# Linking Tools of Forest and Wildlife Managers: Wildlife Habitat Evaluation Using the Landscape Management System

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**Abstract**—Natural resource managers are increasingly being asked to consider values outside their fields. This is especially evident with regards to wildlife habitat changes caused by forest management activities. Forest managers are being asked to balance both wildlife habitat and forest product outputs from the forest. Our approach of implementing a Habitat Evaluation Procedure as a module of the Landscape Management System is an example of how forest growth and yield models can be integrated with existing wildlife models to expand the forest manager's tool set. The Landscape Management System uses the Forest Vegetation Simulator to simulate forest growth and changes caused by silvicultural activities on the Satsop Forest ownership, located in southwestern Washington State. The Habitat Evaluation Procedure module then calculates Habitat Suitability Indexes and Habitat Units for Cooper's hawk (*Accipiter Cooperii*), pileated woodpecker (*Drycopus pileatus*), southern red-backed vole (*Clethrionomys gapperi*), and spotted towhee (*Pipilo erythrophthalmus*) from the resulting projected forest inventories. The result is a tool that allows forest managers to assess changes in wildlife habitat caused by potential forest management at the stand and ownership levels. Because the Landscape Management System produces summaries of a variety of forest outputs, both tabular and visual, the results can then be used in analyses of existing and proposed forest management plans. On a stand-by-stand basis, multiple silvicultural pathways can be tested to assess which pathways meet varying desired habitat and forest product outputs. Through the use of stand and ownership level simulations and analyses of multiple target outputs, forest managers and decisionmakers are able to better understand output tradeoffs at the landscape and watershed levels.

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 forests to intensively managed plantations for timber production has raised concerns about habitat for species that are associated with these forest structures at the present time and in the future. While planning current and future forest management activities, forest managers are being asked to address how management will affect forest systems in the coming decades.

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As concern grows and more species are studied, many of these species become candidates for special consideration ranging from a "species of concern" at the State level, such as the pileated woodpecker (*Dryocopus pileatus*) in Washington State, to "threatened" or "endangered," such as the northern spotted owl (*Strix occidentalis caurina*) in the Pacific Northwest, the red-cockaded woodpecker (*Picoides borealis*) in the Southeast, and the Kirtland's warbler (*Dendroica kirtlandii*) in the Lake States region, at both the State and Federal levels. Listing of these species resulted in regulatory constraints on forest management. Changes in Federal forest management in the Pacific Northwest under the Northwest Forest Plan to protect old forest habitat and the spotted owl exemplify the regulatory constraints. Harvest on Pacific Northwest National Forests has virtually stopped.

Technology has increased greatly during this time as well. Computing power has greatly increased, and forest growth and yield models, such as the Forest Vegetation Simulator (FVS), have been developed to predict forest growth and development though time. Using these tools, forest managers can estimate potential harvest volumes and tree sizes in the future. From initial forest inventory data and simulated future data, managers create forest management plans based on criteria such as allowable harvest volume or stand structures, now and in the future, calculated from stand attributes such as tree species, sizes, and volumes. As demands on forests change, managers must estimate effects on other forest outputs such as wildlife habitat. Using a simulation system that includes wildlife habitat models, it may be possible for managers and other interested parties to gain insight into how current forest management may affect future forest outputs and ensure forests are managed in a sustainable manner.

This study implements a Habitat Evaluation Procedure (HEP; USDI 1980a) within the Landscape Management System (LMS) for two reasons: first, to develop tools to support analysis of new management alternatives for Satsop Forest. Any analysis must be consistent with the original Satsop Forest HEP (Curt Leigh personal communication) to ensure comparable results. The original Satsop Forest HEP was performed on Satsop Forest, formerly the Satsop Nuclear Site, to assess losses of wildlife habitats caused by construction of two nuclear power plants and to analyze management plans to mitigate for lost habitats. Second, because Habitat Suitability Index (HSI) models and the HEP use, primarily, tree-based measures, the HEP is used in this study to demonstrate linking wildlife habitat models with forest growth models within a forest simulation system.

