

silviculture

Using Scenario Modeling for Red Spruce Restoration Planning in West Virginia

Melissa A. Thomas-Van Gundy and Brian R. Sturtevant

Active restoration of threatened or endangered species habitat may seem in conflict with the provisions of the Endangered Species Act because of the prohibition of “take,” which can include habitat modification as well as death or harm to individuals. Risk-averse managers may choose to forego active management in known or presumed endangered species habitat to avoid killing an individual or harming critical habitat. We used the landscape-scale model LANDIS-II to simulate red spruce (*Picea rubens* Sarg.)-dominated forest response to restoration actions for 100 years. Restoration strategies differed in management of the potential habitat for the recently delisted Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*). Model simulations show that active management with protections for existing red spruce stands resulted in a greater area dominated by red spruce than did larger, areawide protections. However, protecting larger areas of potential habitat resulted in an increase in red spruce in areas of low to moderate probability of occurrence for the flying squirrel, potentially increasing the area’s suitability for this species.

Keywords: landscape-scale model, restoration silviculture

Restoration of forest types, disturbance regimes, and individual species is increasing in importance in management of natural resources. Whereas ecosystem restoration may be perceived as a novel forest management objective, restoration of forested ecosystems was one of the initial reasons for the establishment of eastern national forests (Day et al. 2006). In a broad sense, ecosystem restoration is the process of assisting the recovery of a degraded, damaged, or destroyed ecosystem (Society for Ecological Restoration 2004), leading to the return of associated processes and functions.

Active restoration of threatened or endangered species habitat may be seen by some as being in conflict with the provisions of the Endangered Species Act of 1973 (ESA). That legislation emphasizes the preservation of individual plants or animals through the prohibition of “take,” which can include habitat modification (e.g., harvesting or prescribed fire) (Boudreaux 2002) intended to improve overall habitat suitability for the endangered species but with a low probability of harming one or more individuals of the species in the process. Because of this, risk-averse managers and decisionmakers may choose to avoid modifying known

or presumed endangered species habitat rather than risking harm (or the perception of harm) to critical habitat or endangered individuals.

Passed in 1973, the ESA has been called one of the most powerful environmental laws in the United States (Benson 2012) because it was the first to include plants and subspecies. The ESA’s power is also felt through the imposition of a conservation mandate on federal agencies (Doremus 2010). Although becoming the driver of many large-scale ecosystem restoration efforts, the ESA has been criticized for a limited capacity to address complex issues of managing for resiliency in ecological systems (Benson 2012). The law, with its implementation and interpretation through the courts, has also been criticized for creating formal or informal preserved areas through the avoidance of take and identification of critical habitat (Doremus 2010). The three main conservation strategies in the ESA—regulations on hunting, restrictions on commerce, and creation of reserves—address the most obvious threats but lead to the assumption that what is best for nature is for people to leave it alone (Doremus 2010). The inability to address contemporary knowledge

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Affiliations: Melissa A. Thomas-Van Gundy (*mthomasvangundy@fs.fed.us*), USDA Forest Service, Northern Research Station, Parsons, WV. Brian R. Sturtevant (*bstrutevant@fs.fed.us*), USDA Forest Service.

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This article uses metric units; the applicable conversion factors are: meters (m): 1 m = 3.3 ft; centimeters (cm): 1 cm = 0.39 in.; kilometers (km): 1 km = 0.6 mi; hectares (ha): 1 ha = 2.47 ac.

of ecosystem complexity, nonequilibrium, nonstationarity, and regime change limits the ability of the ESA to address current and future challenges in conservation (Mori 2011, Benson 2012).

The tradeoffs of avoiding or manipulating habitat critical to an endangered species can be explored before implementing restoration actions and objectives. Landscape-scale models are useful tools for integrating background disturbance process and management actions over space and time and assessing change under alternative management actions (Shifley et al. 2000, 2006, Akçakaya et al. 2004, Gustafson et al. 2007, Xi et al. 2008). Techniques that show promise in the short-term and at smaller scales can be aggregated and projected into the future using models to gain insight into feedback loops, the influence of existing conditions, and potential cumulative effects and to help decide among alternative management strategies.

This article summarizes an effort to determine whether management in habitat critical to the Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) accelerates, hampers, or is neutral to meeting landscape-scale restoration goals. When this modeling effort began, the species was listed as endangered; in March 2013 the species was delisted. However, under the terms of the ESA, the species is still under special management. We used the landscape-scale model LANDIS-II (Scheller et al. 2007) to simulate and project red spruce (*Picea rubens* Sarg.)-dominated forest response to management by applying alternative restoration scenarios to a forested landscape in the central Appalachian Mountains. In all alternatives, the broad goal was to increase the abundance of red spruce; however the alternatives differed in the way that potential habitat for Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) was treated (Figure 1). The results provide insights into the treatment of critical habitat during active restoration and the interaction of management constraints.

Methods

Case Study Area

The red spruce-dominated forests of West Virginia were severely degraded in composition and function after exploitative logging at the turn of the 20th century (Stephenson 1993). Harvesting and subsequent fires removed seed sources and changed soil



Figure 1. (A) An example of tall red spruce regeneration that might benefit from release from the hardwood overstory. (B) The Virginia northern flying squirrel.

conditions, allowing northern hardwoods to dominate the sites formerly occupied by spruce forests. These cool, moist, high-elevation forests support many rare communities and species including the recently delisted (March 2013) Virginia northern flying squirrel and the federally threatened Cheat Mountain salamander (*Plethodon nettingi*).

