Silvicultural Approaches to Develop Northern Spotted Owl Nesting Sites, Central Coast Ranges, Oregon

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ABSTRACT: *The life-history requirements of northern spotted owls (*Strix occidentalis caurina*), a federally listed "threatened" species, are associated with late-successional habitats. Nesting sites are an important habitat requirement for spotted owls. We used an individual-tree, distance-independent growth model to explore a range of management scenarios for young Douglas-fir stands (age class 50 years) and estimated which scenarios promoted the development of forest patches that emulate the species mix and diameter distributions at known spotted owl nest sites in the central Coast Ranges of Oregon. Our modeling indicates that without silvicultural intervention or natural disturbances, the young stands (170–247 trees/ac) investigated did not develop features associated with spotted owl nest sites within 160-year total stand age. Silvicultural simulations that modeled heavy thinnings at ages 50 and 80 years, followed by tree-planting and additional thinnings developed forest patches structurally similar to our sample of spotted owl nest sites. We infer that silvicultural activities in federally managed, late-successional reserves may need to include alternatives beyond the scope of those permitted under current land use guidelines to accelerate the development of stand structures that better meet the nesting site requirements of spotted owls.* *West. J. Appl. For. 20(1):13–27.*

Key Words: Forest thinning, old-growth, stand structure, wildlife habitat, young stands.

A variety of approaches for managing second-growth Douglas-fir (*Pseudotsuga menziesii*) stands are being implemented to meet multiple land-use objectives (Carey et al. 1999a). One objective is to promote forest structures that meet the life-history requirements of wildlife. Accelerating the development of within-stand features used by wildlife is an important consideration for land managers (McComb et al. 1993, O'Hara 1998, Carey et al. 1999a).

The life-history requirements of northern spotted owls (*Strix occidentalis caurina*) became a public policy concern when the subspecies was designated federally as "threatened" in 1990 under the Endangered Species Act (1973) (Anderson et al. 1990). Northern spotted owls (hereafter, spotted owls) select late-successional forest (forest >80 years), particularly old-growth forest (>200 years), for roosting, foraging, dispersal, and nesting (Forsman et al. 1984, Carey et al. 1990). Individual spotted owls are most fit when the habitat features needed to meet all life-history requirements are available in sufficient quantity and quality within a home range (Thomas et al. 1990). Spotted owl home ranges span several spatial scales. Spotted owl habitat requirements are hierarchal and can be analyzed at each scale or across scales (McComb et al. 2002).

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Land management activities impact the habitats used by spotted owls. In the central Coast Ranges of Oregon, management has converted much of the forest cover to a matrix of early-seral stands, reducing the amount of late-successional forest available to spotted owls (Ripple et al. 2000). Conservation strategies for spotted owls include maintaining late-successional forests while recruiting additional habitat through stand succession and silvicultural treatments. An important aspect of these efforts is the management of young-growth forests to accelerate the development of forest structures suitable as spotted owl habitat (USDA Forest Service and US Department of the Interior 1994). Silvicultural systems may be designed to promote structural features (a range of tree-diameter classes, potential nest structures, and multiple canopy layers) that contribute to the maintenance of spotted owls (McComb et al. 1993, O'Hara 1998, Hershey et al. 1998). Several studies have been conducted and/or are ongoing that deal with wildlife responses to silvicultural manipulation at multiple spatial scales (Carey et al. 1999a, Lehmkuhl et al. 1999).

Growth models can be used to predict the structural attributes of forest stands under different silvicultural regimes (Barbour et al. 1997). Projections of future stand conditions can be used to estimate the utility of management activities in developing structural features that fulfill the habitat requirements of spotted owls. The success of a silvicultural simulation scenario in meeting management objectives can be measured by using multiple indices and scales (McComb et al. 1993, Hansen et al. 1995a, McComb et al. 2002). Characterizing the outcome of alternative management strategies is a key element of adaptive ecosystem management (USDA Forest Service and US Department of the Interior 1994).

Many different structural attributes are associated with suitable spotted owl habitat. Owls require roosting, foraging, dispersal, and nesting habitat to meet their life-history requirements. Different management approaches are being considered to meet specific aspects of spotted owl biology. Each life-history requirement needs to be examined before managers can holistically address silvicultural methods for maintaining and developing habitat. We chose to restrict the scope of our examination to the potential of different silvicultural approaches applied to young stands (age class 50 years) to develop stand structures similar to owl nesting sites. We hypothesized that the structural features that emulate spotted owl nesting sites could be developed more quickly through active management than by forest succession.

We modeled young stands in growth simulations using 32 different silvicultural treatment scenarios representing a range of broadly applicable approaches under the land-use allocations of the Northwest Forest Plan (USDA Forest Service and US Department of the Interior 1994). Treatment objectives ranged from an emphasis on wood fiber production to developing structural complexity similar to naturally developing old-growth forests. We evaluated the outcome of each treatment to determine which if any appeared to hasten the development of forest structures that emulate spotted owl nest sites (the immediate vicinity around known spotted owl nests) compared to a no-treatment scenario. Using silvicultural modeling, we applied standardized prescriptions to three young stands representing a range of different species compositions, diameter distributions, and stocking levels (Appendix A, Figures 1 and 2). We took a set of estimated variables from the growth modeling for use as gross indices of a suite of structural attributes associated with a sample of known spotted owl nesting sites in the central Coast Ranges of Oregon. We tested our hypothesis by estimating the effectiveness of each treatment in developing the features of known spotted owl nest sites using: (1) predictions of potential spotted owl nest structure availability; (2) an index of similarity to spotted owl nest sites; and (3) a ranking approach to identify those simulations that produced structures that most closely approximated nest sites.

Study Area and Methods

We collected data for this project during a demography and habitat associations study of spotted owls on the Eugene

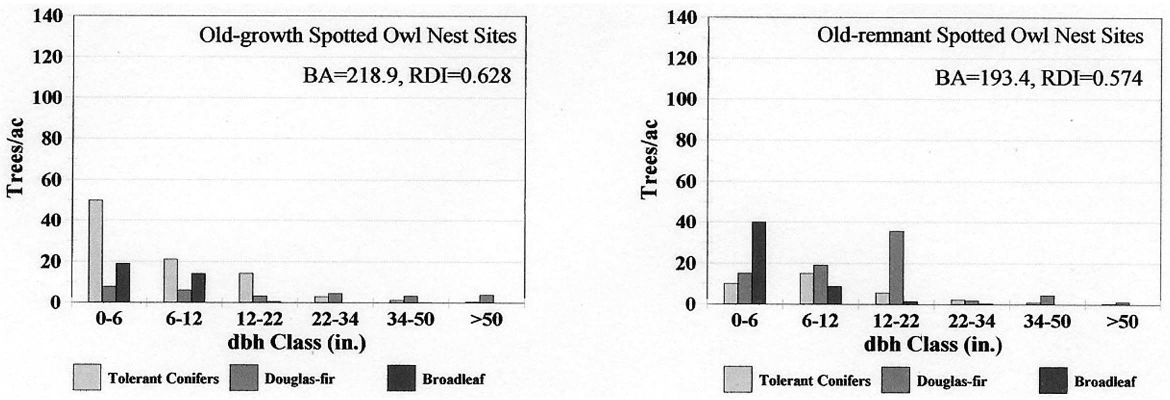

Figure 1. Target stand conditions of old-growth and old remnant spotted owl nest sites used in young Douglas-fir stand development simulations under 32 different scenarios for the central Coast Ranges, Oregon. Relative density index calculations are based on the methods reported in Hann and Wang (1990) and incorporated into the ORGANON version 6.0 model.

