Introduction

The concept of historical variability has emerged as a paradigm for ecosystem management, species conservation, and landscape restoration. This approach is based on the premise that ecosystems are naturally dynamic and that native species have survived disturbance-driven fluctuations in their habitats over past millennia. Because it is not feasible to develop and implement specific management strategies for every species, a logical alternative is to manage for landscape patterns and processes that fall within the historical range of variability. This type of management is essentially a "coarse-filter" approach, which assumes that maintaining a range of forest types similar to historical distributions will preserve most of the native species that depend on these habitats. Quantitative assessments of historical landscape dynamics are needed to provide baselines for comparison with current conditions and potential targets for restoration activities. These assessments must recognize that the assumption of a steady-state landscape is unrealistic and instead quantify a range of possible historical landscape conditions. We developed a stochastic model as a tool for simulating historical variability in landscape patterns of the Oregon Coast Range.

Methods

The spatial extent of our model was the 2,341,000 ha Oregon Coast Range province. We modeled the landscape as a grid of 9 ha (300 x 300 m) cells. The model was parameterized for the 3000-year period preceding Euro-American settlement using data from a number of paleoecological, dendroecological, and historical studies.

1. Fire frequency, severity, and size were all modeled as random variables, reflecting the variability and uncertainty inherent in natural disturbance regimes (Figure 1). Fire regimes were simulated separately for two climate zones: a cool, moist coastal zone characterized by large, infrequent, high-severity fires, and a warmer, drier interior zone characterized by smaller, more frequent low-severity fires.

2. Probability distributions were used to generate a 3000-year time series of individual fire events (Figure 2).

3. The initiation and spread of each fire was modeled using a stochastic cellular automata algorithm (Figures 3-5). Fires were allowed to spread across climate zone boundaries. Fires were also allowed to initiate in a buffer zone outside the core simulation area (Figure 1) and spread into the core area.

4. Landscapes were classified into structure classes based on the time since the last disturbance and the severity of the most recent disturbance (Figure 6).

5. Model output was a series of digital maps of landscape conditions. These maps were then processed with spatial analysis software (APACK, FRAGSTATS) to produce summary output.