## Background

Several methods have been used to 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, population density models, and the HEP. Kliskey and others (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. This study 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. Moore and others (2000) used an optimization technique, which employed 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. Hansen and others (1995) constructed population density response models for 16 species of birds in the Central Oregon Cascades that used densities 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. The HEP is a methodology used to assess impacts to wildlife habitats caused by projects such as power plant construction where wildlife habitat is used as "currency" in an accounting system. Initially developed in the 1970s, this system is still in use today.

## Study Location

Satsop Forest encompasses roughly 1,400 acres south of the Chehalis River in southwestern Washington State (fig. 1) owned by the Grays Harbor Public Development Authority (PDA). About 840 acres are forested, and 220 acres are in grassy meadows, shrubs, or riparian areas and not included in timber management analysis. The remaining 340 acres are part of the developed infrastructure of the Satsop Development Park. Elevation is relatively constant at 250 feet, and forest productivity is moderate to high (56 percent of the forest is Site Class II, Site Index 115 to 135 feet (King 1966)). Stands range from pure conifer to pure hardwood, but most are complex mixtures of Douglas-fir (*Pseudotsuga menziesii*), big leaf maple (*Acer macrophyllum*), western hemlock (*Tsuga heterophylla*), red alder (*Alnus rubra*), and western redcedar (*Thuja plicata*). Most of the area is covered by forest 5 to 10 years old; forests greater than 120 years are present in small proportion on the site (Marzluff and others 2002).

Currently, Satsop Forest management is dictated by a wildlife mitigation agreement. This agreement was put in place to mitigate for wildlife habitat losses caused by the partial construction of Washington Public Power Supply System's Nuclear Plants No. 3 and No. 5. Even though this agreement was created prior to the PDA's acquisition of the land, it is still in force, providing management prescriptions through the year 2040.

The PDA's management objectives for Satsop Forest extend beyond strictly the creation and enhancement of wildlife habitat (Jim Walls, personal communication). There is a desire to create a demonstration forest where alternative silvicultural practices that create both wildlife habitat and income can be showcased to other landowners with the primary focus being nonindustrial private forest (NIPF) owners. Income is important because the trees on forestland are often an investment for the owner.

## Original Satsop Forest HEP (WPPSS 1994)

Performing the original HEP on Satsop Forest involved several steps. First a vegetation cover type inventory of the area was undertaken using aerial photographs with associated criteria (percent canopy closure, percent conifer/deciduous, average d.b.h., average height, total trees per acre, trees per acre greater than 21 inches d.b.h., and number of canopy layers) used to determine 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 cover type 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. For each target year, cover type acreages, HSI, and Habitat Unit (HU) values for each species were calculated. For the life of each

**Figure 1**—Location of Satsop Forest in southwestern Washington.

alternative, Annual Average Habitat Unit (AAHU) values were calculated to estimate average available habitat quantities. AAHU values were compared between alternatives to select the "preferred" management alternative.

We found 21 cover types 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. Nonriparian forested areas that can be managed fit into 13 cover type classifications.

Five species and associated HSI models were selected for the HEP analysis: Cooper's hawk (*Accipiter cooperii*; USDI 1980b), 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 1994). 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.

All HSI models chosen for the Satsop Forest HEP require tree-based measures, such as canopy closure, overstory d.b.h., and number of trees with d.b.h. greater than 21 inches per acre, and all the HSI models, except the Cooper's hawk, also require non-tree-based measures, such as downfall litter, downed logs per acre, and grass cover. All attributes were inventoried on Satsop Forest in 1991 and used in the original HEP analysis. Based on average habitat attribute values for each cover type, HSI values were calculated for each species for each cover type on Satsop Forest. Cover type 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 and 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.

## 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 and others 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-by-stand tree list); stand level data (such as 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.

## Habitat Evaluation Procedure (HEP) Implementation within LMS

Given the similarities between HSI model input data and LMS output data and the modular, integrative nature of LMS, implementation of an HEP was a process of codifying the graphical HSI models and cover typing rules and creating the computer programs needed to read LMS output files, generate model input data, perform cover typing and HSI calculations, and create HEP output files. This was done using the Python programming language (URL: http://python.org). The LMS implementation of the Satsop HEP consists of cover typing and four of the five original HSI models. Because of the spatial nature of the black-tailed deer model and the lack of spatial metrics in LMS output, it cannot be implemented directly in LMS.