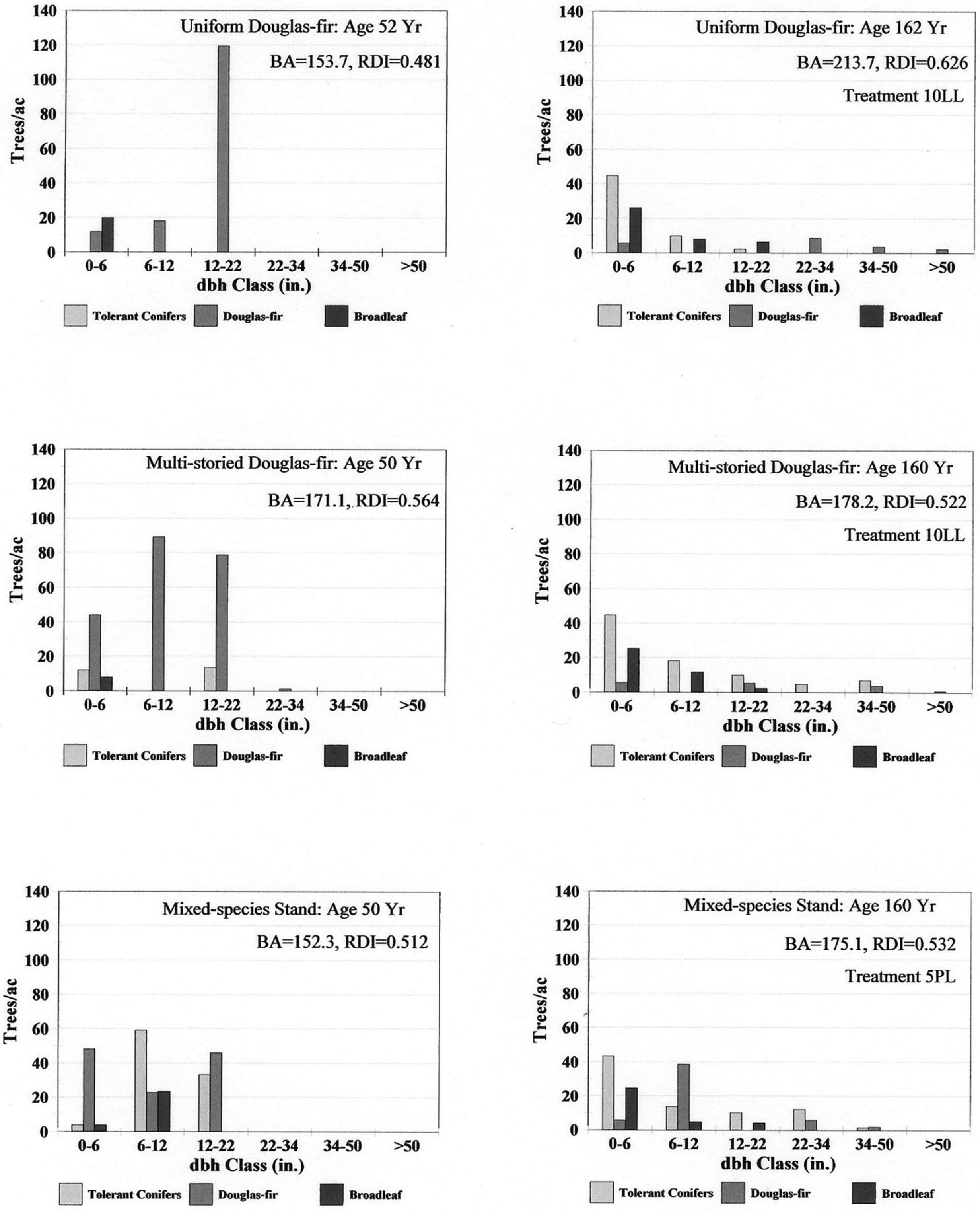

Figure 2. Initial young Douglas-fir stand structure and projected stand structure under the treatment scenarios that most nearly emulated target stand conditions of known old-growth and old remnant spotted owl nest sites in the central Coast Ranges, Oregon.

District of the Bureau of Land Management (BLM), central Coast Ranges, Oregon (1990–1995). The 577-mi^2 study area is a checkerboard pattern of alternating mi^2 sections of BLM and other ownerships. Topography is dissected deeply, with elevations ranging from 400 to 2,900 ft. The study area is within the *Tsuga heterophylla* vegetation zone, where forest stands are composed primarily of Douglas-fir and western hemlock (Franklin and Dyrness 1973).

Table 1. Classification scheme for five forest cover types used in young stand growth simulations and comparisons, central Coast Range, Oregon. Landscape mapping was based on the interpretation of 1:12,000 scale aerial photos taken in 1990.

Young (Y): Overstory composed mostly of conifers 5–21 in. dbh. These stands were used for stand growth simulations and outcome classification.

Mature-young (MY): Mostly conifers 5–12 in. dbh with 4–15 conifers/ac that were 21–34 in. dbh. A small element of conifers >34 in. dbh might be present. These stands were used for ingrowth estimation and outcome classification.

Mature (MA): Stands with >15 conifers/ac that were 21–34 in. dbh. A small element of conifers >34 in. dbh might be present. These stands were used for ingrowth estimation and outcome classification.

Old remnant (OR): Stands composed mostly of conifers 5–21 in. dbh with 1–9 conifers/ac that were >34 in. dbh. A small element of legacy conifers 21–34 in. might be present. These stands were produced by fire and selective timber harvest that left some large remnant legacy structures to be carried over into the regenerating stand. These stands were used for outcome classification.

Old-growth (OG): Patches with >9 conifers/ac that were >34 in. dbh. A small element of conifers 21–34 in. dbh might be present. These stands typically have multi-layered canopies, multiple tree species, large diameter snags and down woody materials. These stands were used for outcome classification.

Late-successional forests accounted for approximately 63% of the land cover in the study area prior to mid-19th century settlement of the region (Ripple et al. 2000). As of 1990, 19% of this landscape was composed of late-successional forest embedded within a matrix of early-successional forest in which 29% of the landscape was represented by young stands. Young stands in our sample are primarily even-aged conifers between 35 and 60 years (average dbh <21 in.), with single-storied canopies, and little regeneration in the understory (Appendix A, Table A1) (Tappeiner et al. 1997). Young stands may be suitable as dispersal and foraging habitat for spotted owls. However, they usually lack the structural attributes (a range of tree diameters, multistoried canopies, large trees/snags) associated with nesting sites (Forsman et al. 1984). Young stands are good candidates for exploring silvicultural manipulations relative to the development of nesting sites because this forest type is abundant and spotted owls are generally absent (Hershey et al. 1998).

Stand Typing

Stereoscope interpretation of natural color aerial photographs (1:12,000 scale; 1990) were used to produce an eight-stand-type (also referred to as covertype) map of the study area (Thrailkill and Meslow 1990, Thrailkill et al. 1998, Perkins 2000). Stand types represent a simplified method of characterizing different structures, ages, and/or species mixes of forest patches. This method provides a gross but useful surrogate for categorizing stands with different structural features. Forest stand-typing based on live tree aggregations are easily extended to growth and yield modeling. We used five of the eight stand types in our modeling comparisons: young, mature-over-young (MY), mature (MA), old-remnant (OR), and old-growth (OG) (Table 1).

