCT_CT
	Barbour15-75	Hansen0-120	Barbour30-250	Hansen0-80
	Barbour30-150	CareyBDPS	0_NA	CC80_PCT_2CT

Table 4.4: HSI values and top five pathways for individual pathway simulations using young open stand

	Hawk	Vole	Woodpecker	Towhee
Max	0.628	0.937	0.635	0.096
Min	0.213	0.525	0.060	0.030
Average	0.437	0.820	0.408	0.048
Top five pathways	Barbour30-75	0_NA	Barbour15-75	Hansen0-40
	Barbour30-150HL	Mit_SOP	Barbour15-150	CC40_PCT
	CareyBDPF	McComb_PR	BarbourNT	CC60_PCT_CT
	Barbour30-150	CareyBDPS	YSTD-Light	Hansen0-80
	YSTD-Heavy	Hansen0-120	Barbour30-250	CC80_PCT_2CT

Table 4.5: HSI values and top five pathways for individual pathway simulations using old single storied stand

	Hawk	Vole	Woodpecker	Towhee
Max	0.723	0.967	0.792	0.105
Min	0.257	0.086	0.000	0.000
Average	0.452	0.746	0.421	0.028
Top five pathways	DEMO40	Hansen150-40	Hansen150-120	DEMO20
	Hansen50-40	Hansen150-80	Hansen150-80	McCombSS
	McCombMS	Hansen150-120	Hansen150-40	Hansen10-40
	0_NA	0_NA	0_NA	Hansen5-40
	Hansen150-40	Hansen50-120	Hansen50-120	Hansen15-40

Table 4.6: HSI values and top five pathways for individual pathway simulations using old multiple storied stand

		Hawk	Vole	Woodpecker	Towhee
Max		0.644	0.976	0.914	0.080
Min		0.261	0.605	0.000	0.000
Average		0.419	0.817	0.492	0.027
Top five pathways		Hansen50-40	McCombMS	0_NA	McCombSS
		McCombMS	DEMO40	DEMO40	Hansen5-40
		Hansen30-40	0_NA	Hansen150-120	Hansen10-40
		DEMO20	DEMO20	Hansen150-80	CC60_PCT_CT
		Hansen150-40	Hansen150-40	McCombMS	CC40_PCT

Table 4.7: Total harvested volumes (mbf/ac) and top five pathways for individual pathway simulations using young-open, young-dense, old-single-story, and old-multiple-story stands

	Young-open	Young-dense	Old-single-story	Old-multiple-story
Max	216	260	248	216
Min	0	0	0	0
Average	80	96	94	99
Top Five Pathways	Hansen0-80	Hansen0-80	Hansen5-80	Hansen5-80
	McComb_CC	McComb_CC	Hansen10-80	Hansen10-80
	CC80_PCT_2CT	CC80_PCT_2CT	Hansen15-80	Hansen15-80
	CC40_PCT	CC40_PCT	Hansen20-80	Hansen20-80
	Hansen0-40	Hansen0-40	McCombSS	McCombSS

Discussion and Management Applications

Discussion of this approach to habitat assessment and applications to management is presented in four components:

- Habitat model responses
- Management applications
- Advantages of integrating the HEP and LMS
- Limitations of integrating the HEP and LMS

Habitat Model Responses

Each species' HSI model responds differently in response to the simulated management scenarios. From a landscape-level habitat perspective, Cooper's hawk habitat quantity declined with all simulated management alternatives, with the more intensive harvesting in the 45-year rotation and intensive enhancement alternatives causing the largest declines. The declines are caused by a mortality of shorter-lived hardwood species, such as red alder, during the simulation with increased declines with the conversion of hardwood stands to conifer stands in the 45-year rotation and intensive enhancement alternatives. Hardwood components of stands are important for the Cooper's hawk HSI models.

Similarly, spotted towhee habitat quantity declined during the simulation period because canopy closure increased as the stands grew. The 45-year rotation alternative provided the smallest decline because harvesting stands at 45 years provided the most early-successional, open stands used by the spotted towhee for habitat.