Study Area

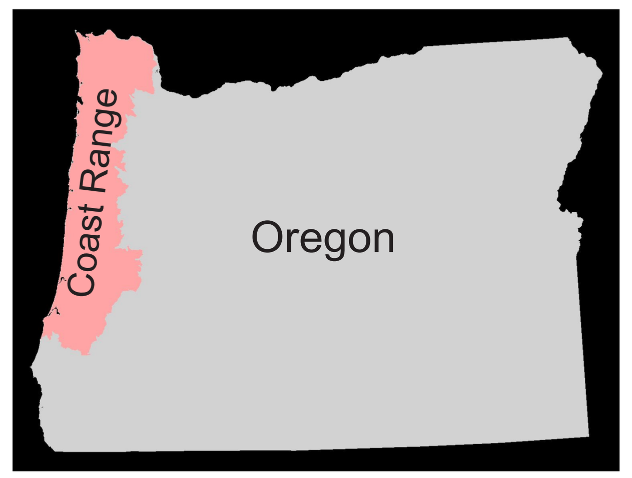
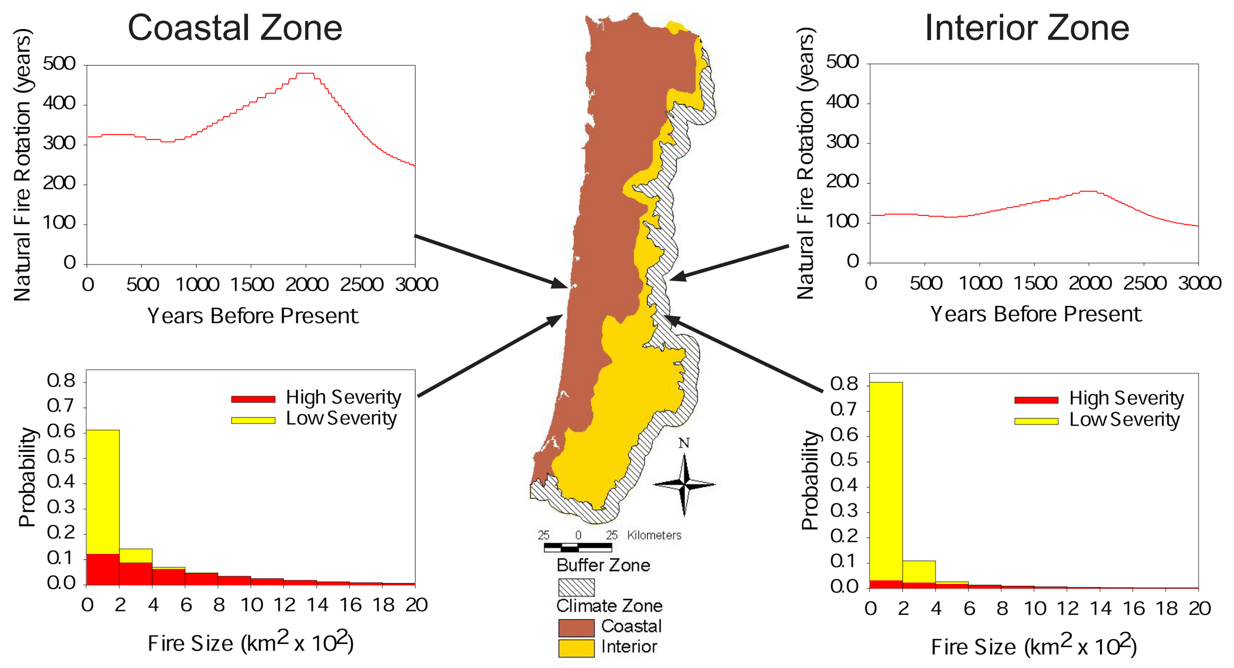
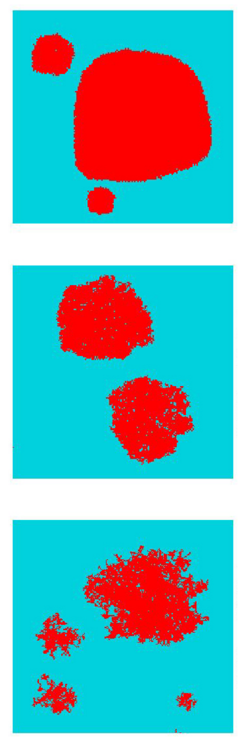


Figure 1: Fire Regime Characterization



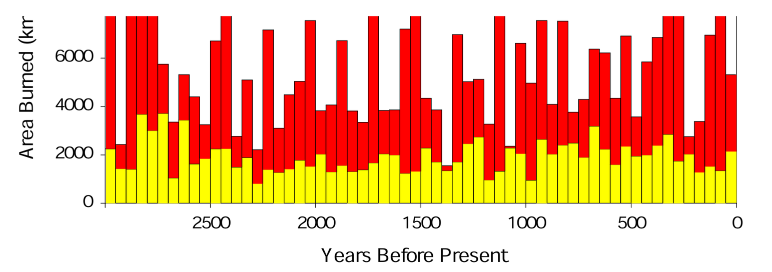
The number of fires occurring each year was modeled as a Poisson random variable, based on a 3000-year time series of fire frequency that varied with historical climate changes. The proportional area burned by high-severity fires was specified by FSEV (FSEV=0.85 for the coastal zone, FSEV=0.5 for the interior zone). The size of each fire was modeled as a geometric random variable with mean MSIZE (MSIZE=9,000 ha for low-severity fires, MSIZE=63,000 ha for high-severity fires)