## HSI Model Implementation

HSI models contain several component variables that contribute to the total habitat suitability for a species. Each component variable has its own graphical relationship between that habitat attribute and that attribute's contribution to the overall HSI value. Each of these component HSI's varies from 0.0 to 1.0. When each component HSI has been estimated, an overall HSI is determined by geometric averages or minimum values, depending on the relative importance of attributes to the particular species. The HSI model for Cooper's hawk (fig. 2) is an example of the graphical model.

To be used in a computerized simulation system, HSI models must be converted into piecewise equations. An

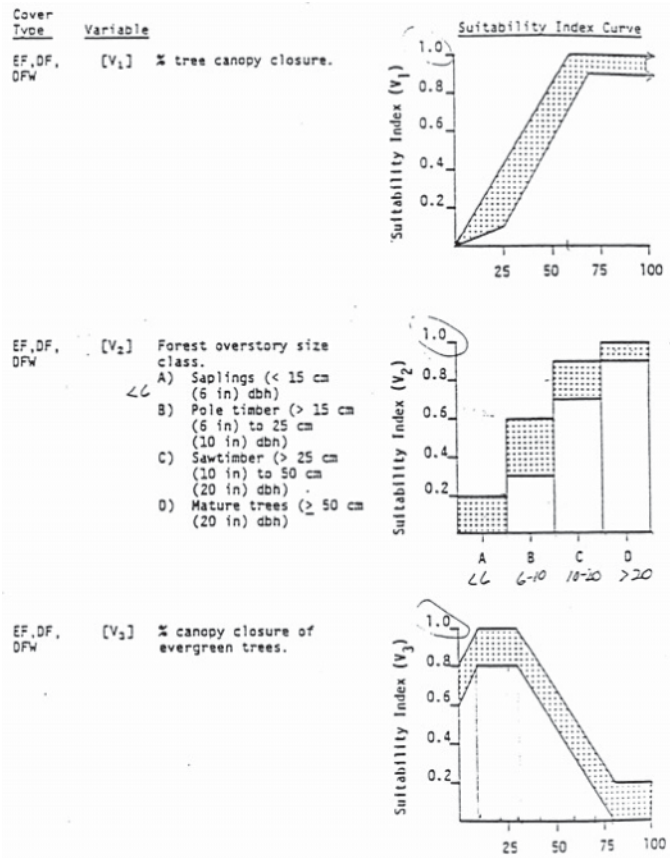


**Figure 2**—Cooper's hawk Habitat Suitability Model from USDI (1980b)

example of this are the equations for the Cooper's hawk HSI model as implemented in the Satsop HEP module of LMS:

Variable 1 (V1) – % Canopy closure
Input – % Canopy closure (CC)
$V1 = 1/60 * CC$, where $CC \leq 60$
$V1 = 1$, where $CC > 60$

Variable 2 (V2) – Overstory size class
Input – Average DBH (ADBH)
$V2 = 0.2$, where $ADBH \leq 6$
$V2 = 0.6$, where $6 < ADBH \leq 10$
$V2 = 0.9$, where $10 < ADBH \leq 20$
$V2 = 1$, where $ADBH > 20$

Variable 3 (V3) – % Conifer canopy closure
Input – % Conifer canopy closure (CCC)
$V3 = 0.8 + 0.2/10 * CCC$, where $CCC \leq 10$
$V3 = 1$, where $10 < CCC \leq 30$
$V3 = 1 - 0.8/50 * (CCC - 30)$, where $30 < CCC \leq 80$
$V3 = 0.2$, where $CCC > 80$

HSI = Lesser of: $(V1 * V2)^{1/2}$ or V3

## Cover Type Rule Implementation

Generating the algorithm to perform the cover typing required writing a series of "if" statements based on the rules in table 1. Within each "if" is a series of "and" statements to test all criteria required for each cover type. If all criteria are satisfied, the stand is assigned that cover type. If any one criterion is not satisfied, the algorithm moves to the next cover type. The process continues until the stand satisfies all criteria for a cover type or ends in the catchall "Brush" cover type.