Within Stand Measurements

Ten stands were selected from each of five stand types for ground truth validation using a prospective, stratified, random sample with equal allocation. All stands measured were >12 ac and <700 ft from an access road. In each sample stand, five plots were systematically laid out at 165- or 330-ft intervals (depending on stand size). Measurements were collected using 0.05-ac fixed-radius plots to sample trees <6 in. dbh. A prism with a basal area factor (BAF) of 40 was used to sample trees ≥6 in. dbh. Species and dbh were recorded for all small trees within the fixed-radius and variable-radius plots. Height and crown ratio were recorded for a subsample of trees (Bell and Dilworth 1988). Plot data from the validation examinations of young stands was used for modeling in ORGANON-Southwest Oregon Version 6.0, an individual-tree, distance-independent growth model (Hann et al. 1997). Individual young stands were used; i.e., we did not average stand attributes among the different young stands. Single plots centered at the nest tree were used for measurements in old-growth (OGN) ($n = 41$) and old remnant (ORN) ($n = 8$) nest sites using the same plot design as in the validation stand examinations (Thrailkill et al. 1998) (Appendix A, Figure 1).

Stand Treatment Models

We followed three preliminary steps in developing our treatment simulations:

1. Stand selection: ordination techniques were used to identify groups of young stands with similar species composition or structure; we then selected a single representative stand from each group.
2. Ingrowth: we developed ingrowth schedules for managed and unmanaged stands.
3. Potential spotted owl nest structures (PN): using tree/snag diameters, we developed a model to predict the per-acre density of potential spotted owl nest structures in each stand.

A complete summary of our approach in these three steps is outlined in Appendix B.

We used ORGANON to simulate a collection of stand management scenarios for each young stand. We evaluated our results in two ways:

1. Stand Structure: using multivariate methods, we compared projected stand structures to spotted owl nest sites.
2. Number of potential nest structures: based on tree diameter we used the predictive model to evaluate the success of each treatment scenario in developing large trees/snags that might be available as spotted owl nest structures.

Table 2. Description of approaches developed for the young stand modeling simulations using three part treatment codes for silvicultural modeling.[a] Generalized harvest guidelines at 50 and 80 years (Treatments 1 to 8) meet REO (Knowles 1996) standards for Late-successional Reserves: (1) prioritize the removal of Douglas-fir, (2) secondarily thin western hemlock when Douglas-fir management alone is insufficient to meet basal area retention targets, and (3) retain hardwoods.

Basal area (BA) based cut guidelines
- Treatment 1—no treatment
- Treatment 2—thin to 125 ft^2 BA/ac retention at 50 years; plant 120 mixed species trees/ac.
- Treatment 3—thin to 125 ft^2 BA/ac retention at 50 years; plant 120 mixed species trees/ac; at 80 years regeneration retaining the single largest tree and stems <6 in. dbh on 0.5 ac and thin from below to 135 ft^2/ac retention on the other 0.5 ac; plant with 180 Douglas-fir/ac.
- Treatment 4—thin to 125 ft^2 BA/ac retention at 50 years; plant 120 mixed species trees/ac; regeneration at 80 years retaining the two largest trees/ac; plant with 180 Douglas-fir/ac.
- Treatment 5—thin to 125 ft^2 BA/ac retention at 50 years; plant 120 mixed species trees/ac; 60 ft^2 BA/ac retention at 80 years; plant with 180 Douglas-fir/ac.
- Treatment 6—thin to 125 ft^2 BA/ac retention at 50 years; plant 120 mixed species trees/ac; 115 ft^2 BA/ac retention at 80 years; plant with 180 Douglas-fir/ac.
- Treatment 7—thin to 125 ft^2 BA/ac retention at 50 years; plant 120 mixed species trees/ac; 135 ft^2 BA/ac retention at 80 years; plant with 180 Douglas-fir/ac.
- Treatment 8—thin to 125 ft^2 BA/ac retention at 50 years; plant 120 mixed species trees/ac; 30 ft^2 BA/ac retention at 80 years; plant with 180 Douglas-fir/ac.
- Treatment 9—thin to 25 ft^2 BA/ac retention at 50 years; plant w/180 Douglas-fir/ac.
- Treatment 10—thin to 25 ft^2 BA/ac retention at 50 years; plant w/160 mixed species trees/ac.

Method of cut guidelines at 80 years
- Treatment A: thin from above at 80 years.
- Treatment B: thin from below at 80 years.
- Treatment H: no thinning at 80 years.
- Treatment L: thin 50% of trees <6 in. dbh at 80 years.
- Treatment P: thin proportionally at 80 years.
- Treatment R: regeneration cut at 80 years.
- Treatment X: patch cut (0.5 ac thinned to 135 BA and 0.5 ac clearcut with one leave tree) at 80 years.

Projected at 120 years stocking level target cut guidelines
- Treatment H: no cut at 120 years.
- Treatment L: thin proportionally to 100 ft^2 BA/ac at 120 years.

[a] Example: Treatment 6 A L =
- thin to 125 ft^2 BA/ac retention at 50 years; plant 120 mixed species trees/ac. Thin at 80 years leaving 115 ft^2 BA/ac retention; plant with 180 Douglas-fir/ac.
- thin from above at 80 years.
- thin proportionally to 100 ft^2 BA/ac at 120 years.

We identified the treatments that most nearly approximated spotted owl nest sites using our projections of stand structures, comparisons with spotted owl nest sites, and estimates of the number of future PN structures per ac for each of the modeled young stand types.

Treatments

Treatments simulated different schedules, approaches, and intensities of timber harvesting. These approaches were intended to cover a range of alternatives that would be applicable for different land uses, objectives, and/or ownerships. The treatments were not designed specifically to develop spotted owl nesting sites but were meant to compare the outcomes of silvicultural simulations to known spotted owl nesting sites in a heuristic manner.

Each simulation was treated as independent in a repeated-measures design (Hansen et al. 1995b). The treatment simulations used a 50-year site index of 125 (King 1966) to standardize growth rates. Tree-planting in the understory was modeled for different stand types/treatment regimes. Ingrowth to simulate natural regeneration was introduced in a range of species mixes and stocking densities. To better correlate the attributes of understory trees with overstory trees, thinning simulations were based on several levels of basal-area retention (Acker 1995). Stand management and growth was modeled to age class 160 years.

Treatment simulations presented alternative management scenarios at different stand ages (Table 2):

1. 50 Years: a no-treatment approach and two different levels of thinning from below retaining either 25 ft^2/ac (30–45 trees) or 125 ft^2/ac (126–149 trees) were simulated.
2. 80 Years: a second series of thinnings, a group selection, and a regeneration cut were modeled. In the thinning simulations, we used retention targets of 30 ft^2/ac (30–31 trees), 60 ft^2/ac (59–157 trees), 115 ft^2/ac (116–183 trees), and 135 ft^2/ac (144–195 trees). Thinnings were conducted from above, below, or proportionally. Proportional cuts were conducted across species and diameter classes. In stands that had been thinned to 25 ft^2/ac at 50 years, one-half of the small diameter trees <6 in. dbh were removed. Additionally, a 1-ac harvest was modeled as a group selection in which one-half was regenerated by clearcutting (with one leave tree per 0.5 ac) and the one-half thinned from below to 135 ft^2/ac.
3. 120 Years: a third series of proportional thinnings (to 100 ft^2/ac retention) was modeled. Stand development with ongoing ingrowth was then simulated to age class 160 years.

Table 3. Rank classification for modeling simulation outcomes. A rank of 0 is the most similar and a rank of 8 is the least similar to old-growth spotted owl nesting sites in the central Coast Ranges, Oregon (see Table 2 for stand type descriptions).