Figure 4: Fire Shape Calibration



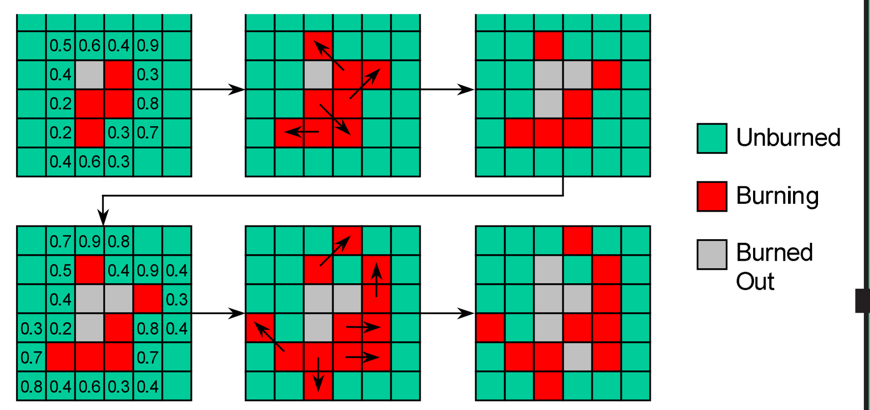
Fire shape was calibrated using the FCAL parameter, which specified the probability that a burning cell would burn out during each iteration of the fire spread algorithm. Increasing FCAL produced fires with more complex perimeter shapes and greater areas of unburned interior "islands". We used an FCAL value of 0.92 for all runs based on comparisons with recent fires.

Figure 2: Time Series of Simulated Fires



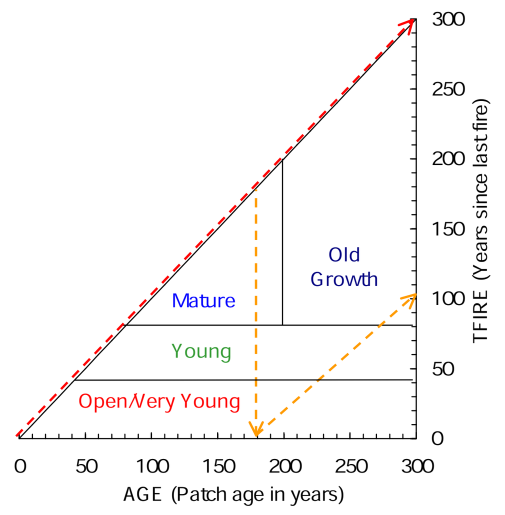
The model generated a series of fires of various sizes and severities. This chart summarizes a single model run, giving the total area burned in each 50-year period for a single model run over the past 3000 years.

Figure 3: Fire Spread Algorithm



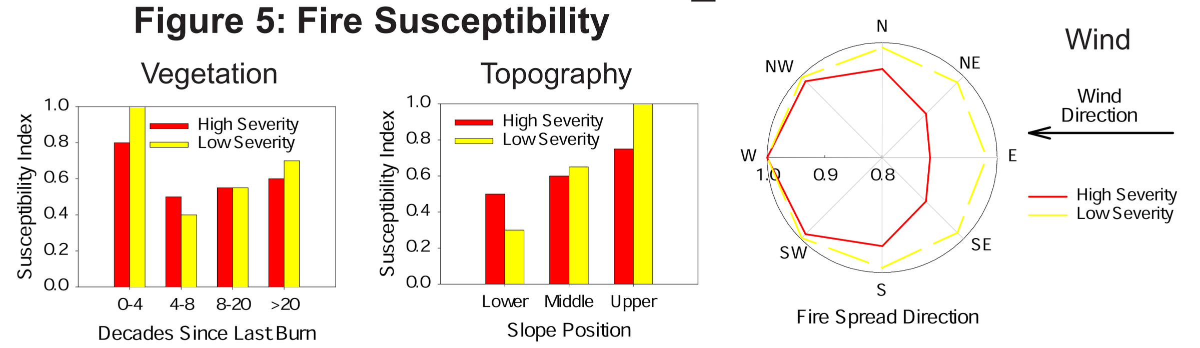
Fire initiation sites were selected randomly, weighted by topography and vegetation. Fire moved from each burning cell into one neighboring unburned cell during each iteration of the algorithm. Spread direction was chosen randomly, weighted by the topographic, vegetation, and wind susceptibility of neighboring cells. Each burning cell had a probability of burning out during each iteration, specified by (FCAL) (Figure 4). The algorithm was repeated until the fire reached its predetermined size.