## HEP Input Data Generation

Cover types and HSI model implemented within LMS require LMS generated data. These data come from two sources: (1) Tree-based measures (total canopy closure, conifer canopy closure, percent conifer/deciduous, dominant height, average d.b.h., overstory d.b.h., trees per acre, trees per acre with d.b.h. greater than 21 inches, and canopy layers) are calculated from initial and simulated future tree lists. (2) Non-tree-based data (downfall litter, grass cover, stumps per acre, logs per acre, snags per acre with d.b.h. greater than 21 inches, average d.b.h. of snags with d.b.h. greater than 21 inches, total ground cover, and a Shrub Suitability Index) are taken from a lookup table based on the cover type of the stand.

Calculation of tree-based data is performed using algorithms within LMS plus implementations of the canopy closure equation published by Crookston and Stage (1999) and the canopy layers algorithm published by Baker and Wilson (2000). All tree based measures are calculated then stored for use by the cover typing and HSI calculation algorithms.

Extracting the non-tree-based measures from the lookup table is done after the stand has been assigned a cover type. Within the lookup table there are habitat attribute values, from the 1991 habitat attribute inventory, presented as cover type averages. The non-tree-based data extraction algorithm reads the cover type of a stand then retrieves the non-tree-based values and stores them to be used by HSI calculation algorithms.

After all HSI model inputs have been generated, HSI calculations are performed for each species chosen for the analysis. The results are relative measures, on a 0.0 to 1.0 scale, of habitat suitability for each stand for each species. Habitat suitability is analogous to habitat quality. Estimating the amount of potential available habitat is done by multiplying the HSI value by the acreage of the stand resulting in HU values. HU values are a relative measure of available habitat where a value of 50 may be 50 acres of optimal habitat, with HSI of 1.0, or 500 acres of poor habitat, with an HSI value of 0.1. HU values can then be summed across the entire landscape to get a relative measure of available habitat for the species used in the analysis. Estimating the amount of habitat available over the life of the simulation is done with Average Annual Habitat Units (AAHU).

**Table 1**—Timbered cover type thresholds for Satsop Forest from the original HEP.

| Cover type | Description | Canopy closure | Percent conifer | Percent deciduous | TPA | TPA >21" d.b.h. | Avg. d.b.h. | Avg. height | Canopy layers |
|---|---|---|---|---|---|---|---|---|---|
| | | - - - - - - - - - - | *Percent* | - - - - - - - - - - | | | *Inches* | *ft* | |
| C4 | Conifer late-successional | >70 | >75 | | | 20 | ≥21 | >40 | 3 |
| C4T | Conifer late-successional, thinned | <70 | >75 | | | | ≥21 | >40 | |
| C3 | Mature conifer | >70 | >75 | | | | 12-21 | | |
| C3T | Mature conifer, thinned | <70 | >75 | | | | 12-21 | | |
| C2 | Conifer pole/sapling | >50 | >75 | | | | 4-12 | | |
| C1 | Early-successional conifer | >50 | >75 | | ≥150 | | 1-4 | | |
| M3 | Mature mixed | >70 | <75 | <75 | | | 12-21 | >40 | |
| M2 | Mixed pole/sapling | >50 | <75 | <75 | | | 4-12 | | |
| M1 | Early-successional mixed | >50 | <75 | <75 | | | 1-4 | | |
| H3 | Mature deciduous | >50 | | >75 | | | 12-21 | >40 | |
| H2 | Deciduous pole/sapling | >50 | | >75 | | | 4-12 | | |
| H1 | Early-successional deciduous | >50 | | >75 | | | 1-4 | | |
| B | Brush | <50 | | | | | | | |

## Satsop Forest HEP Output Tables

Output tables from the HEP analysis performed by LMS are designed to be compatible with the tables used in the original Satsop Forest HEP. In addition, there are other summary tables and tables formatted to be imported into ESRI ArcView for mapping of cover types and habitat suitabi1ty values. Four cover type output tables are available: cover type designation for each stand for each year of the simulation with acreage for each stand; summary of acreage in each cover type for each year of the simulation; cover type by stand for each year of the simulation and the acreage summary; and a table to be imported into ESRI ArcView. Seven habitat-related output tables are available: HSI, HU, By Species, HSI Summary, AAHU, All HEP tables, and an HSI table to be imported into ESRI ArcView for mapping habitat suitability. This suite of tables will allow the analysts and managers to answer many questions regarding habitat suitability and availability.