Natural restoration of these forests is hampered by the loss of red spruce seed source, slow maturity of red spruce to seed-bearing age, and limited dispersal distance of seed (Pielke 1981). Spruce regeneration is also hampered by competition from abundant reproduction of hardwoods. However, red spruce is extremely shade tolerant and responds well to release even after decades of suppression (Korstian 1937, Hart 1959, Blum 1990). Hence, the current red spruce forest exhibits a regeneration response (understory spruce) that bodes well for restoration of this forest type (Koon 2004, Nowacki et al. 2010). Although we have

predictive models for current and future red spruce occurrence (Prasad et al. 2007, Nowacki and Wendt 2010, Beane et al. 2012) and recent studies on the growth response of red spruce stands to management (Schuler et al. 2002, Rentch et al. 2007), there are no broad-scale and long-term projections for red spruce forest response to restoration actions.

The restoration of red spruce-dominated forest communities on large blocks of federally owned land represents an opportunity to evaluate the ability of management actions to meet the goals of restoration at a landscape scale. Over two-thirds of high-elevation spruce and spruce-hardwood forests in West Virginia are found on the Monongahela National Forest (MNF) (Menzel et al. 2006). The MNF, recognizing the potential for natural spruce regeneration in many areas and the need to expand and connect rare species habitat, has targeted spruce and spruce-northern hardwood forests for resto-

Management and Policy Implications

The results of a landscape-scale modeling tool to predict restoration of habitat for an endangered species are presented. The model was developed to answer some specific questions about meeting restoration goals for red spruce (*Picea rubens* Sarg.), while protecting habitat for the Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*). This work shows the utility of the landscape-scale model to aid in long-term decisionmaking and planning. The patch cuts modeled here were designed to be close to the intended restoration actions. Only one type of harvest was modeled with the alternatives differing in how potential habitat for Virginia northern flying squirrel was protected. The active management modeled shows that hands-off approaches to threatened or endangered species habitat can delay progress on restoration goals in this red spruce-dominated landscape. The harvests as modeled (size, rate of entry, and proportion of area harvested) show that some restoration goals will not be met in 100 years. These results suggest that the restoration goals, given current land management constraints, may be unrealistic, and alternative strategies should be considered.

ration in their forest plan with the creation of the Spruce and Spruce-Hardwood Ecosystem Management prescription area. Within this area, the forest plan calls for 400–2,000 ha of active restoration per decade (US Department of Agriculture [USDA] 2006a). The impacts in the accompanying environmental impact statement are based on the upper limit of 2,000 ha of management per decade.

The study area lies within two ecological subsections, the Northern High Allegheny Mountains (NHAM) and the Southern High Allegheny Mountains (SHAM) (Cleland et al. 2007), and encompasses the highest elevations of the MNF, mainly in Greenbrier, Pocahontas, Randolph, Tucker, and Webster counties. Both subsections are generally cool and moist compared with the other subsections making up the greater MNF, with an average annual maximum temperature of 14.5° C for the NHAM and 15.2° C for the SHAM and minimum average annual temperatures of 2.0 and 2.4° C, respectively (Cleland et al. 2007). Average annual snowfall ranges from 224.5 cm (SHAM) to 263.5 cm (NHAM), and average annual precipitation ranges from 128.2 cm (NHAM) to 138.1 cm (SHAM) (Cleland et al. 2007).

For this modeling effort, national forestland within the Spruce and Spruce-Hardwood Ecosystem Management prescription area was buffered by 5 km to reduce the influence of edge effects, for a total of approximately 275,850 ha in the modeled area (Figure 2). Results presented here are only for national forestland with the red spruce management prescription (62,000 ha). Most of the area in this red spruce management prescription is above 975 m elevation and includes extremely acidic to acid soils with frigid temperature regimes, although soils are not exclusively frigid. Soil drainage ranges widely with diverse topography, including high elevation bogs.

The extractive logging boom that reshaped the original forest of West Virginia occurred between 1870 and 1920, reaching a peak in 1909 (Stephenson 1993). Estimates of the extent of red spruce-dominated forests in West Virginia before European settlement range from 600,000 to 900,000 ha (Hopkins 1899, Stephenson 1993). Early 20th century exploitative logging and subsequent fires in the spruce and spruce-hardwood forests reduced these forests to about 300,000 ha by 1865, 90,000 ha by 1899 (Hopkins 1899), and approximately 24,000