Figure 6: Successional Pathways



Cells were classified into structure classes as a function of AGE (stand age) and TFIRE (time since last fire). High-severity fires were assumed to kill the majority of trees in a cell, and reset both AGE and TFIRE to zero. Low-severity fires were assumed to kill a portion of the trees within a cell, and reset only TFIRE to zero. Dashed lines represent two patches following different successional pathways. One patch, represented by the red line, follows an even-aged pathway through the open, young, mature, and old growth classes. The other patch, represented by the orange line, experiences a low-severity fires at age 180 and reverts to the open class. This patch then passes through the open and young classes, reaching the old growth class after an additional 80 years.

Figure 5: Fire Susceptibility



Vegetation susceptibility reflected changes in fuel loads with time since fire. Topographic susceptibility reflected drier conditions on upper hillslopes, and the tendency for fires to burn uphill. Spatial variability in topographic and vegetation susceptibility was assumed to be relatively low during high-severity fires. Wind susceptibility was a function of fire spread direction relative to wind direction. Prevailing fire winds came from the east, but varied between and during fire events. Sensitivity to wind direction was greatest during high-severity fires.

Results

1. Periods of intensive burning had persistent effects on landscape patterns. Large fires also left distinctive spatial legacies, often influencing landscape patterns for centuries (Figure 7). This effect was evident in the lagged responses of open, young, mature, and old-growth forest that followed widespread fires (Figure 8).

2. Mean fire return interval was highest inland, and increased with proximity to the coast (Figure 9). Because fires burned across the climate zone boundary, changes in fire return interval were manifested as a continuous gradient rather than an abrupt transition. When no buffer zone was used, mean fire return interval increased along the eastern boundary because prevailing east winds pushed fires away from the eastern border of the simulation area. The buffer zone compensated for this edge effect, because fires were allowed to initiate outside of the core simulation area and spread into it.

3. Patch size distributions were numerically dominated by small patches for all structure classes (Figure 10a), although larger patches covered most of the landscape area (Figure 10b). Over 90% of patches in the young, mature, and old growth classes were smaller than 100 ha. Small patches were created by the heterogeneous fire patterns that left many remnant islands within larger burned areas (Figure 7). Over 90% of the areas of open/very young, young, and mature patches were concentrated in patch sizes larger than 1000 ha, and over 90% of the total area of old growth patches occurred as patches larger than 100,000 ha.

4. The simulated historical landscapes were dominated by old growth, which typically occupied between 30% and 70% of the landscape (Figure 11). There was at least one large old growth patch on the landscape at all times. This patch covered at least 200,000 ha and frequently covered more than 1,000,000 ha. Other patch types covered lesser portions of the landscape and had smaller maximum patch sizes.

Discussion

Our model included several new features that have not previously been incorporated into landscape disturbance models. These were: 1) two fire severity classes, each with a unique size distribution, fire spread behavior, and ecological effects, 2) a buffer zone around the simulation area to reduce edge effects, and 3) a simple fire-spread subroutine that modeled fires as a mosaic of burned and unburned patches and allowed us to control fire shape through a calibration parameter.

Our current ability to simulate spatial patterns represents a major advance over previous assessments of historical Coast Range landscapes. The simulations suggest that historical landscapes were dominated by old growth forests, with the majority of old growth area concentrated into large (> 100,000 ha) patches. Sensitivity and uncertainty analyses (not shown) indicate that these general results are robust to moderate changes in most parameter values. Old-growth forests are comparatively uncommon in the present landscape (< 5% of total area) and are distributed in smaller fragments (< 100 ha).

Areas of continuing research include:

1. Modeling disturbance responses of specific habitat features such as down wood and snags.

2. Developing linkages with metapopulation models and population viability analysis to examine the dynamics of various types of species in historical landscapes.