## 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 in 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 percent confidence intervals containing 0.0 (fig. 3). 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. Because all 95 percent confidence intervals contain 0.0, the models predict as well as the original HSI models 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.

## Applications of the Satsop Forest HEP Using LMS

LMS with the HEP module is currently being used to develop potential management alternatives for Satsop Forest that will be used in wildlife mitigation agreement renegotiations. Development of management alternatives involves two processes: stand-level analyses and landscape-level analyses. These analyses allow the manager to examine tradeoffs between habitat values and other

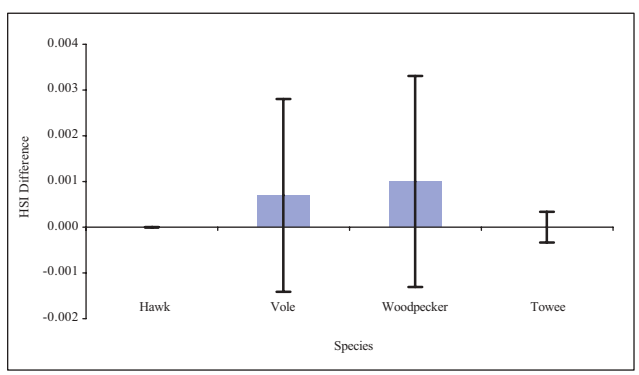


**Figure 3**—Mean difference between HSI values reported in original HEP and values calculated by LMS using original HEP data, with 95 percent confidence intervals.

outputs from many stand-level silvicultural pathways and landscape level management plans. Performing stand-level analyses allows planners and managers to screen potential silvicultural pathways based on habitat quality, potential harvest volume, or other criteria. Preferred pathways are assigned to specific stands to create a landscape-level management plan. Landscape-level analyses of the management plan assess potential consequences of applying the plan on the landscape.

Management of Satsop Forest is constrained by the requirements of a wildlife mitigation agreement. Any alternative management plans must meet the habitat levels of the current management plan. Screening potential alternative silvicultural pathways was done with four stands: two 10-year-old stands, with 435 t.p.a. and 1350 t.p.a, and two 90-year-old stands, open stand with a single canopy layer and dense stand with multiple canopy layers. Thirty pathways were simulated using the young stands, and 21 pathways were simulated using the older stands. Many of the pathways were taken from previous studies that assessed the effect of timber harvesting on habitats or populations in other areas of the Pacific Northwest (CCEM 1993; DeBell and Curtis 1993; McComb and others 1993; Hansen and others 1995; Carey and others 1996; Barbour and others 1997). Based on the results of these simulations, the pathways that produced the highest habitat levels for individual species or highest harvest volume, regardless of habitat provided, were selected. Examples of the pathways that produce the highest levels of habitat and harvest volume are shown in table 2. It should be noted that different pathways provided different amounts of habitat or harvest volume. If a land manager is to balance providing habitat for many species and produce harvest volume, one silvicultural pathway cannot be applied on all acres of a landscape. Designing landscape level plans from simulated pathway results can be done with a spreadsheet known as "the Toggle Program" (Johnson 2001) that allows managers to assess tradeoffs between many objectives by apportioning different amounts of the landscape acreage to different pathways.

Landscape-level management alternatives are analyzed to assess consequences of applying the management plan on the landscape. Questions such as "How much habitat is available?" and "How much timber volume is being harvested?" can be answered for the entire landscape. Tradeoffs between average harvest volume and average available habitat for each species can be assessed for the life of the management plan (table 3). Flows of habitat can be examined as well (fig. 4). Flows of habitat are important to avoid "boom-and-bust" cycles of habitat and species populations. AAHU values do not address potential changes in habitat availability over the life of the management plan.