Southern red-backed vole habitat quantity increased for all harvest intensity levels, with the intensive enhancement alternative providing the most habitat. All alternatives provide trees of sufficient size and enough canopy closure for the southern red-backed vole HSI model to respond positively.

Pileated woodpecker habitat quantity generally increased as well, with the exception of the 45-year rotation alternative. Increases were caused by the development of stands with larges tree cover type classifications that provide more, larger snags, stumps and logs - all of which are important to this HSI model.

Changing to a stand-level perspective changes in habitat quality caused by different silvicultural pathways can be assessed. Cooper's hawk HSI values ranged from 0.200 to 0.723 for all pathways simulated, with an average of 0.423. This range was caused by the changes in total canopy closure and conifer canopy closure. Since all stands simulated had >80% of total basal area in conifers, these canopy closures tended to counteract each other in the calculations, resulting in lower HSI values.

Southern red-backed voles showed the least sensitivity to different stand pathways, with a range of HSI values from 0.086 to 0.967 and an average of 0.811 for all simulations. Here, too the low sensitivity to harvesting was caused by these pathways providing sufficient canopy closure and large trees to provide high habitat quality values.

Pileated woodpecker showed great sensitivity to simulated pathways. Average HSI values ranged from 0.000 to 0.914, with an average 0.452. Since the model required large trees and snags, the time that the stand is allowed to grow before harvest and the type of harvest both affect the resulting HSI values. Since not all of the pathways allowed stands to attain sufficient large trees, the HSI models for pileated woodpeckers were generally quite sensitive.

The spotted towhee model showed a similar sensitivity, with HSI values ranging from 0.105 to 0.000 and an average of 0.032. This model required low canopy closure for increased quality of shrubs and ground cover; thus, increased harvest intensity and heavier thinning provided better results from the model. When stands were allowed to remain in an open condition longer, the average HSI values increased.

Management Applications

Given the responses of the HSI models to the various silvicultural pathways questions should be asked regarding "broad-brush", single-species, and ecosystem management approaches. Results from the landscape simulations give insights into the appropriateness of the "broad-brush" approach of applying a 45-year rotation to all stands on the landscape. The simulation demonstrated declines in habitat quantity for all species except the southern red-backed vole. The loss of habitat comes with the benefit of increased harvested volume, and hence increased income, over the simulation period. An alternative to this approach is the Intensive Enhancement landscape simulation where different silvicultural pathways were applied to different stands on the landscape. Habitat quantity is increased for both the vole and pileated woodpecker under this management regime.

Assessing trade-offs among management objectives is an important aspect of management planning (Table 5.1). For example, annual average harvest is at a maximum with a 45-year rotation but it comes at a cost to wildlife habitat. This management approach reduces Cooper's hawk and pileated woodpecker habitat the greatest, while reducing spotted towhee habitat the least. On the other hand, a moderate approach with minimal thinning can be done to provide good habitat levels for all species other than the spotted towhee. This comes at a cost of approximately 867.3 mbf (95% reduction) of harvested volume per year. Another approach is to implement a system of multiple thinnings with the intensive enhancement scenario. This provides very good habitat for both southern red-backed voles and pileated woodpeckers, but reduces habitat for Cooper's hawks and spotted towhees. Harvest with this scenario is reduced by 436 mbf/yr (48%). This may be an acceptable loss of harvested volume to the decision maker.

Costs associated with providing wildlife habitat can be further increased by higher logging costs. Leaving more trees in a harvest unit makes harvesting more difficult, with an associated increase in logging costs (Kellogg, Pilkerton et al. 1991; Kellogg, Bettinger et al. 1996; Chambers, McComb et al. 1999).

Some or all of these extra costs may be recovered through other means. Increased wildlife may bring added revenue through activities such as wildlife viewing and hunting (Freese and Trauger 2000; Loomis 2000). If wildlife revenues are quantified and related to timber volumes, areas of stand structures, habitat levels, or other attribute that can be calculated using LMS this revenue could then be included into financial analyses within LMS.