Rank	Classification criteria
0	OGN[a] or ORN[b] are nearest or next nearest to simulation outcome and are, on average, within 1.5 squared standard deviations of each variable (18 variables*$1.5^2 \cong 40$ Euclidean Distance [ED]) for both OGN and ORN.
1	ORN is nearest to the simulation outcome and within 40 ED of OGN sites.
2	OGN or ORN are not the most similar stand types but the simulation outcome is within 40 ED of OGN sites.
3	ORN is nearest or next nearest to simulation outcome but >40 ED from OGN sites.
4	OG[c] is nearest to simulation outcome and within 40 ED of ORN sites.
5	OR is nearest to simulation outcome and within 40 ED of ORN sites.
6	MA or MY is nearest to simulation outcome, OR is next nearest and within 40 ED of ORN sites.
7	MA or Y is the nearest to simulation outcome.
8	Unclassified—no stand type is within 40 ED.

[a] OGN, spotted owl nest sites in old-growth stands.

[b] ORN, spotted owl nest sites in old-remnant stands.

Treatment Classification and Selection

After modeling the representative stands to an approximate age class of 160 years, we calculated the Euclidean Distance (ED, a similarity index) of all simulations to the average of the different types of stands and spotted owl nest sites (Manly 1986). This comparison used a simple methodology in which different species mixes and diameter distributions served as indicators of commonly associated structural features, e.g., successional stage, amounts of downed woody material, and decadence. ORGANON cannot model spatial heterogeneity. We compared treatment outcomes by using the frequency of stems in six diameter classes (≤6, 6–12, 12–22, 22–34, 34–50, and >50 in.) for three tree types (tolerant conifers, intolerant conifers, and broadleaf trees). We classified the results of the stand-growth simulations using the sum of the standardized multivariate distances, representing no more than a 1.5^2 standard deviation per variable (an ED of approximately 40.0), relative to the seven reference stand categories (Table 3). We evaluated the success of each stand simulation in developing suitable nest-site structures based on the percentage of similarity in ED from nesting sites (100-%ED; using the stand/treatment with the greatest ED as the denominator in the percentage calculations) (Table 4).

We categorized nest sites as OGN or ORN. ORN sites had experienced a major disturbance since the settlement of the central Oregon Coast Ranges in the mid-19th century, usually as a result of logging, fire, or both. OGN sites appeared to have had no recent coarse scale disturbance. We then compared the estimated PN structures and difference in percentage ED to the outcomes of our treatment simulations relative to OGN and ORN sites. Ranking was used to select the treatment simulation that most nearly emulated owl nest sites for each young stand type (McComb et al. 1993). The treatments that had the greatest number of potential nest structures and the lowest rank to nest sites were selected as the preferred scenarios (Table 5).

Modeling

Nest site measured plots were centered at the nest structure. This could introduce a bias in the number of large-diameter stems that were counted in the variable radius plots. We may have overestimated the number of large trees present in the nest stands (Bias and Gutierrez 1992). However, the ORGANON model underestimates tree mortality from causes other than intertree competition, such as insects, disease, windthrow, and stem breakage (Tappeiner et al. 1997). These two factors may have helped counterbalance one another.

We used ORGANON-Southwest Oregon Version 6.0 for the species mixture found in our sample. We substituted incense cedar (*Calocedrus decurrens*) for western redcedar (*Thuja plicata*) and bigleaf maple (*Acer macrophyllum*) for red alder (*Alnus rubra*) (David Hann, Oregon State Univ., May 1998). The southwestern Oregon version of the ORGANON model was developed by using uniform-aged stands predominated by few species. The wide range of treatments we applied in our modeling has not been validated. This introduces additional uncertainty to the outcomes of our modeling that needs to be taken into account when considering our conclusions. We felt that this approach was valid given the exploratory nature of our modeling and comparisons but would not be suitable for economic valuation of the simulation outcomes (Hann 1998). The ORGANON model will extrapolate results beyond 120 years. We modeled our stands up to approximately 160 years of age. We felt that this time frame did not seriously violate the assumptions of the ORGANON model (Hann 1998).

Different rates of ingrowth were used to model the development of the Douglas-fir-dominated and the mixed-species young stands. The density of overstory trees changed dramatically between some treatments. The levels of treatment in our modeled stands would, in practice, produce a wider range of stocking densities than we attempted to simulate.

Many of the structural attributes of forest stands cannot be directly modeled using ORGANON. We used diameter distributions, tree densities, and species mixes at spotted owl nesting sites as a gross means of approximating stand features. We felt that this method was appropriate given that dbh (or its standard deviation) in relation to the density of large-diameter trees can be used to differentiate age classes

Table 4. Percent similarity (100-%ED) to old-growth spotted owl nesting sites and rank of young stand simulations by management scenario and applicable Land-use Allocation under the Northwest Forest Plan (1994) (see Table 2 for treatment descriptions). The treatments nearest (lowest rank) to spotted owl nest sites with the greatest number of potential nest trees were considered to most nearly emulate the structural attributes of the spotted owl nesting sites used in our comparisons (see Table 3 for ranking descriptions). Ranks 0 to 2 are considered potentially suitable, ranks 3 to 5 marginal, and ranks 6 to 8 unsuitable as nesting sites.

Uniform Douglas-fir				Multi-storied Douglas-fir				Mixed-species			
Trt[a]	100-%ED	Rank	LUA[b]	Trt	100-%ED	Rank	LUA	Trt	100-%ED	Rank	LUA
10LL	57.3	2	F[c]	10LL	58.2	0	F	5PL	52.2	1	F
10LH	52.7	2	F	10LH	49.7	0	F	6PL	47.8	1	F
6BL	43.4	2	F	7BH	46.0	0	L[d]	10LL	47.3	1	F
5AL	42.0	2	F	5PL	47.4	1	F	6BL	46.2	1	F
6AL	40.8	2	F	8PL	46.3	1	F	7PL	46.3	1	F
2HH	17.6	3	L	7PL	45.7	1	F	7BL	45.6	1	F
3XL	30.7	5	F	5PH	44.4	1	F	5PH	49.2	2	F
6PL	40.6	6	F	8PH	42.9	1	F	5AL	44.9	2	F
7AL	39.7	6	F	3XH	52.3	2	F	7AL	43.2	2	F
7BL	39.6	6	F	5AL	48.5	2	F	6AL	43.1	2	F
5BL	37.4	6	F	10HH	47.5	2	F	8PL	38.4	3	F
7PL	36.9	6	F	6BL	46.2	2	F	8PH	36.5	3	F
5PL	35.8	6	F	7BL	45.8	2	F	9LL	34.6	3	F
5PH	35.5	6	F	6PL	45.5	2	F	6PH	38.5	6	F
9LL	22.4	6	F	6AL	42.7	2	F	5BL	37.4	6	F
8PL	17.8	6	F	2HH	39.6	3	L	5BH	32.9	6	F
8PH	14.6	6	F	1HH	27.9	3	L	9HH	18.3	6	F
1HH	12.9	6	L	5BL	49.1	5	F	10LH	37.8	7	F
9HH	6.7	6	F	3XL	35.1	5	F	10HH	36.6	7	F
5BH	28.4	7	F	6PH	40.7	6	F	3XL	35.9	7	F
7AH	27.2	7	F	7AL	39.1	6	F	5AH	35.6	7	F
6AH	26.8	7	F	9LL	37.2	6	F	6BH	35.1	7	L
6PH	25.9	7	F	9LH	35.2	6	F	7PH	34.9	7	F
7PH	25.0	7	F	9HH	30.7	6	F	7BH	33.5	7	L
5AH	24.5	7	F	5BH	44.1	7	L	7AH	31.3	7	F
10HH	23.8	7	F	5BH	40.5	7	F	1HH	30.4	7	L
3XH	23.5	7	F	7PH	38.9	7	F	3XH	29.7	7	F
6BH	23.0	7	L	6AH	32.4	7	F	4RH	28.1	7	F
7BH	21.2	7	L	5AH	28.6	7	F	2HH	24.4	7	L
4RH	18.6	7	F	4RH	24.9	7	F	4RL	23.3	7	F
9LH	14.4	7	F	7AH	23.0	7	F	6AH	30.1	8	F
4RL	9.9	7	F	4RL	16.6	7	F	9LH	21.0	8	F

[a] Trt, Treatment.
[b] LUA, Land-use Allocation.
[c] F, Forest Matrix.
[d] L, Late-successional Reserve.

and that age is loosely correlated to numerous structural attributes (Carey et al. 1991, Spies and Franklin 1991).