## Advantages of Integrating HEP and LMS

Implementing the HEP calculations in LMS provided several advantages. First, because an empirical growth model is used, all assumptions are held constant for all forest

**Table 2**—HSI and harvest volume (m.b.f.) values and top five pathways for individual pathway simulations using young dense stand.

| | Hawk | Vole | Woodpecker | Towhee | Harvest volume |
|---|---|---|---|---|---|
| Max | 0.614 | 0.968 | 0.651 | 0.078 | 260 |
| Min | 0.200 | 0.580 | 0.112 | 0.012 | 0 |
| Average | 0.383 | 0.863 | 0.486 | 0.024 | 96 |
| **Top five pathways** | | | | | |
| | Barbour15-150 | Barbour30-250 | YSTD-Light | Hansen0-40 | Hansen0-80 |
| | Barbour30-150HL | YSTD-Light | BarbourNT | CC40_PCT | McComb_CC |
| | Barbour30-75 | BarbourNT | Hansen0-120 | CC60_PCT_CT | CC80_PCT_2CT |
| | Barbour15-75 | Hansen0-120 | Barbour30-250 | Hansen0-80 | CC40_PCT |
| | Barbour30-150 | CareyBDPS | 0_NA | CC80_PCT_2CT | Hansen0-40 |

**Table 3**—Comparison of annual harvested volumes (mbf/yr) to percent changes in wildlife habitat over an 80-year simulation (bold = maximum, *italics = minimum*).

| | Annual harvest | Cooper's hawk | | Southern red-backed vole | | Pileated woodpecker | | Spotted towhee | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2038 | 2078 | 2038 | 2078 | 2038 | 2078 | 2038 | 2078 |
| | *mbf/yr* | *Percent* | | | | | | | |
| 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 |

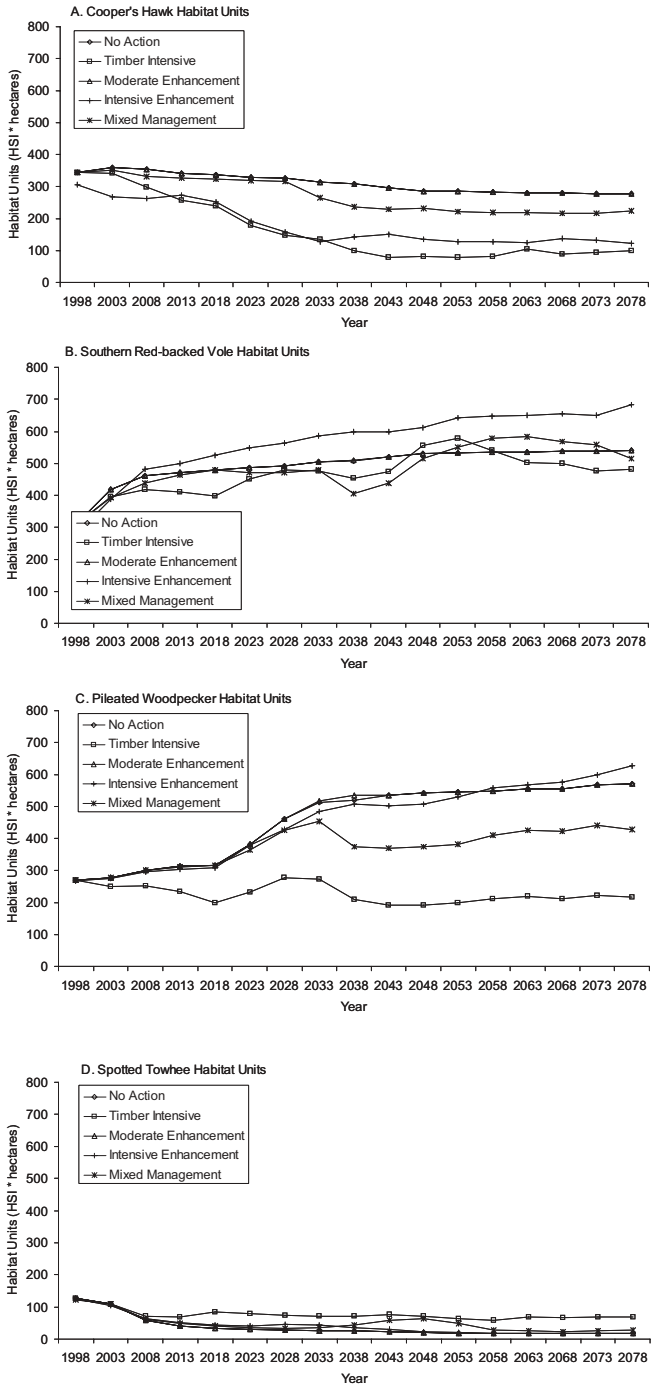


**Figure 4**—Flows of habitat for four species under five management alternatives

growth simulations, allowing alternatives to be compared without bias. Also, with the HSI models hard-coded into the Satsop HEP module, any bias in HSI model application is held constant as well.