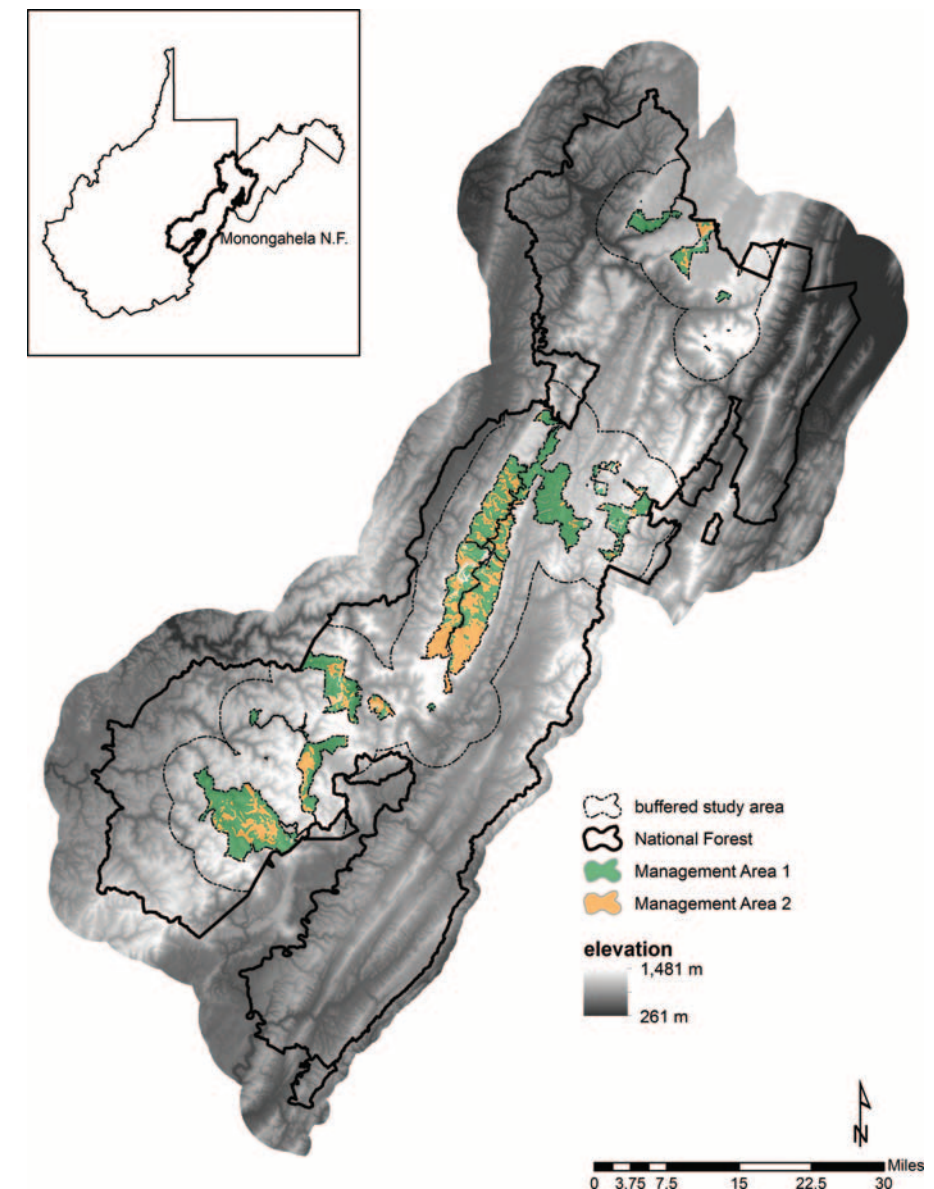


Figure 2. Location of study area and model area. Stands assigned to the Spruce and Spruce-Hardwood Ecosystem Management prescription in the Monongahela National Forest were buffered by 5 km to create the model area; however, results are only reported for the Spruce and Spruce-Hardwood Ecosystem Management prescription (study) area. Areas assigned Management Area 1 are those with low to moderate probability of habitat for Virginia northern flying squirrel; areas assigned Management Area 2 are those with high probability.

ha by the 1990s (Stephenson 1993). On the MNF, red spruce-dominated forests were estimated to cover 69,000 to 174,000 ha before European settlement but currently cover only 20,000 ha (USDA 2006b).

Modeling Description and Parameterization

LANDIS-II (Scheller et al. 2007) is a process-based, stochastic, and spatially dynamic model that simulates broad-scale (>100 ha) landscape dynamics, including

succession, disturbance, seed dispersal, forest management, and climate change effects (Mladenoff 2004). Landscapes are represented as a grid of interacting cells with user-defined cell size, in this case 0.25 ha. Individual cells have homogeneous light environments and are aggregated into land types with homogeneous climate and soils. Forest composition at the cell level is represented as age cohorts of individual tree species that interact via a suite of vital attributes

Table 1. Descriptions of management alternatives.

Alternative	Management areas included	% Area harvested/decade	% Area in 1-ha patch openings	Species/cohorts removed	Harvest rules
No Restrictions	Both	Up to 3	30 or less	All commercial species except red spruce; all but the youngest cohort	A harvest stand must have at least 10% of its cells contain red spruce 1–300 yr old. Stands had to be greater than 50 yr old and less than 120 yr old; 10 yr between stand entries.
Protect Habitat	1—low to moderate probability	Up to 5	30 or less	Same as No Restrictions	Same as No Restrictions
Protect Spruce	Both	Up to 3	30 or less	Same as No Restrictions	A harvest stand should not include 31–100% of cells of red spruce 80–400 yr old; 10 yr between stand entries.
No Harvest	None	None	None		Biomass succession simulated by model

(i.e., shade tolerance, fire tolerance, seed dispersal, vegetative regeneration potential, and longevity) to produce successional pathways sensitive to disturbance type and severity. LANDIS-II consists of a core collection of software libraries (Scheller et al. 2007) and a collection of optional extensions that represent the ecological or management processes of interest (e.g., fire, wind, harvest, insects, and succession).

Stand data (forest type and year of origin as of April 2006) from the MNF were summarized to create the initial community conditions for LANDIS-II. Each stand polygon was assigned a forest type and age class (i.e., old northern hardwoods) and converted to a 50-m × 50-m raster. Each cell consists of a list of species and age cohorts (10 years) present in that cell. These stand data were used to create the initial conditions map of species and age cohorts and the stand boundaries map for input into LANDIS-II. Field observations indicated that some of the Spruce and Spruce-Hardwood Ecosystem Management prescription areas contained young or understory red spruce cohorts. The MNF plot data were queried for remarks noting the presence of understory red spruce and those stands were given a young cohort in the initial conditions. The specific details for these and other model parameters are provided in Supplemental Appendix A1.⁵

The model requires additional inputs including tree species life history traits, maximum biomass, annual net primary productivity, age-related mortality, and soil and climate data by ecologically defined land types. Tree species life history parameters (longevity, age of maturity, shade tolerance class, effective seeding distance, maximum seedling distance, vegetative reproduction proba-

bility, and minimum age of vegetative reproduction) were determined through literature review (Burns and Honkala 1990, Brown 1996, He and Mladenoff 1999, Lorimer et al. 2001, USDA Natural Resources Conservation Service 2002, Kitamura et al. 2003, Nesom 2006).