In some treatment scenarios, we modeled understory tree regeneration (natural and/or tree-planting) into stands that were very dense. We were aware that regeneration, particularly Douglas-fir, would not release under several of the modeled regimes. ORGANON mortality estimates removed excess stocking where modeled levels of ingrowth may have been too high. We believe this evened out stem recruitment to a realistic rate at each level of overstory density, allowing the use of generalized ingrowth schedules that standardized our modeling.

In our modeling, the largest trees were retained in the heaviest thinnings conducted from below, while proportional thinning or thinning from above retained smaller diameter trees. When simulations modeled low thinning we sought to retain trees with the smallest height-diameter (H/D) ratios to develop into legacy trees but we could not make this assumption where we modeled other thinning approaches. Experimental plot data indicates that there are substantial deviations in H/D predictions in distance independent growth models (Wilson and Oliver 2000). Consequently, we can only estimate the resistance that our simulated stands might have to wind snap and windthrow.

The condition of PN structures is a factor that we did not incorporate in our analysis. In the central Coast Ranges of Oregon, nesting by spotted owls has been shown to be associated with stands possessing a large component of trees with defect, particularly broken tops (Hershey et al. 1998). We used a simplifying model that only incorporated dbh to differentiate our sample of nest and unused trees. This simplification was necessary for our analysis since ORGANON version 6.0 does not predict the effects of wind or pathogens. However, we believe that the relationship of tree dbh to growth and time is an imperfect but useful surrogate for the development of decadent features such as

Table 5. Comparisons of final outcomes for each young stand type under a no treatment scenario (1HH) and the treatment simulation scenario (10LL or 5PL) that most nearly approximated the diameter distributions, species mix, and tree densities of spotted owl nesting sites in old-growth stands in the central Coast Ranges, Oregon (Table 4). Young stand growth simulations under a no treatment scenario produced fewer large diameter potential nest trees, and were less structurally diverse than the managed stand scenarios.

Stand	Treatment	Total ft^3/ac^a	Harvest ft^3/ac^a	Conifers/ ac $\leq$ 22 in.	Conifers/ ac > 22 in.	PNT^b/ ac > 44 in.	PNS^c/ ac > 44 in.
Uniform Douglas-fir, age = 162	1HH	23192	—	46.5	53.6	0.0	0.0
	10LL	16763	5857	63.1	15.3	4.0	0.0
Multi-storied Douglas-fir, age = 160	1HH	26202	—	51.9	52.0	1.0	0.4
	10LL	15946	7599	84.4	16.7	1.6	0.3
Mixed-species, age = 160	1HH	22032	—	103.2	77.7	0.0	0.4
	5PL	16188	7656	111.5	21.2	0.0	0.4

[a] Cumulative sums.
[b] Number of potential live nest trees.
[c] Number of potential nest snags.

broken tops, cavities, and platforms shown to be suitable substrates for spotted owl nests (Carey et al. 1999b). Mindful of the uncertainties associated with the assumptions of our model, we chose to be conservative and to limit our estimate of the number of potential nest structures to conifers ≥44 in. dbh.

Results

For each young stand type, the 32 simulations were categorized relative to their similarity to OGN sites (Table 3). The no-treatment option (1HH) did not generate stand structures that closely emulated spotted owl nesting sites. The multistoried Douglas-fir (100%ED = 27.92, rank = 3, PN/ac = 1.3) and the uniform Douglas-fir stands (100%ED = 12.89, rank = 6, PN/ac = 0.0) were most similar to MA stands when modeled using the no treatment scenario. The mixed- species stand was most similar to MY stands (100%ED = 30.35, rank = 7, PN/ac = 0.4) under the no-treatment simulation (Tables 4 and 5). Compared to ORN sites, the estimated structure for the uniform Douglas-fir stand in the no treatment option was most similar (100%ED = 53.97) while the multistoried Douglas-fir stand was more similar (100%ED = 53.38) than the mixed-species stand (100%ED = 25.24).

Treatment 10LL most closely emulated OGN (100%ED = 57.3, 58.2) and ORN sites (100%ED = 59.1, 64.6) for both the uniform Douglas-fir (rank = 2) and multistoried Douglas-fir stands (rank = 0), respectively (Figure 2; Tables 4 and 5). Treatment 10LL produced more PN structures in both stand types (4.0/ac for the uniform and 1.9/ac for the multistoried Douglas-fir stands). For the mixed-species stand, treatment 5PL (rank = 1) most closely emulated the structure of ORN (100%ED = 62.2) and OGN sites (100%ED = 52.1) with 0.4/ac PN structures produced by age class 160 years (Figure 2; Tables 4 and 5).

Several of our treatments produced stand structures that were very different from the sample of spotted owl nest sites. Treatment 9LH produced stand structures that were the least similar to OGN sites in the mixed-species stand (100%ED = 21.0, rank = 8, PN = 0.4). The estimated stand structure developed by the mixed-species stand when modeled using treatment 9LH was greater than 40 ED from any stand type used for comparison in our analysis and could not be classified (Tables 3 and 4). The projected structure of the uniform Douglas-fir stand using treatment 9LH ranked furthest from OGN sites (100%ED = 9.9, rank = 7, PN = 5.9) and was most similar to the MA stand type. Treatment 9LH produced structures that were more similar to ORN than OGN sites in the mixed-species (100%ED = 43.7) and the uniform Douglas-fir stands (100%ED = 41.3). For the multistoried Douglas-fir stand, treatment 4BL produced an estimated structure that was the least similar to OGN sites relative to all other treatment scenarios (100%ED = 16.6; rank = 7, PN = 1.2), and more like ORN sites (100%ED = 32.6) (Table 4). The structure developed in the multistoried Douglas-fir stand when modeling treatment 4BL was most similar to MY stands.

Discussion

Stand Development and Management

There is extensive literature that addresses managing young stands for habitat and silvicultural objectives. The integration of stand thinning into management scenarios that are patterned on natural disturbance and forest succession is a nascent approach in meeting both objectives. Franklin et al. (2002) formulated a model for forest succession in the Douglas-fir region. Succession is presented in terms of a series of stages that include: (A) lower tree canopy loss; (B) death and pruning of lower branch systems; (C) biomass accumulation; (D) density-dependent tree mortality; (E) mortality attributable to competition among tree life form/thinning mortality; (F) density-independent tree mortality; (G) mortality due to agents (such as wind, disease, or insects); (H) canopy gap initiation and expansion; (I) generation of coarse woody material (snags and logs); (J) uprooting; (K) ground and soil disruption as well as the creation of structures; (L) understory re-development; and (M) the initiation of shrub and herb layers.

Successional pathways that lead to old-growth forests in the Pacific Northwest appear to follow several courses, possibly reflecting regional variability (Spies and Franklin 1991). The growth rates of some older forests indicate slow regeneration over a long period with little tree-to-tree competition (Franklin et al. 1981, Tappeiner et al. 1997, Poage and Tappeiner 2002). Other old-growth forests appear to have developed from a relatively even-aged cohort that has undergone long-term ongoing suppression mortality, little understory regeneration of Douglas-fir, and episodic release of established tolerant conifers (Winter et al. 2002a, 2002b).