Using stand-by-stand forest inventory, compared to cover type averages, allows the variability within each cover type to be included in the analysis. Cover type classification rules allow a wide range of tree sizes and canopy closures within each cover type. Selecting only cover type average attribute values, instead of stand-level forest inventory data, may neglect variability and result in lower habitat quality estimations.

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. Working at the stand level, several alternative silvicultural pathways can be compared to assess potential benefits. Using hypothesis-testing framework, pathways can be selected that may closely meet management goals in the present and the future, before they are applied on forest landscapes.

Many other analyses are available to the user of LMS. More 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 and other measures such as carbon sequestration and stand structures.

Other assessments include landscape-level 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. These visualizations are especially important when some parties involved in planning have backgrounds other than forestry and therefore do not understand standard forestry metrics such as volume, tree sizes, and stand structures, allowing managers to communicate forest changes caused by forest management activities.

## Limitations of Integrating HEP and LMS

This approach also has several limitations. A primary limitation is the HSI models themselves. All models used in this study are knowledge-based (expert opinion) models designed for the entire ranges of the Cooper's hawk, pileated woodpecker, southern red-backed vole, and spotted towhee. The primary weakness of these models is lack of validation and local calibration. None of the HSI models used were validated using data to assess their performance prior to use in the original Satsop Forest HEP. Results from the HSI models and HEP may not actually reflect actual habitat use for the species in southwestern Washington without validation and calibration to local habitat uses.

Because understory, snag, and downed wood data are needed for calculating HSI values for all models used in this study, with the exception of Cooper's hawk, the applicability of these models is limited to the Satsop Forest ownership. Applying these models elsewhere would require collection of the appropriate understory, snag, and downed wood 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 and others 1998; Van Pelt and Franklin 2000). Relationships have been developed into models for other regions of the Pacific Northwest (McPherson 1992; Klinka and others 1996; Mitchell and Popovich 1997), but none were found for southwestern Washington. Forest inventory that is limited to tree measures will have little success in estimating wildlife habitat using the Satsop Forest HEP module of LMS because both the spotted towhee and southern red-backed vole require understory metrics as well as tree metrics. Development of understory models for other regions demonstrates 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. A snag and downed wood model is scheduled to be included in future versions 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 and accuracy.

Spatial arrangement and size of habitat patches are important for some species. Pileated woodpeckers need a home range of up to 600 acres (Schroeder 1983). In the case of Satsop Forest, with an average polygon (habitat patch) size of 5.2 acres, the ability to arrange harvest activities, in 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 600 acres 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 3.5 acres (Allen 1983).

## Conclusion

This study provide the conceptual process of linking forest growth models with wildlife habitat models within a simulation system that brings many advantages over the old process of separate habitat and forest growth simulations but also many limitations. Given the limitations of the HEP within LMS and the variability between growth model outputs and actual tree and stand growth, this system should be used in an adaptive management context. Ensuring stands are developing on the desired trajectory will require managers to revisit the results after several years to verify that silvicultural pathways are providing the desired results. If the silvicultural pathways are not producing the desired results, silvicultural pathways and assessment tools can be adjusted to produce the needed forest outputs.

HSI models used in this study, which are limited by their lack of verification and validation, do not provide estimates of actual species populations, only measures of potential habitat quality and quantity. Thus, if population estimates are required, managers will need to perform field surveys 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. Alternatively, if the models are found to be completely inadequate and better models are constructed, these models can be implemented within LMS to expand and refine the wildlife habitat analysis capabilities of LMS.

Even with the limitations of the HEP within LMS, using this type of simulation system in a gaming context will allow people to gain valuable insights into tradeoffs of various forest outputs under many potential forest management plans with all assumptions being held constant for all analyses. Even though results of the models may only be an abstract representation of reality, relative differences between the outputs of compared silvicultural pathways can be examined. Comparing these differences for a large array of management objectives between many alternatives developed using LMS will help to avoid unintended consequences of forest management plans.

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