The Biomass Succession extension version 2.2 for LANDIS-II (Scheller and Mladenoff 2004) was used to project growth and competition for all alternatives. Parameters for this extension include minimum relative biomass by shade class, species probability of establishment for each land type, woody decay rate, mortality curve shape, maximum annual net primary productivity, and maximum biomass. Species probability of establishment parameters was calculated as a function of species climatic and edaphic tolerances, and sensitivity to nitrogen limitation as applied to the climate and soil conditions for each upland land type (Gustafson et al. 2010). Average minimum, maximum, and total monthly temperatures for the calculation of species establishment probabilities were summarized from data obtained electronically from the National Climatic Data Center (National Oceanic and Atmospheric Administration 2009) for two sites within the study area. Soil parameters including field capacity, wilting point, and base soil nitrogen were estimated from MNF soil pits in high-elevation spruce sites. Soil water characteristics were estimated using soil texture and organic matter content in the Soil Water Characteristics calculator version 6.02.74 (Saxton and Rawls 2006). The probability of a seed arriving at a site is based on effective and maximum seeding distances by species (Ward et al. 2005). Maximum biomass and annual net primary productivity were estimated from published estimates

based on forest types (Jenkins et al. 2001). General silvics references were used to estimate the start of age-related mortality for each species (Fowells 1965, Burns and Honkala 1990, Hicks 1998). In these high-elevation forests, gap dynamics is the main natural disturbance regime (White et al. 1985, Rentch et al. 2010); therefore, no large-scale wind events, disease outbreaks, or fires were simulated. Unlike boreal spruce-fire forests, the stand dynamics of these montane red spruce forests (very little fir is found in the study area) are not dominated by fire and insect outbreaks (Cogbill and White 1991).

Forest Management Scenarios

The Spruce and Spruce-Hardwood Ecosystem Management prescription area was created by the MNF mainly for the protection and enhancement of flying squirrel habitat. To protect existing flying squirrel habitat, stands with greater than 30% red spruce and those that are greater than 80 years old are not suitable for active management (USDA 2006a). Active management, as opposed to passive management, includes manipulation of the forest through commercial or noncommercial methods. With or without management, uneven-aged stand conditions are a goal for forested habitat within this area (USDA 2006a).

With this guidance from the MNF Forest Plan, alternative scenarios for management of the red spruce restoration area were created (Table 1). National forestland within the Spruce and Spruce-Hardwood Ecosystem Management prescription area was identified as either high probability or moderate and low probability of Virginia northern flying squirrel habitat based on a model by Menzel et al. (2006). In this logistic regression model based

⁵ Supplementary data are available with this article at <http://dx.doi.org/10.5849/jof.13-287>.

on nest box surveys and habitat characteristics, forest type and elevation define Virginia northern flying squirrel habitat. Higher probability areas are higher in elevation and dominated by red spruce. These categories were used as management areas for the application of the patch cutting prescription. Management Area 1 included stands with low to moderate probability of flying squirrel habitat, and Management Area 2 included stands with high probability of flying squirrel habitat. Stands could not be split between management areas; therefore, if part of a stand was considered to have a high probability of flying squirrel habitat, the entire stand was assigned to Management Area 2.

The LANDIS-II Base Harvest extension version 1.3 (Gustafson et al. 2000) was used to implement alternative forest management scenarios. Management alternatives were defined based on their potential effect on habitat for the endangered flying squirrel and the protection of existing mature overstory red spruce. Our intent was to evaluate the influence of alternative strategies for the protection of Virginia northern flying squirrel habitat. All alternatives use the same prescription, patch cutting with partial removal of all commercial species, so that the impacts of habitat protection can be more easily compared across the landscape (Table 1). No spruce were removed through harvests, all but the youngest cohorts of commercial species were removed in the patches identified for harvest, and stands identified for harvest had to be greater than 50 years old and less than 80 or 120 years old (depending on alternative) with 10 years between stand entries. The alternatives modeled were (1) harvest in stands regardless of potential for flying squirrel habitat (No Restrictions), (2) no harvest in areas of high probability of flying squirrel habitat (Protect Habitat), (3) harvest in all areas with the exclusion of stands with existing mature red spruce in the overstory (Protect Spruce), and (4) succession only (No Harvest). These were chosen out of many possible management alternatives to compare the results of avoiding impacts (i.e., the risk of unintended take) to flying squirrel habitat and established red spruce-dominated stands (Protect Habitat and Protect Spruce) with the results of management in all possible stands (No Restrictions) and succession only (No Harvest).

Under the No Restrictions alternative, up to 3% of the area may be harvested per decade in 1-ha patch openings that make up

30% or less of a stand. To be eligible for harvest, at least 10% of a stand's cells must contain red spruce of any age to ensure that the model is harvesting in areas with red spruce to release or regenerate. For the Protect Habitat alternative, harvests were allowed only in the low to moderate potential for flying squirrel habitat management area. In this alternative, up to 5% of the area could be harvested per decade in 1-ha patch openings. The same harvest is applied in this alternative as is applied in No Restrictions; however, only one management area is available for harvest. In the Protect Spruce alternative, harvest was allowed in all areas available regardless of flying squirrel habitat status. Up to 3% of the area may be harvested per decade in 1-ha patch openings that make up 30% or less of a stand. For a stand to be eligible for harvest, 31–100% of its cells could not contain red spruce 80–400 years old. This alternative attempts to apply a guideline that allows for succession only in stands with existing overstory red spruce. This, in effect, protects flying squirrel habitat regardless of management area designation. The No Harvest alternative was created to be a comparison against the harvest alternatives. The area harvested in each alternative (3 or 5%) was set so that the model could meet the forest plan objective of 400–2,000 ha of active restoration management (commercial or noncommercial timber harvest) per decade.