Stand management can, therefore, follow multiple routes that emulate natural processes to move dense young stands toward structures similar to old-growth forests. Some stages of forest succession may be shortened or side-stepped by moderate to heavy thinning in young stands. Thinning young stands can promote the development of characteristics Franklin et al. (2002) proposed for older forests: (1) the establishment of shade-tolerant tree species assuming the pioneer cohort is shade-intolerant species; (2) shade-patch (anti-gap) development; (3) maturation of pioneer tree cohort; (4) achievement of maximum height and crown spread; (5) canopy elaboration; (6) development of multilayered or continuous canopy through growth of shade-tolerant species into co-dominant canopy position; (7) re-establishment of lower branch systems on intolerant dominants; and (8) the development of large branches and branch systems.

Young, uniform stands can be diversified by early thinning (DeBell et al. 1997, Hayes et al. 1997, Carey et al. 1999a). Early commercial thinnings have been shown to be beneficial to the future development of understories, the promotion of natural regeneration, and in enhancing biodiversity (Muir et al. 2002). Overstory trees can develop deep canopies and large-diameter branches in open stands (McGuire et al. 1991). Low overstory density facilitates the establishment of understory trees (McGuire et al. 1991, Bailey and Tappeiner 1998, Miller and Emmingham 2001). Heavy thinnings may aid the establishment of understory conifers by reducing overstory competition as well as facilitating natural regeneration (Cole 1996, Chan et al. 2000). Silvicultural efforts in young stands <50 years old suggest the efficacy of early underplanting with mixed-species stock and density control in developing old-growth-like structures sooner than would develop naturally (Barbour et al. 1997, Hershey et al. 1998). Underplanting with a mixture of shade-tolerant conifers and hardwoods will promote structurally complex stands with greater vertical connectivity, particularly in stands lacking adequate shade-tolerant trees for midstory development (Tappeiner et al. 1992, McComb et al. 1993, Carey et al. 1999a). Many naturally regenerated old-growth stands in the Coast Ranges appear to have initially developed at low stocking densities (approximately 50 trees/ac) with gradual and ongoing ingrowth, probably owing to periodic and relatively intense wildfire events. Heavy thinnings in young stands could be used to promote the development of structures that emulate old-growth stands in the central Coast Ranges of Oregon (Tappeiner et al. 1997, Poage and Tappeiner 2002).

Thinning from below to higher densities than those observed by Tappeiner et al. (1997) also has produced stands with dominant overstories that are structurally similar to old-growth forests (Newton and Cole 1987). However, the crowns of retained trees rapidly fill canopy gaps developed through moderate thinnings, inhibiting understory establishment and growth (Hayes et al. 1997, Chan et al. 2000, Carey et al. 1999b). In many stands, multiple entries that thin both canopy layers may be required to optimize understory development when light or moderate thinning is applied (McComb et al. 1993, Carey et al. 1999a, Muir et al. 2002).

Although heavy thinnings might be helpful in the long-term to develop structures that emulate old-growth, there are short-term drawbacks to creating open stands. Heavily thinned stands may be difficult to regenerate as surface drying increases, the development of brush fields is promoted, and the site becomes subject to invasion by exotic plant species (Chan et al. 2000, Carey et al. 1999a, Thysell and Carey 1999). Brush control may be necessary and the survival of planted stock problematic (Curtis et al. 1998).

Windthrow will occur to some extent in most stands, both thinned and unthinned, during development (Tappeiner et al. 1992). Windthrow creates canopy gaps and supplies coarse woody materials as a fine-scale disturbance (Hayes et al. 1997). Heavy thinning of dense, developing young stands increases the potential for windthrow. If canopy loss due to windthrow is expected, it can be incorporated into silvicultural planning. Leave trees may be managed for wind snap/windthrow resistance by selecting trees with the lowest H/D ratios. Several entries can be used to thin stands in stages to reduce the potential for windthrow (Hayes et al. 1997, Carey et al. 1999a). Low H/D ratios can be promoted through maintaining low initial stocking densities and/or by early stand thinning (Wilson and Oliver 2000). Dominant trees in naturally developing old-growth stands in the central Coast Ranges exhibited a strong relationship between low stocking densities early in development and individual tree longevity (Poage and Tappeiner 2002).

The use of several different management scenarios, including a no-treatment option, should be considered for developing forest structures similar to old-growth stands. Even-aged stands have the capacity to diversify into structurally complex forests through succession with little or no management. Old-growth forests with deep-crowned trees have been shown to develop through self-thinning (Winter et al. 2002a, 2002b). Mechanical thinning can emulate self-thinning and may accelerate the development of old-growth forest structures.

Variable-density thinning offers a means of incorporating management approaches that emulate several natural pathways for promoting the development of structurally diverse stands. Variable-density thinning manages for structural heterogeneity. The distribution of overstory and understory trees is intended to be nonuniform. Variability in tree spacing and density produce a mosaic of structures within stands. Thinning intensity varies widely between no removal and gap formation (Carey et al. 1999a, Chan et al. 2000). This promotes the development of a patchwork where intermediate-canopy trees can be released and regeneration, including underplantings, is encouraged (Tappeiner et al. 1992, McComb et al. 1993, Curtis et al. 1998). Variable-density thinning is designed to maintain structurally diverse elements in managed stands. The objective is to promote biological diversity within the developing forest canopy and understory similar to that of older forests (Carey 1995, Franklin et al. 1997, Thysell and Carey 2001).

The mosaic produced by variable-density thinning emulates suppression mortality (light-thinning), fine-scale disturbance (heavy-thinning), and coarse-scale disturbance (patch cutting) within stands (McComb et al. 1993, Carey et al. 1999a). When multiple entries are used to accomplish these tasks, uniform crown closure can be prevented and the wind resistance of the residual stand improved (Carey et al. 1999a, Chan et al. 2000, Muir et al. 2002). Extended rotations can be used in conjunction with variable-density thinning to encourage the development of a wide range of tree diameters and vertical heterogeneity (Curtis et al. 1998, Thysell and Carey 2001).

Management Implications

Our treatment simulations presented a range of possible stand management alternatives and were illustrative of the potential structures that might be expected given the initial conditions in our modeled stands. The distribution of rank scores for the outcomes of the 32 standardized treatments used in the simulations indicated that the response of the three young stands was highly variable (Table 4). The mean rank of projected stand structures for the multistoried Douglas-fir stand ($\bar{x}$ = 3.78; SE = 0.466), was lower than either the mixed-species ($\bar{x}$ = 4.81; SE = 0.468) or the uniform Douglas-fir stand ($\bar{x}$ = 5.66; SE = 0.316) using the same suite of treatment simulations. As has been noted in other efforts, we found it difficult to alter the development trajectories of well-established young stands that were first managed at age class 50 years (Hanson et al. 1995b). Historic and current conditions must be taken into account when planning silvicultural treatments for young stands intended to promote the development of structures similar to spotted owl nesting sites.

Modeling management earlier in the development of natural stands would have promoted the growth of large trees with deep crowns, reduced overstory density to levels consistent with those of older forests, and lead to greater differentiation in the diameter distributions of the final treatment outcomes in a shorter time frame (Newton and Cole 1987, Carey and Johnson 1995, Poage and Tappeiner 2002). In practice, earlier thinning also would promote the development of a more open environment for understory diversification, including shrub layers (Curtis et al. 1998). In most of our models, we conducted a commercial thinning from below at 50 years to capture mortality of shade-intolerant Douglas-fir, to release shade-tolerant trees in the understory, and to calibrate our stands to compare the effects of the standardized thinnings we subsequently modeled. In this thinning and subsequent simulations, we modeled stand treatments that were consistent with the recommendations of several sources; we retained hardwoods, shade-tolerant conifers (whenever possible), and large-diameter Douglas-fir (Tappeiner et al. 1992, Carey and Johnson 1995, Knowles 1996).