Managing for maximum habitat for a single species may not be appropriate if there are multiple species of concern in an area. As an example, managing at the landscape level applying the silvicultural pathways that provided the maximum amount of pileated woodpecker habitat cam at the expense of spotted towhee habitat. At the stand level silvicultural pathways that provide high levels of vole or woodpecker habitat generally provide for lower levels of Cooper's hawk habitat and little or no spotted towhee habitat. If the intent of management is to provide habitat for multiple species on the landscape, through ecosystem management, it will be necessary to apply several different silvicultural pathways on a landscape to provide a variety of stand structures and associated habitat values across the landscape.

Assessing trade-offs in habitat and harvest volume was done by in a hypothesis-testing framework. Compiling all pathways that were among the five best for each species resulted in twenty pathways for young stands (Table 5.2). For stands that are initially 10-years old and with an initial density of approximately 435 tpa, four of the 20 pathways provided the most habitat for two species - southern red-backed vole and pileated woodpecker. Thirteen of the remaining pathways provide the most habitat for a single species - five for Cooper's hawk and spotted towhee independently, two for pileated woodpecker, and one for southern red-backed vole. The remaining three pathways provide the most habitat only with initially dense stands. For the initially dense 10-year old stand with approximately 1300 tpa, all pathways provided the most habitat for a single species. Five provided the most habitat for pileated woodpecker, southern red-backed vole, Cooper's hawk and spotted towhee, independently. Averaging the habitat for both stands yielded four stands that provide the most habitat for 1.5 species - Cooper's hawk and southern red-backed vole either together or independently. Thirteen pathways provide habitat independently, either Cooper's hawk, southern red-backed vole, pileated woodpecker, or spotted towhee. Three pathways that provided the most habitat for an average of 0.5 species, either Cooper's hawk or southern red-backed vole in half of the pathways.

Compiling pathways for older stands yielded sixteen pathways that benefited on, or more, species in simulations of single and multiple story stands (Table 5.3). With an initially single storied stand, two pathways provided the most habitat for three species, (Cooper's hawk, southern red-backed vole, and pileated woodpecker), three pathways that provided the most habitat for two species, (southern red-backed vole and pileated woodpecker), and eight pathways that provided the most habitat for a single species, (either Cooper's hawk or spotted towhee). Three pathways provided the most habitat only with an initially multiple storied stand. With an initially multiple storied stand, one pathway provided the most habitat for three species, (Cooper's hawk, southern red-backed vole, and pileated woodpecker), six pathways provided the most habitat for two species, (either southern red-backed vole and pileated woodpecker or southern red-backed vole and pileated woodpecker), and seven pathways that provided the most habitat for only a single species, (either spotted towhee or Cooper's hawk). Two pathways provided the most habitat only with an initially single storied stand. When averaged, two pathways provide the most habitat for 2.5 species, (Cooper' hawk and southern red-backed vole and/or pileated woodpecker), three pathways provided the most habitat for two species, (southern red-backed vole and pileated woodpecker and/or Cooper's hawk), two pathways provided the most habitat for 1.5 species, five pathways provided the most habitat for a single species and four provided the most habitat for 0.5 species, on average.

Harvested volume from each pathway can be assessed as well. With the young stand simulations the average maximum harvested volume was 238 mbf/ac. Pathway simulations for older stands resulted in an average total harvested volume of 221.5 mbf/ac. Pathways that provided the most benefit for the wildlife species can be examined from the perspective of reduction of harvested volume (Tables 5.4 and 5.5).

Pathways that benefited the most species tended to have lower harvested volumes. Pathways with higher total harvested volumes tended to provide the best average habitat for a single species, the spotted towhee. One exception is the CareyDBPS pathway for young stands. This pathway provided very good southern red-backed vole habitat (HSI values of 0.966 and 0.929 for initially open and dense stands, respectively) as well as good pileated woodpecker habitat (HSI value of 0.637 and 0.492 for initially open and dense stands, respectively) and fair Cooper's hawk habitat (HSI values of 0.342 and 0.506 for initially open and dense stands, respectively).