The LANDIS-II extension Reclass Output version 1.1 was used to group the individual species model outputs into the following forest types: northern hardwoods, red spruce, red spruce-northern hardwoods, mixed cove hardwoods, and mixed oak. These forest types were chosen to match those used in the MNF forest plan and were used to compare the model outputs to the stated forest plan goals of the percentage of the area in each age class and by forest type. The Reclass Output extension uses the species and age cohort information for each cell to calculate a dominance value using the maximum age for each species on the site and the species longevity. The LANDIS-II extension Age Cohort Statistics version 1.0 was used to organize the species and cohort output. Average age was calculated for each cell for red spruce, all species found on the cell, and selected other species.

Critical response variables included area in red spruce-dominated forest types by seral stage (described below), the area with red spruce present in three seral stages, and

the area with red spruce present by flying squirrel habitat class. The results of each model run were averaged by alternative to create the final output. Previous power analysis and one-sample *t*-tests of these alternatives concluded that three runs of each alternative were sufficient to achieve a power of 0.9 at $\alpha = 0.05$ (Thomas-Van Gundy 2011).

Results

The MNF forest plan sets a goal for 3–8% of the Spruce and Spruce-Hardwood Ecosystem Management prescription area to be in early-seral stage (1–19 years) red spruce and red spruce-northern hardwood forest types. All model scenarios resulted in a 1–19 year age class area below the MNF Forest Plan goal. The scenario with harvest in both management areas but with some red spruce stands excluded (Protect Spruce) was the closest at about 2% in the third decade of the model. In all scenarios this age class declined in abundance over time, going below 0.5% at 80 years. When compared by age class and over time, the harvest scenarios differ from succession-only (No Harvest) for the first three decades of the model for the youngest age class (Figure 3).

The midseral stage (20–119 years) is further divided in the Forest Plan into three age classes with goals ranging from 3–15% (or 13–38% if summed) of the total area. The response of this seral stage was similar under all alternatives with No Harvest nearing the upper goal of 38% of the area by the end of the model period (Figure 3). By the end of the model period all alternatives show a decline in the percentage of the area in this seral stage.

The oldest seral stage was protected because the maximum age of harvest was limited to 120 years in all harvest scenarios. However, harvests did change the average age of a cell compared with that for No Harvest, and differences in the four scenarios for the 120 and greater age class do occur starting at decade eight (Figure 3). For the last two decades of the model projection, the No Harvest scenario resulted in greater amounts of area in this age class compared with those for the harvest scenarios. The MNF forest plan goal for these forest types in this age class is 60–80%; at the end of the model period, No Harvest resulted in about 59% of the area in these forest types in this age class.

Similarities between the alternatives in the creation of age classes for red spruce and red spruce-northern hardwood forest types

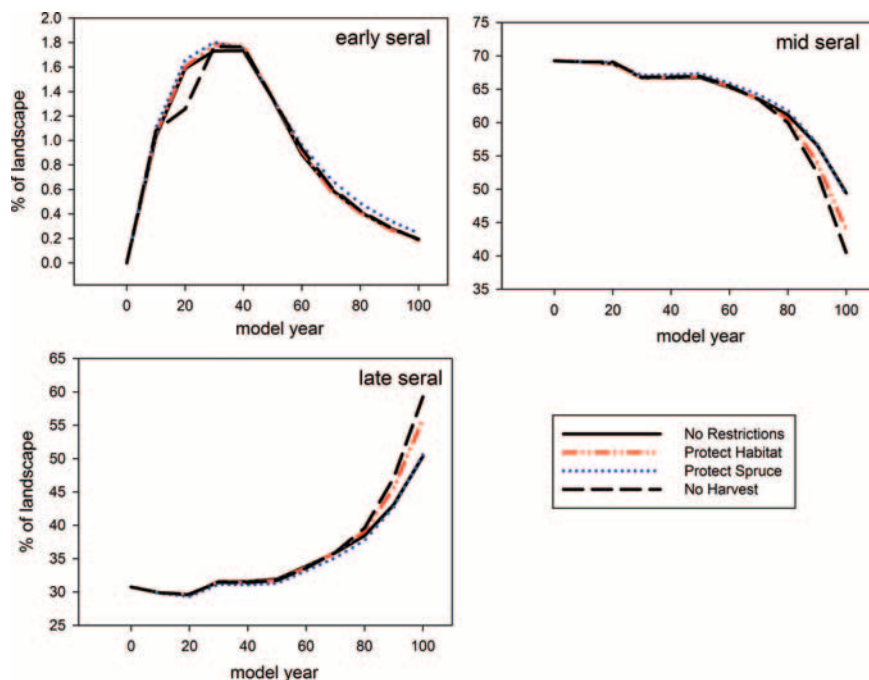


Figure 3. Percentage of the landscape in red spruce and red spruce-northern hardwood forest types by seral stage as a result of implementing the four management alternatives for 100 years. Note the differences in the vertical scale for the different seral stages.

can be seen when a section of the study area is viewed in detail (Figure 4). In this section of the study area, Protect Habitat and No Harvest produce nearly identical landscapes because the area includes mainly high probability flying squirrel habitat not available for harvest under the Protect Habitat alternative. The Protect Spruce and No Restrictions alternatives result in similar landscapes, but display slight differences in stands chosen for harvest based on stand selection criteria.

When all ages are combined, Protect Spruce results in the greatest area in red spruce-dominated forest types (Figure 5). Although the difference between this alternative and the others at year 100 is only about 600 ha, this trend occurs early in the model period. Using the age structure of red spruce alone and not the reclassified forest types, Protect Spruce differs from the other alternatives with an increase in the representation of total area with young red spruce and total red spruce of any age at about 200 ha at peak (Figure 5). As with the comparison by forest type, these differences are not large; however, it is notable that this alternative (Protect Spruce) results in a different age structure than the other alternatives and that the other harvest alternatives do not differ greatly from succession (No Harvest).