We attempted to model management scenarios incorporating processes that emulated coarse- and fine-scale disturbances following the approaches discussed by McComb et al. (1993): single-story, few-storied, and many-storied stands. We did this by simulating management in three "pulses." At 50 years, we modeled thinning from below at light and very heavy intensities. At 80 years, we simulated thinning across a range of basal area retentions while thinning from above, below, or proportionally. At 120 years, we modeled a uniform proportional thinning (Table 1).

Thinning reduces the time frame in which young stands move through stages A to E in the succession model proposed by Franklin et al. (2002), and may help to promote biodiversity in managed stands (Carey et al. 1999a). In our simulations, heavy to moderate thinning with extended rotations appeared to promote the development of a diameter distribution and species mix of live trees that was similar to spotted owl nesting sites while shortening the duration of the least diverse (for wildlife) stage of stand development (Hayes et al. 1997, Curtis et al. 1998). The approaches in our modeling that most closely emulated the live tree diameter distributions and species mixes that characterized spotted owl nesting sites used heavy thinnings at age class 50 years that would have shortened the most intense period of intertree competition for light and space in the developing of young stands. Reducing the period of tree-to-tree competition, and understory suppression will decrease suppression mortality within young stands (Carey 1998). Provisions need to be made for the retention and production of snags and coarse woody material under these scenarios (Carey and Johnson 1995, Hayes et al. 1997, Curtis et al. 1998). The young stands in our modeling would probably require both the creation of snags and steps to retain or develop downed woody material.

Young-growth trees in low-density stands appear to have crown lengths and H/D ratios similar to old-growth trees (Poage 2001). Where young stands lack legacy structures, trees with the lowest H/D ratios, multiple large limbs, and potential for epicormic branching may be cultured to fill the niche occupied by legacy trees in stands experiencing natural disturbance (Tappeiner et al. 1992). We infer from our modeling that by heavily thinning stands at age class 50 years, legacy surrogates may develop quickly to diversify future stand structures. Leave trees retained during heavy thinnings of young stands that had lacked legacy trees would rapidly grow larger in the next rotation, eventually filling the roll of legacy trees. Trees cultured for legacies could be managed as a part of the living canopy or may alternatively be managed for large-diameter snags or coarse, woody material once they have reached the suitable size or form. Legacy trees have been shown to be important habitats for flying squirrels (*Glaucomys sabrinus*), a common prey item in the diet of spotted owls in the Coast Ranges of Oregon, and management for legacy tree development may improve conditions for this species (Forsman et al. 1984). Numerous spotted owl nesting sites have been associated with legacy trees in old-remnant stands in the central Coast Ranges (Thrailkill et al. 1998).

Under most scenarios (89%) the projected structure of the young stands better emulated the structural conditions found at spotted owl nest sites when modeled with management than without management. Generally, as the number of management entries increased, the simulation outcomes became more similar to the species mix/diameter distributions found at nest sites (Table 4). We infer from our modeling that management intervention can be considered as a tool to promote the development of structural complexity in young stands and that without silvicultural treatments or natural disturbances, considerable additional time may be needed to develop the structural features associated with spotted owl nest sites.

Late-successional Reserves (LSR) and Forest Matrix (FM) are categories of Land-use Allocations (LUA) under the Northwest Forest Plan (USDA Forest Service and US Department of the Interior 1994). LUA objectives bound the range of potential developmental pathways, influencing the future structure of forest stands and landscapes. Management guidelines are specific to each LUA, limiting the scope of permissible silvicultural activities. The outcome of silvicultural treatments in LSRs are of particular importance because they are intended to provide the foundation for the conservation of many wildlife species associated with late-successional forests, including spotted owls. Silvicultural activities designed to create late-successional habitat in LSRs are permitted in stands up to 80 years of age (USDA Forest Service and US Department of the Interior).

In our modeling, stands managed according to the Regional Ecosystem Office guidelines (Knowles 1996) for LSRs did not emulate spotted owl nesting sites within the time frame of our simulations (Table 4). Silvicultural treatments following the guidelines for LSRs were more effective in capturing mortality and reducing competition between residual trees than in developing the features of known spotted owl nesting sites in the central Coast Ranges of Oregon. It is unlikely that stands that are lacking tolerant conifers and hardwoods will quickly develop multistoried/multispecies canopies under the management guidelines for LSRs. Growth simulations that followed the guidelines for LSRs projected future stand structures that were most similar to mature forest within the time frame we modeled. In the Coast Ranges of Oregon, relatively few nest sites have been located in mature forest (Forsman et al. 1984, Thrailkill et al. 1998). In our modeling, silvicultural simulations not meeting the constraints for management in LSRs (Treatments 5PL and 10LL) produced stand structures that were more similar to spotted owl nest sites (Figures 1 and 2; Tables 3 and 4). We infer that silvicultural activities in LSRs may, in some cases, need to include alternatives beyond the scope of those permitted under the Regional Ecosystem Office guidelines to accelerate the development of stand structures that better meet the long-term nesting site needs of spotted owls. The results of our modeling is in agreement with the results of other modeling exercises directed at promoting the development of diverse structures in young stands (Carey et al. 1999c, Kintop 2003).

The simulations that produced within-stand structures that were the least similar to spotted owl nesting sites modeled regeneration harvests at either 50 (treatment 9HL) or 80 years (treatment 4BL). These simulations were intended to follow approaches that emphasize economic forest rotations. The modeling outcomes indicate that management for optimizing timber production might provide foraging and dispersal habitat but probably would not produce suitable nesting sites in the central Coast Ranges of Oregon (Table 4).

Longer simulated rotations may have changed the results of our modeling outcomes. Additional thinnings at the end of the simulations might have improved the structures of our modeled stands relative to known spotted owl nest sites located in old-growth stands. Even without additional management, and given a longer time frame, stands may have been developing along trajectories that would have eventually reordered the outcomes of our treatment comparisons.

No single approach appeared to have been the most effective in promoting the development of spotted owl nesting sites for all of our young stands, reflecting differences between initial structures at age class 50 years. However, there were several different approaches that produced stand structures that appeared to be suitable spotted owl nesting sites. Four treatments (10LL, 6BL, 5AL, and 6AL) projected the development of structures that emulate suitable spotted owl nesting sites in all three young stand types (Table 4). These four treatments may offer a generalized approach, applied singly or in tandem, for developing suitable spotted owl nesting sites in the central Coast Ranges of Oregon across a range of stand conditions. Although the ORGANON model was not developed to predict the development of stands managed under multiple regimes, it is robust enough to approximate projections of nontraditional management scenarios (Hann 1998).

The same rational could be applied to the treatments that appeared to best approximate spotted owl nest sites for a single stand type (Table 4). Multiple treatment scenarios could be incorporated into a suite of management options within a stand. Combinations of several treatment regimes applied during the same management pulses, in a manner analogous to variable-density thinnings, might produce structurally diverse stands with broad similarities to spotted owl nesting sites. For example, a combination of treatments 10LL (heavy, early thinning), 7BH (light, early thinning), 3XH (light, early thinning followed by gap creation mid-rotation) and 5PL (light, early thinning followed by moderate thinning mid-rotation) could be conducted in the multistoried young Douglas-fir stand. This approach would take better advantage of stand heterogeneity and unplanned disturbances (windthrow etc.) compared to a single uniform prescription.

Accelerating the development of multistoried stands may increase the risk of wildfire. Dense understories created by tree-planting could produce fuel loadings greater than would be expected in naturally developing stands. The treatments in our modeling that most closely emulated nesting sites included a proportional thinning at approximately 120 years that could be used to reduce fire hazards associated with ladder fuels. Intermediate treatments would need to include provisions for fuels management using controlled burning and/or slash disposal.