All these proposed pathways had been intended to produce habitat as well as allowed some harvesting. Testing them with LMS and the habitat models allowed the pathways to be simulated on local forest conditions before they are applied. Since the pathways were proposed for other regions of the Pacific Northwest and for other stands conditions the results may be different than reported for the area that they were developed for. Variations in initial conditions have an effect on the habitat outputs from the pathways, as can be seen in the differences between the HSI values for each species when comparing individual stand pathways on stands with different initial conditions on Satsop Forest. The number of species benefited is also dependent on initial conditions. The same pathway may benefit multiple species with one initial condition while none with another initial condition. These potential effects can be assessed using these models in a hypothesis-testing framework to avoid potential unintended consequences when pathways are implemented in the forest.

After the assessment of habitat and volume trade-offs was completed the top performing pathways for each species and harvested volume are used to create landscape-level management alternatives. Selecting the proportion of the landscape that a particular silvicultural pathway is applied to is accomplished by grouping stands on the landscape into ecologically similar groups, simulating all the pathways using an "average" stand from the group, then using the Toggle Program to apportion the amounts of each group that receive particular pathways (Johnson 2001).

Analyzing trade-offs among multiple, often conflicting, objectives it one of the primary strengths of the Toggle Program. As the user adjusts the percentage of each group that pathways are applied to, resultant values of all outputs included in the Toggle Program are calculated. Outputs include wildlife habitat, sequestered carbon, standing and harvested volumes by tree size classes, landscape-level structural diversity, reserve areas, susceptibility to windthrow, and even potential employment.

Working with the Toggle Program the user develops several management alternatives. Outputs from each set of silvicultural pathways are reported in matrix format for side-by-side comparisons of the various outputs of interest. The resulting matrix can then be given to the person, or people, in charge of making the final decision regarding a management plan for a landscape.

Advantages Of Integrating HEP and LMS

Implementing the HEP calculations in LMS provided several advantages. First, since an empirical growth model is used, all assumptions are held constant for all forest growth simulations, allowing alternatives to be compared without bias.

Using a forest inventory allows the variability within each cover type to be included in the analysis. Based on the cover type classification rules there can be a wide range of tree sizes and canopy closures as well as understory, snag and downed wood components. Selecting only an average tree size or other value, instead of using a forest inventory, may neglect variability result in lower habitat quality. Examples of this are the improved results using the 1998 Satsop Forests inventory instead of the original HSI calculations based on cover type averages from the original HEP data collection.

The most significant advantage of automating these calculations in LMS is the ability to develop and analyze many alternatives quickly. Both landscape level and stand level simulations can be made to assess and communicate the effects of proposed management regimes. The rapid analysis is especially important when some parties involved in planning have backgrounds other than forestry, and so do not understand standard forestry metrics such as volume, tree sizes and stands structures. When working at the stand level, several alternative silvicultural pathways can be compared to assess their potential benefits. Using hypothesis-testing framework before they are applied in a whole forest landscape.

Other approaches to habitat assessment over spatial and temporal scales could be used. For example, using FVS directly, without the LMS interface, to perform forest growth projections then feeding the resulting data into the HSI models would result in equivalent results. Using FVS within LMS adds other dimensions to an analysis. FVS can provide a set of raw outputs tables that will need further summarization to perform other analyses. In this analysis only a small segment of the functionality and power of LMS are used. HSI, HU, and volume calculations all use only the inventory and stand attribute files to create output tables.

Many other analyses are available to the user of LMS. Over thirty analysis tables are included with LMS that are created by programs within LMS, which summarize the current and projected future inventories in different ways. Tables created in this process have been developed to answer questions relating not only to levels of habitat and volumes but also other forestry measures such as inventory tables and stand summary tables as well as other measures such as carbon sequestration and stand structures.

Other assessments include landscape and stand level visualizations using the Stand Visualization System and EnVision programs, developed by Robert McGaughey, Research Forester, USDA Forest Service, Pacific Northwest Research Station, University of Washington, Seattle, WA, that are included with LMS. Using these assessments of aesthetic changes to the forest can be performed. Visualizations also allow the analyst to communicate changes in to forest caused by forest management activities.