The two alternatives where harvest locations were not related to flying squirrel

habitat (No Restrictions and Protect Spruce) resulted in greater area of red spruce within areas of high probability of flying squirrel habitat (Figure 6). For those areas deemed to have low to moderate probability of flying squirrel habitat at the start of the model period, Protect Habitat resulted in greater area with red spruce present, about 1,600 ha at the greatest difference, than the other alternatives. Under No Harvest, greater red spruce occurred in areas determined to have no potential for flying squirrel habitat; these areas were primarily open, grassy, or shrub habitat at the start of the modeling period.

The model inputs of 3 or 5% of area harvested per decade set the upper bounds for possible area to be harvested near the upper Forest Plan objective of 2,000 ha per decade. The actual total area harvested per decade by alternative was tallied by LANDIS-II (Figure 7), and we used this result to determine whether active restoration harvests were sustainable for the entire model period given differences in harvest constraints between alternatives. The Protect Spruce alternative sustained the greatest area of harvest and remained within objectives. The Protect Habitat alternative dropped below the 400 ha objective (the lower bound of the forest plan objective) at about 50 years into the modeling period and remained below this level, whereas the No

Restrictions alternative dropped below the lower bound at the end of the model period. The drop in all alternatives seen at year 50 is probably due to the influence of the initial conditions, particularly stand age, given the mainly even-aged nature of the forest.

Discussion

Model results show some progress toward the restoration goals outlined in the MNF Forest Plan in all scenarios. More importantly, the results show that the restoration goals, which are based on age classes more applicable to even-aged management, may not be appropriate in the long term because the uneven-aged conditions blur stand boundaries. Because no stand-replacing natural events or harvests were included in the management alternatives, average cell age of all species present was used and summarized by age class, which may not truly represent the uneven-aged conditions created in these stands. This possible conflict was acknowledged in the plan (USDA 2006a), and the model results suggest the need for a better measure of successful restoration.

The guideline that community composition and structure be maintained primarily through natural processes in stands 80 years or older with an overstory of 30% red spruce or more appears to be a useful restoration strategy based on model results. The harvests allowed in the Protect Spruce scenario created more area with red spruce of any age and young spruce than the other scenarios. However, the Protect Habitat scenario resulted in more area with red spruce in areas considered low to moderate probability for flying squirrel habitat at the start of the model, because the model was forced to harvest only in those areas and not the high probability areas. This increase in red spruce in low to moderate probability areas may increase the probability that the area could support flying squirrel.

The response of red spruce was relatively insensitive to the treatments as applied at the rates specified (an attempt to keep active management within the Forest Plan objectives). At the end of the model period (100 years), the forests resulting from all scenarios were uneven-aged. Given the longevity and shade tolerance of red spruce, it is not surprising that limited partial harvesting in relatively small patch cuttings over 100 years did not show dramatic differences over succession only. The implication may be that to see a real response in early-seral stage red spruce-dominated forest types, more inten-