It is beyond the scope of this article to attempt to characterize the results of our treatment simulations in terms of developing habitat breadth (Carey 1998). Nesting sites are one component of the habitat requirements of spotted owls. The forest structure at spotted owl nesting sites may not provide for other life-history requirements of spotted owls. There are temporal and spatial tradeoffs in managing stands to better meet the life-history requirements of spotted owls in the central Coast Ranges of Oregon (Hayes et al. 1997). Some young stands present little inherent potential to rapidly develop the structural features associated with spotted owl nesting sites. The early management of stands with the least potential to emulate nest sites may reduce the amount of foraging and roosting habitat within the home range of a spotted owl in the near term but in the long-term could provide more nesting sites.

Focusing on the nest-site characteristics of a single species within a portion of its range would not be expected to provide for the habitat requirements of other species associated with late-successional forests. The effects of forest thinning on ecosystem processes beyond tree diameter growth and canopy development needs to be considered. Soil compaction, microbial communities, and invertebrate populations all are affected by silvicultural practice. To manage for habitat breadth and biodiversity, additional information is needed.

Several manipulative studies are examining multiple levels of response to forest thinning (Carey et al. 1999a, Lehmkuhl et al. 1999). These efforts include developing prey/foraging, roosting, and dispersal habitat applicable to spotted owls. Experimental designs that test scenarios for the development of spotted owl nesting sites are also needed. Information developed in multidisciplinary and multiscaled design based studies is essential before effective conservation of the all species associated with old-growth forests can be implemented in a regulated landscape (Wolff 2000).

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Appendix A

Table A1. Initial number of trees/ac for three young stand types used in simulation modeling and for known old-growth/old remnant spotted owl sites located in the central Coast Ranges of Oregon. The number of trees per acre at old-growth/old remnant spotted owl sites represent averaged values within categories.

	Uniform Douglas-fir, age = 52			Multi-storied Douglas-fir, age = 50			Mixed-species, age = 50			Old-growth owl nest sites ($n = 41$)			Old-remnant owl nest sites ($n = 8$)		
dbh[a]	TC[b]	DF[c]	BL[d]	TC	DF	BL	TC	DF	BL	TC	DF	BL	TC	DF	BL
0–4	0	8[e]	20	12	32	8	4	0	4	44	7	11	5	13	38
4–8	0	4	0	0	49	0	24	71	24	21	5	18	20	3	3
8–12	0	18	0	0	52	0	35	0	0	6	2	4	0	19	0
12–16	0	84	0	8	47	0	27	32	0	10	1	1	0	20	6
16–20	0	29	0	6	32	0	0	14	0	4	2	2	6	11	2
20–24	0	7	0	0	0	0	7	0	0	1	2	0	0	6	0
24–28	0	0	0	0	0	0	0	0	0	1	2	0	2	0	2
28–32	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
32–36	0	0	0	0	1	0	0	0	0	1	1	0	2	1	0
36–40	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0
40–44	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
44–48	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0
48–52	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
>52	0	0	0	0	0	0	0	0	0	0	4	0	0	1	0
Totals	0	150	20	26	213	8	97	117	28	90	31	36	35	78	52

[a] Diameter at breast height (in.).

[b] Trees/ac (TPA) tolerant conifers = western hemlock, western red cedar, grand fir.

[c] TPA Douglas-fir.

[d] TPA Broadleaf trees = bigleaf maple, golden chinkapin, Pacific madrone, red alder.

[e] Rounded to whole numbers.

Appendix B

Stand Selection

The young stands in our sample ranged in age from 39 to 59 years and had regenerated naturally or via aerial seeding after logging, fire, or both (Eugene District BLM stand development and exhibit "A" files). The young stands used for growth simulations were selected from the original sample by grouping similar stands using cluster analysis (Everett et al. 1997). The ordination variables that we used were tree species type (tolerant conifers, intolerant conifers, and broadleaf trees) in five dbh classes (≤6, 6–12, 12–22, 22–34, >34 in.). Ordinations were conducted twice: before any growth simulation and after simulating 110 years of growth. The number of clusters and cluster membership of each stand was determined using average linkage cluster analysis according to pseudo-t and pseudo-F criteria (Stafford and McGarigal 1992, SAS/ETS Software 1995). The outcome of the ordinations was used to distinguish between age and species-composition differences among the young stands.

We identified three distinct subgroups within the sample of young stands: (1) uniform stands dominated by Douglas-fir; (2) multistoried Douglas-fir stands; and (3) stands with mixed-species canopies, including tolerant conifers, intolerant conifers, and broadleaf trees. Based on age (50–52 years) one stand from each of the clusters was subjectively selected for our modeling (Appendix A; Figure 2).

Ingrowth

Ingrowth estimates are a necessary component of simulations that model the development of multistoried stands (David Marshall, Oregon State Univ., May 1998). To estimate the rate and species composition of ingrowth, the difference in stem densities between MA and MY stands was compared to the outcome of our young stand growth simulations. We used average linkage cluster analysis to ordinate the MA and MY stands among themselves. Three tree types and five diameter classes (described above) were used as variables. The number of clusters and cluster membership of each stand, within each cover type, was determined by using pseudo-t and pseudo-F criteria.

Within each cover type, MA and MY stands ordinated into four clusters. As described previously, the young stands ordinated into three clusters. The averaged values of each variable within the young, MY, and MA clusters, excluding stems ≤6 in. dbh, then were ordinated among each other. At a simulated stand age of 120 years, the two clusters of Douglas-fir dominated uniform and multistoried young stands ordinated with a MA stand cluster, whereas the cluster of multistoried/mixed species young stands ordinated with a MY cluster. We used the estimated difference in stem densities ≤6 in. dbh between the three young clusters and MY/MA clusters to approximate the rate of ingrowth.

Potential Nest Structures

We selected a simple random sample of 50 live conifers or snags (which had not been used as a spotted owl nest trees during the study period), one from each stand measured for the validation of cover types, and recorded the dbh. This was contrasted with the dbh of 49 trees/snags in which northern spotted owls were known to have nested. Using logistic regression we developed a descriptive model for nest trees and unused trees (Ramsey and Schafer 1997).

We derived the following model based on the diameter of live trees and/or snags to estimate the per acre PN density:

$$\textbf{Logit}(\boldsymbol{\phi}) = \mathbb{R} = -5.051 + 0.1112(\text{tree/snag dbh}) \quad (1)$$

$$(1.009)\ (0.0207)$$

$$d.f. = 97$$

$$\text{deviance} = 60.4$$

This model reflected the characteristics of spotted owl nest trees. The threshold diameter at which a tree or snag became a PN was approximately 44 in. dbh ($p \geq 0.5$). Taking the exponent of the function, we developed a predictive model for the number of trees/snags per acre that might be available as a PN, noting that this was not to be interpreted as a probability of use by spotted owls for individual trees (Lisa Ganio, Oregon State Univ., June 1996; Jeff Feen, Oregon State Univ., Jan. 1997):

$$\rho = e^{-5.051+0.112(\text{tree/snag dbh})}/1 + e^{(-5.051+0.112(\text{tree/snag dbh})} \quad (2)$$

We estimated the recruitment of Douglas-fir and western hemlock snags using ORGANON mortality tables and rates of decay with the program CWDM (Mellen and Agar 2002). The predictive model then was used in conjunction with ORGANON and CWDM reports to estimate the number of PN structures >44 in. dbh in each treatment simulation using the product of the number of trees or snags/ac, broken down into 2-in. diameter classes, and the probability function.