A second approach developing a landscape level management plan uses the ORGANON growth model in conjunction with a GIS system and the harvest-scheduling program SNAP-II (McComb, Spies et al. 1993). This approach differs from the LMS and Toggle Program approach in one main way: SNAP-II is decision-making program while LMS is a decision-support program. Through optimization routines with constraints on various outputs SNAP-II determines an optimal schedule of what to harvest when and when. Implicit in the ORGANON / SNAP-II approach is an assumption that the analyst knows the appropriate weighting levels for the desired outputs creating a top-down approach to decision making. When using the LMS / Toggle Program approach no assumptions are made about the importance various objectives. It is up to the user to select the appropriate mix of pathways. The LMS / Toggle are used as decision-support tools in the management plan development process.

Limitations Of Integrating HEP and LMS

This approach also has several limitations. Since understory, snag and downed wood data are needed for calculating HSI values for all models except Cooper's hawk, the applicability of these models is limited to the Satsop Forest ownership without collection of appropriate understory, snag, and downed wood data. Applying these models elsewhere would require collection of the appropriate data and calculations of average values based on cover types classified by the cover type classification algorithm.

Understory relationships in Pacific Northwest forests have been studied in great depth. Studies have focused on developing relationships between overstory and understory structure and composition, as well as responses of the understory to disturbances, including harvesting, in old-growth, mature, and young forests (Halpern and Spies 1995; Bailey, Maysohn et al. 1998; Van Pelt and Franklin 2000). Relationships have been developed into models for other regions of the Pacific Northwest (McPherson 1992; Klinka, Chen et al. 1996; Mitchell and Popovich 1997), but none were found for Southwest Washington, where Satsop Forest is located. Forest inventory that is limited to tree measures will have little success in estimating wildlife habitat using the framework of this paper, since both the spotted towhee and southern red-backed vole require understory metrics as well as tree metrics. Development of understory models for other regions shows that it can be done, and building models for Western Washington would increase the applicability of the models to other areas of the region.

Snags and downed wood are important habitat attributes for pileated woodpecker and southern red-backed vole models. The current version of LMS, version 2.0.42h, does not model snags and downed wood. Earlier versions had included a snag and downed wood model. A snag and downed wood model is scheduled for release with the next version of LMS. Application of this model will allow the models to estimate habitat with variability of snags and downed wood within each cover type included. It is hoped that including snag and downed wood in the models will increase their sensitivity in the same way as using the 1998 Satsop Forest inventory rather than the original cover type averages.

Creation of snags through various methods has been proposed to provide habitat for cavity-nesters where insufficient snags are present (Lewis 1998). Use of these snags has been noticed where they have been created in commercial forests (Chambers, Carrigan et al. 1997). Creation of snags and downed wood, however, cannot be simulated with the current version of LMS. Inclusion of this snag creation along with the snag and downed wood model with the next version of LMS will also allow estimation of the benefit provided by creation of these structures in managed forest landscapes.

Spatial arrangement and size of habitat patches is important for some species. Pileated woodpeckers need a home range of at up to 600ac (Schroeder 1983). In the case of Satsop Forest, with an average polygon (habitat patch) size of 5.2ac, the ability to arrange harvest activities is such a way that minimum home range requirements are met is through iterative applications of silvicultural pathways to various stands. After an initial management plan simulation, there may be 600ac of pileated woodpecker habitat but it may be arranged in a series of small patches that are not of use for the woodpeckers. This is less of a concern for a species with a small home range such as the southern red-backed vole with a home range size of up to approximately 3.5ac (Allen 1983).

Adaptive Management

These models should be used in an adaptive management context as well. Growth model outputs are only a representation of what may exist in the future. It is necessary to revisit the results after several years to ensure that the silvicultural pathways are providing the desired results. If the silvicultural pathways are not producing the desired habitat results the pathways can be modified to produce the needed habitat structures.

The HSI models do not provide actual species populations, only measures of potential habitat quality and quantity. Thus it will be necessary to perform field surveys in the future to determine if animals are actually using the habitats that are expected to exist on the landscape. If species are using habitats different from the model’s predictions, the models may be modified using the monitoring data to predict habitat suitability indices better. This may also allow relationships between HSI values and actual populations numbers to be developed.