3. Using historical landscape dynamics as a basis for designing and testing novel forest management strategies.

Figure 7: Model Output - One Set of Possible Landscape Changes Under the Historical Fire Regime

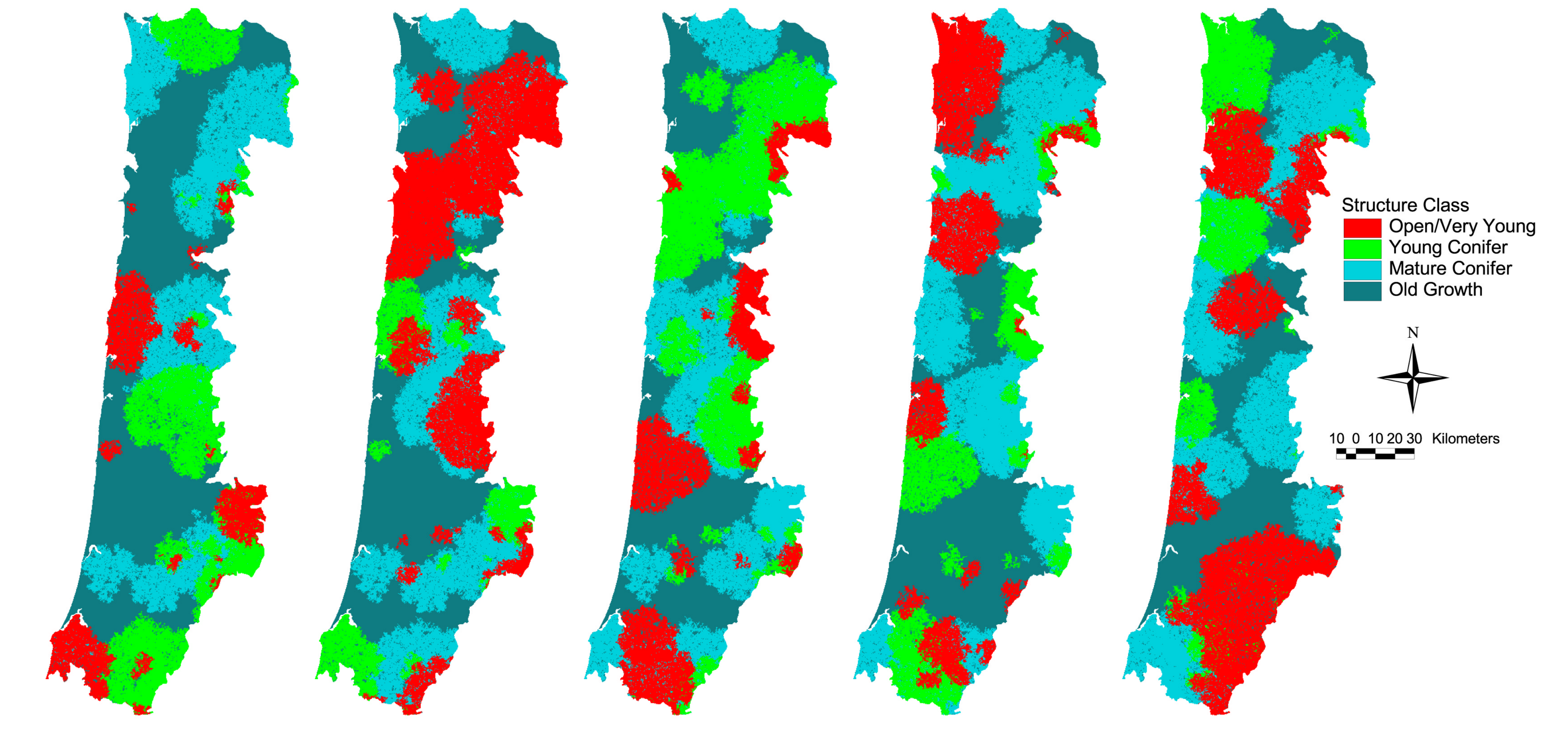
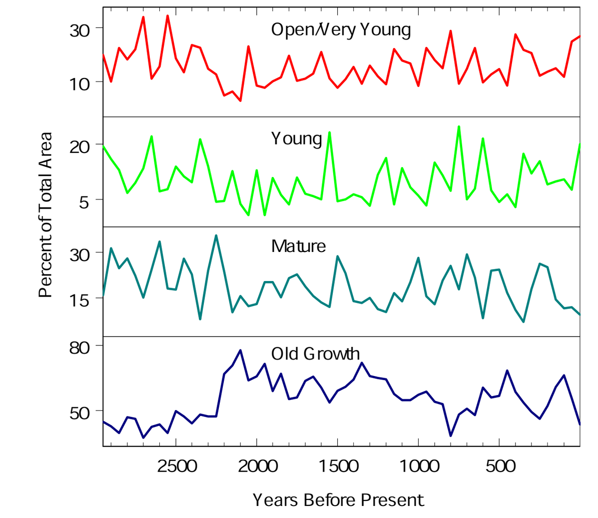
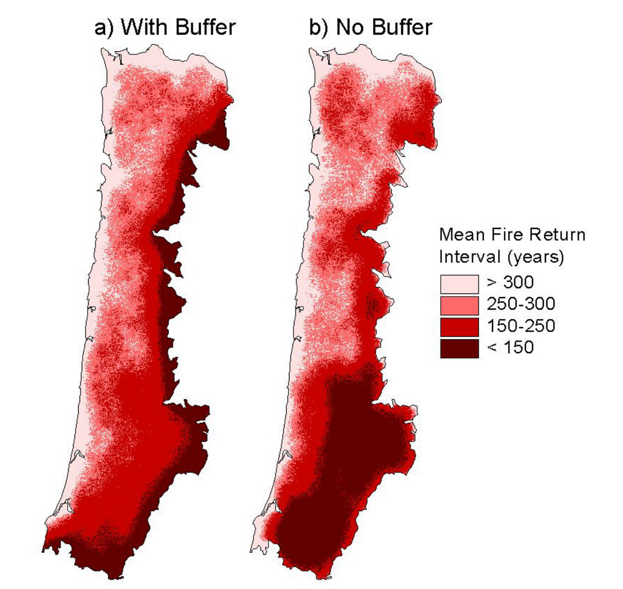