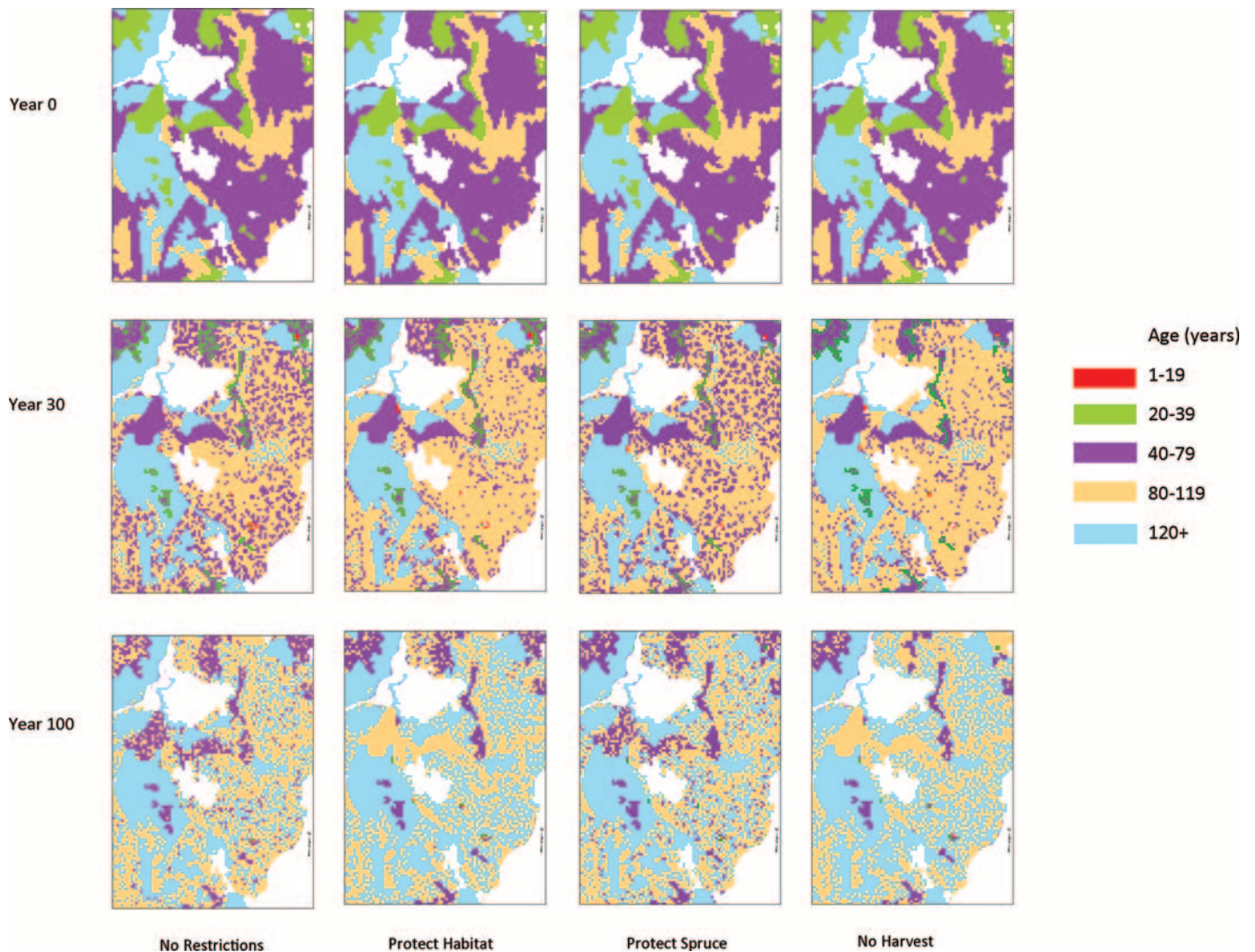


Figure 4. Changes in age classes for red spruce and red spruce-northern hardwood forest types combined for a section of the study area at three time steps; the section displayed is ~5,200 ha.

sive restoration actions, such as planting, two-stage shelterwood, or overstory removal may be necessary. Stands with existing red spruce understory were included in this simulation; however, better maps that document the occurrence of this understory are now available. Alternatives to target overstory removal in these areas could be developed to determine how these actions may change the distribution of seral stages across the landscape.

Although impacts on age classes across the landscape may not be great, stand-level composition and structural changes may occur and benefit red spruce. At the stand level, crown thinning may delay spruce movement to the canopy, whereas thinning from below may increase the importance of red spruce based on simulated management (Schuler et al. 2002). However, Rentch et al. (2007) found that thinning from above (crown

thinning) to 50% of the original basal area could double red spruce basal area in 20–40 years. In the harvest alternatives modeled here, patch cuttings were intended to act as both release for any existing red spruce and also as potential sites for new red spruce regeneration, but relatively few hectares were treated.

Climate change may affect spruce expansion into suitable habitat because red spruce is a specialist species. Statistical models of current spruce habitat have determined that climate, soils, and site conditions are important predictors of spruce habitat in West Virginia (Nowacki and Wendt 2010, Beane et al. 2012). Based on habitat suitability modeling, climate change has the potential to greatly reduce habitat available for red spruce over the next 100 years (Prasad et al. 2007, Beane 2010), with a complete loss of habitat in West Virginia possible under an

aggressive model of climate change (Beane 2010). However, an analysis of resiliency to climate change (the capacity of an area to respond to change without losing diversity) determined that mountainous areas of West Virginia, including the MNF, are highly resilient (Anderson et al. 2012). High-elevation areas may not follow regional climate trends and may be resistant to climate change with thermal inversion and cloud fog as possible mitigating factors (Seidel et al. 2009).

Conclusions

Although many data sources were readily available for the basis of this analysis, setting LANDIS-II parameters did take considerable time and interpretation and should be done in cooperation with other land managers and someone with knowledge of the model itself. LANDIS-II is well supported

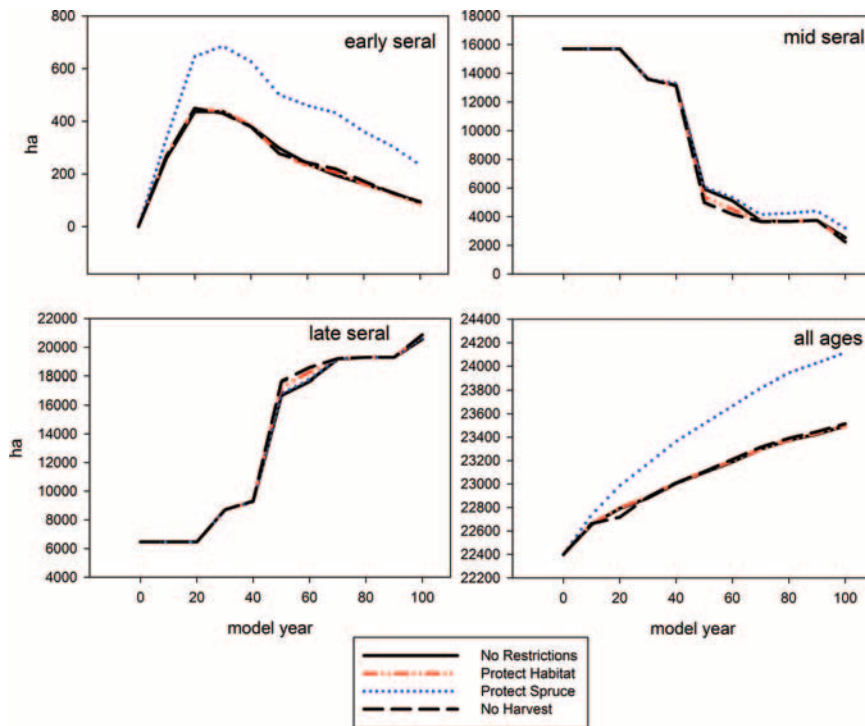


Figure 5. Area in red spruce by seral stage and all ages combined by projected year as a result of implementing the four management alternatives for 100 years.