Table 5.1: Comparison of annual harvested volumes (mbf/yr) to percent changes in wildlife habitat over an 80-year simulation (bold = maximum, *italics = minimum*)

	Annual harvest (mbf/yr)	Cooper's hawk		Southern red-backed vole		Pileated woodpecker		Spotted towhee	
		2038	2078	2038	2078	2038	2078	2038	2078
1. No Action	*0.0*	**-10%**	**-19%**	65%	75%	93%	112%	*-80%*	*-86%*
2. 45-yr rotation	**914.4**	*-71%*	*-71%*	47%	*56%*	*-22%*	*-20%*	**-45%**	**-47%**
3. Moderate enhancement	47.1	**-10%**	**-19%**	65%	75%	**98%**	112%	*-80%*	*-86%*
4. Intensive enhancement	478.4	-53%	-60%	**116%**	**146%**	90%	**135%**	-70%	*-86%*
5. Mixed management	337.5	-31%	-35%	*32%*	67%	39%	58%	-65%	-77%

Table 5.2: Twenty pathways with highest average HSI values over an 80 year simulation for stands initially 10-years old, open (~435 tpa) and dense (~1300 tpa), with species benefited (CH = Cooper's hawk, SRV = southern red-backed vole, PW = pileated woodpecker, ST = spotted towhee)

Pathway	Open	Dense	Average	Open	Dense
Barbour30-250	2	1	1.5	SRV, PW	PW
BarbourNT	2	1	1.5	SRV, PW	PW
Hansen0-120	2	1	1.5	SRV, PW	SRV
YSTD-Light	2	1	1.5	SRV, PW	PW
0_NA	1	1	1	PW	SRV
Barbour15-150	1	1	1	CH	PW
Barbour15-75	1	1	1	CH	PW
Barbour30-150	1	1	1	CH	CH
Barbour30-150HL	1	1	1	CH	CH
Barbour30-75	1	1	1	CH	CH
CareyBDPS	1	1	1	SRV	SRV
CC40_PCT	1	1	1	ST	ST
CC60_PCT_CT	1	1	1	ST	ST
CC80_PCT_2CT	1	1	1	ST	ST
Hansen0-40	1	1	1	ST	ST
Hansen0-80	1	1	1	ST	ST
Mit_SOP	1	1	1	PW	SRV
McComb_PR	0	1	0.5		SRV
CareyBDPF	0	1	0.5		CH
YSTD-Heavy	0	1	0.5		CH

Table 5.3: Sixteen pathways with highest average HSI values over an 80 year simulation for stands initially 90-years old, single and multiple layered canopy, with species benefited (CH = Cooper's hawk, SRV = southern red-backed vole, PW = pileated woodpecker, ST = spotted towhee)

Pathway	Single	Multiple	Average	Single	Multiple
0_NA	3	2	2.5	CH, SRV, PW	SRV, PW
Hansen150-40	3	2	2.5	CH, SRV, PW	CH, SRV
Hansen150-120	2	2	2	SRV, PW	SRV, PW
Hansen150-80	2	2	2	SRV, PW	SRV, PW
McCombMS	1	3	2	CH	CH, SRV, PW
DEMO20	1	2	1.5	ST	CH, SRV
DEMO40	1	2	1.5	CH	SRV, PW
Hansen50-120	2	0	1	SRV, PW	
Hansen10-40	1	1	1	ST	ST
Hansen5-40	1	1	1	ST	ST
Hansen50-40	1	1	1	CH	CH
McCombSS	1	1	1	ST	ST
Hansen15-40	1	0	0.5	ST	
CC40_PCT	0	1	0.5		ST
CC60_PCT_CT	0	1	0.5		CH
Hansen30-40	0	1	0.5		CH

Table 5.4: Total harvested volume (mbf/ac) from an initially 10-year old stand during an 80-year simulation for 16 top habitat-producing pathways and species benefited (CH = Cooper's hawk, SRV = southern red-backed vole, PW = pileated woodpecker, ST = spotted towhee.)