Figure 8: Landscape Composition Trends



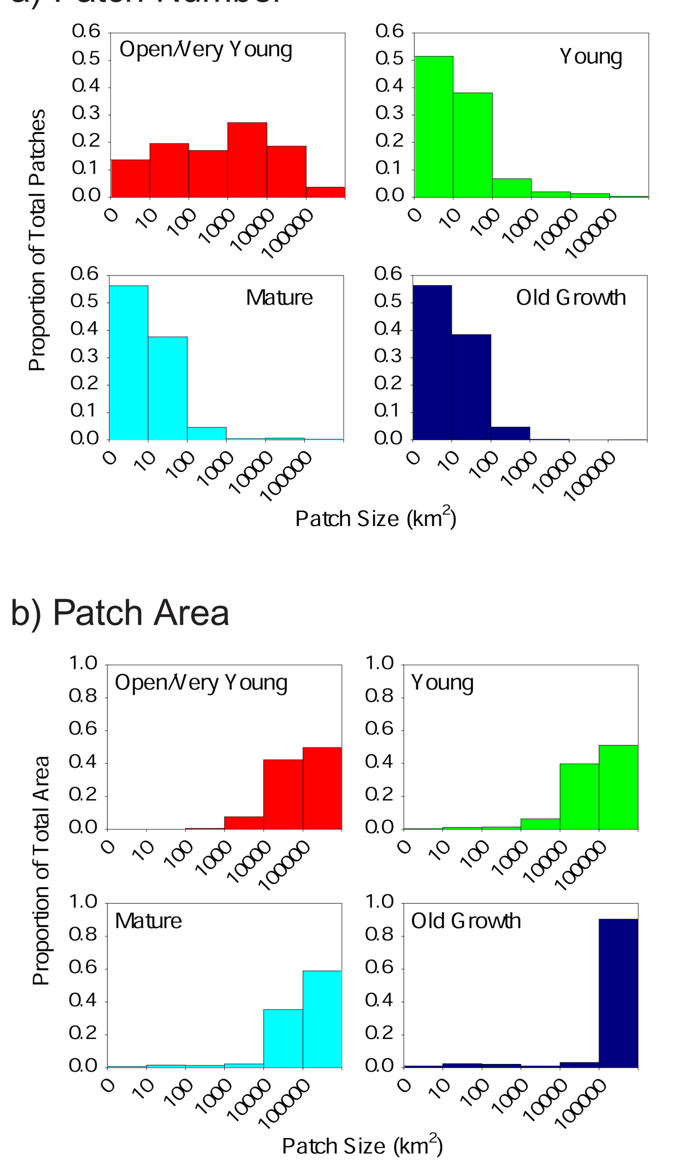
Percent of total landscape area occupied by each structure class over time for a single 3000-year model run.