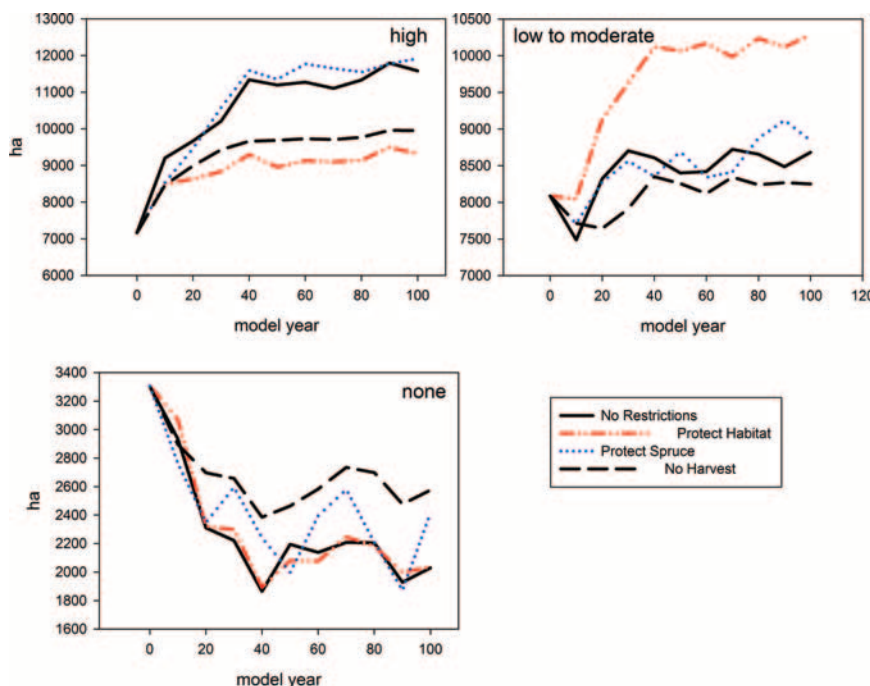


Figure 6. Area with red spruce biomass present by probability of Virginia northern flying squirrel habitat (high, low to moderate, or none) as a result of implementing the four management alternatives for 100 years.

by the USDA Forest Service and academic partners, with software, supporting documentation, and a user's group available online.¹ Training workshops for LANDIS-II users are available and encouraged for any-

one wishing to add this landscape-scale model to their land management planning.

Only one type of harvest was modeled in this case study in an attempt to hold some factors constant so that the effects of man-

agement on habitat for Virginia northern flying squirrel could be better compared. Again, the alternatives differed in where management occurred in relation to Virginia northern flying squirrel habitat instead of comparing patch-cut harvests to single-tree selection to shelterwood harvests; LANDIS-II has great flexibility in the type of harvest modeled and certainly other harvest methods should be modeled if land managers expect to incorporate them in restoration strategies. The design of the patch harvests (with partial removal of cohorts) modeled here was based on the first author's experience on the MNF forest plan revision team and reflects the ideas land managers envisioned for this restoration. The MNF has only recently implemented active restoration management harvests in the Spruce and Spruce-Hardwood Ecosystem Management prescription area. These have, to date, been noncommercial releases of existing red spruce in the understory by girdling overstory hardwoods with sites chosen by the presence of a red spruce understory, resulting in a patchy distribution of release. Monitoring of the response of red spruce to these restoration efforts will certainly inform the next Forest Plan and may also be used to create new alternatives to model in LANDIS-II. The forest plan allows for both commercial and noncommercial actions for restoration and enhancement of spruce-dominated forests. The patch cuts modeled here were not constrained to be commercial harvests. Based only on area harvested, the Protect Habitat alternative is not likely to be economically viable (Figure 7).

In this modeling, an attempt was made to apply forest plan goals, objectives, and constraints to determine what landscape changes develop over time and to determine the feasibility of the forest plan goals and objectives. The forest plan objective to actively manage spruce-dominated forests at 400–2,000 ha per decade was incorporated into the LANDIS-II model (Figure 7). At these low levels, less than 1–3% of the area every decade, it is not surprising that large differences are not apparent at the landscape-scale. This low level of direct manipulation of stand structure and composition also exposes the mismatch between the stated forest plan desired seral stage distributions and the results of restoration actions. The forest plan goals for certain percentages of the area to be in seral stages that are based on even-aged principles are not likely to re-

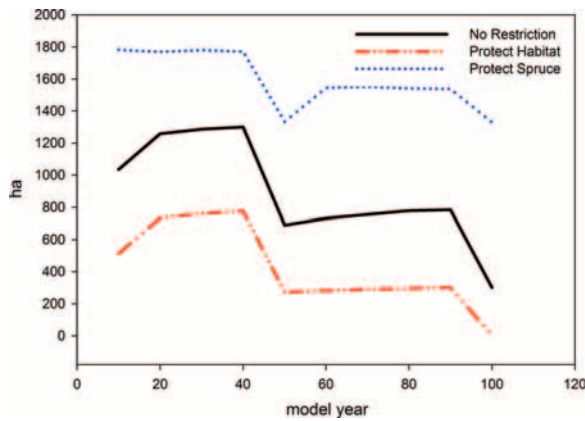


Figure 7. Total area harvested by decade by alternative.

sult from management actions that are essentially uneven-aged. In addition, the larger unmanaged area that will move toward uneven-aged conditions is not likely to result in early- and midseral stage forest, given the high shade tolerance and longevity of red spruce and the dominant disturbance regime of gap-phase dynamics. This disconnect was mentioned in the forest plan, and given the results of this analysis, it would seem that stand-level goals are more important for determining the success of red spruce restoration. If true even-aged, early- and midseral stage red spruce forest is determined to be essential for this management area, the forest plan objectives should be expanded so more area is harvested or treated and even-aged harvests are considered.

There are many opportunities to use the modeling approach shown here to conduct “what if” scenarios, making modifications to parameters such as age of stand entry and time between stand entries, developing harvests other than patch cutting, and including disturbances such as severe wind events and insect outbreaks. Whereas this study focused on implementing one part of the MNF Forest Plan, many other restoration or management ideas could be modeled. The model for the Spruce and Spruce-Hardwood Ecosystem Management prescription lands can continue to be a valuable tool for evaluating and discovering the landscape-level results of forest management. The tool is flexible in time and the variety of disturbances modeled. This area-based, stochastic model does not make decisions for the land manager but can inform decisions through long-term simulations of events and interactions.

Endnote

1. For more information on LANDIS-II, see www.landis-ii.org/home.

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