Pathway	Open	Dense	Average	Open	Dense
Barbour30-250	34	41	37.5	SRV, PW	PW
BarbourNT	4	5	4.5	SRV, PW	PW
Hansen0-120	3	4	3.5	SRV, PW	SRV
YSTD-Light	37	44	40.5	SRV, PW	PW
0_NA	0	0	0	PW	SRV
Barbour15-150	26	32	29	CH	PW
Barbour15-75	22	27	24.5	CH	PW
Barbour30-150	46	55	50.5	CH	CH
Barbour30-150HL	56	67	61.5	CH	CH
Barbour30-75	56	67	61.5	CH	CH
CareyBDPS	126	151	138.5	SRV	SRV
CC40_PCT	155	185	170	ST	ST
CC60_PCT_CT	139	166	152.5	ST	ST
CC80_PCT_2CT	170	204	187	ST	ST
Hansen0-40	147	177	162	ST	ST
Hansen0-80	216	260	238	ST	ST
Mit_SOP	34	41	37.5	PW	SRV
McComb_PR	57	69	63		SRV
CareyBDPF	105	126	115.5		CH
YSTD-Heavy	66	80	73		CH

Table 5.5: Total harvested volume (mbf/ac) from an initially 90-year old stand during an 80-year simulation for the 16 top habitat-producing pathways and the species benefited (CH = Cooper's hawk, SRV = southern red-backed vole, PW = pileated woodpecker, ST = spotted towhee.)

Pathway	single	multi	Average	single	multi
0_NA	0	0	0	CH, SRV, PW	SRV, PW
Hansen150-40	0	2	1	CH, SRV, PW	CH, SRV
Hansen150-120	0	1	0.5	SRV, PW	SRV, PW
Hansen150-80	0	8	4	SRV, PW	SRV, PW
McCombMS	48	10	29	CH	CH, SRV, PW
DEMO20	42	0	21	ST	CH, SRV
DEMO40	24	0	12	CH	SRV, PW
Hansen50-120	61	11	36	SRV, PW	
Hansen10-40	148	113	130.5	ST	ST
Hansen5-40	166	127	146.5	ST	ST
Hansen50-40	36	33	34.5	CH	CH
McCombSS	181	143	162	ST	ST
Hansen15-40	127	99	113	ST	
CC40_PCT	152	118	135		ST
CC60_PCT_CT	128	100	114		CH
Hansen30-40	78	64	71		CH

Conclusions

Managing forests for wildlife habitats and timber harvest simultaneously requires assessing habitats and harvest at a landscape level. "Landscapes" range from a few stands of several acres to ownerships of hundreds or thousands of acres to watersheds or regions. The common element in developing management plans is looking at multiple stands in a landscape as the analysis unit rather than an individual stand. Performing analyses at this level is necessary for habitat assessment because animals may have home ranges much larger than a single stand. Furthermore, in an area there may be more than one species of concern requiring different management strategies. By moving to analyses at a landscape level trade-offs between habitat areas may be noticed and management plans tailored to the needs of multiple species rather than a single species. LMS is well suited for this type of analysis because it integrates data at a landscape level and performs landscape level simulations.

Stand level simulations can also be performed in LMS to assess how well alternative silvicultural pathways perform in local forests. Pathways that were proposed for a forest in a different region may not provide the same habitat values when moved to a different region with a similar forest type. Reasons for the non-transferability include differences in site quality, species mixtures, stand ages, and stand structures. Using LMS these pathways can be tested to assess if they are appropriate for a specific stand type before they are applied in the forest. Performing this analysis prior to application may help to avoid potential unintended consequences.

Analyses in this study have used only a portion of the functionality of LMS. Many output tables are available that calculate typical forestry metrics such as basal area and volumes, economic values, as well as ecological metrics such as canopy layers and stand structural stages. This study has expanded the set of tables to include wildlife habitats. The range of tables allows analysts to perform trade-off analyses from a variety of perspectives. In addition to the tabular output stand and landscape level visualizations can be produced using the Stand Visualization System and EnVision programs. Tabular data are primarily useful for forestry and wildlife professionals but are difficult for people without train to understand. Visualizations are one way to help communicate effects of silvicultural treatments to people involved in the planning process. Through integrative, analytical, and communicative functions, LMS can be used as an effective decision support and forest-planning tool.

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