Figure 9: Fire Frequency Patterns



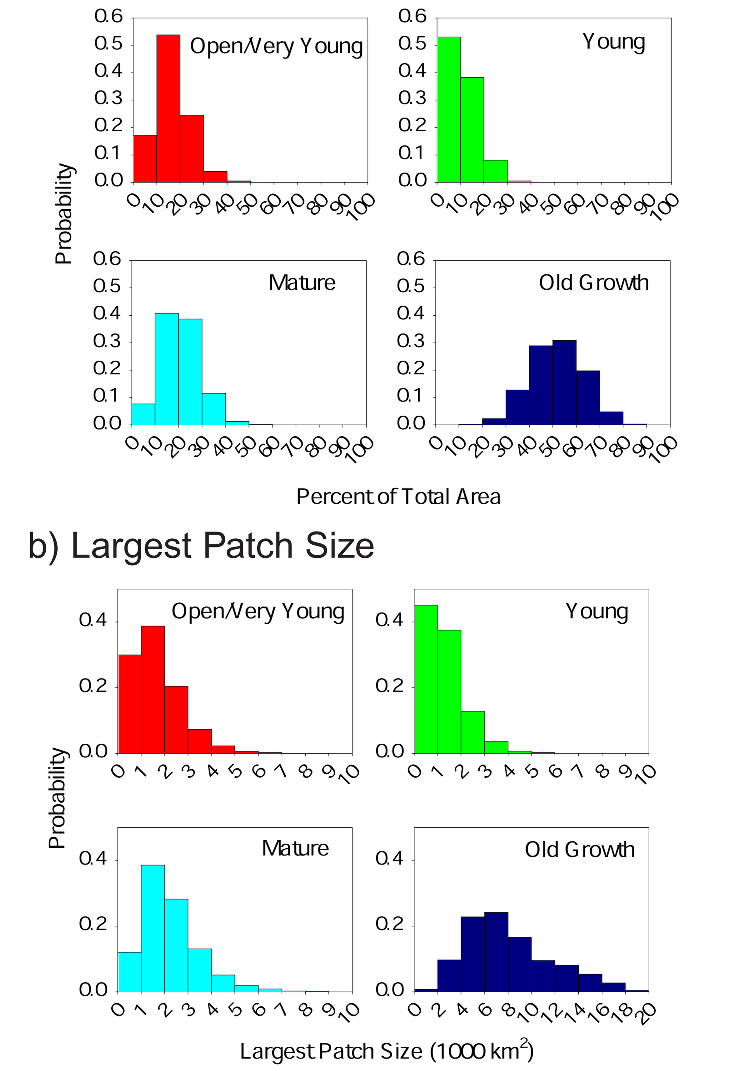
Simulated spatial patterns of fire frequency with and without a buffer zone (Figure 1).

Figure 10: Patch Size Distributions



Distributions of a) the total number of patches, and b) the total area by size class for each forest structure type. Results were obtained from a single 3000-year model run.

Figure 11: Historical Ranges of Variability



Simulated historical ranges of variability for various landscape attributes over the past 3000 years. a) Probability distributions of percent of the total landscape covered by each patch type. b) Probability distributions of the largest patch size for each structure class. Results were obtained from 50 3000-year model runs.

Simulating Historical Landscape Patterns in the Oregon Coast Range

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