ANNUAL REVIEW

RESTORATION PLANNING AND EVALUATION FOLLOWING DAMAGE BY THE SOUTHERN PINE BEETLE IN SOUTHERN APPALACHIAN FORESTS

Bent Creek Experimental Forest
Asheville, NC

John Waldron, Postdoctoral Research Associate

Principal Investigator: Robert Coulson
Co-PI: Maria Tchakerian
Co-PI: Charles Lafon
Co-PI: David Cairns
Co-PI: Kier Klepzig
MEETING AGENDA

Monday May 24, 2004

9:00 AM – 9:15 AM ? Welcoming Comments: Robert Coulson
9:15 AM – 9:30 AM ? Comments by Kier Klepzig
9:30 AM – 11:00 AM ? Progress Report
11:00 AM – 11:30 AM ? Discussion on Progress Report
11:30 AM – 1:00 PM ? Lunch
1:00 PM – 2:00 PM ? Discussion on Project Technical Aspects
2:00 PM – 4:30 PM ? Discussion of Year 2
4:30 PM – 5:00 PM ? Closing Comments: Robert Coulson
Building 2, Bent Creek Experimental Forest, Asheville, NC, December, 1931

Building 2, Bent Creek Experimental Forest, Asheville, NC, April, 2004
Progress Report

RESTORATION PLANNING AND EVALUATION FOLLOWING DAMAGE BY THE SOUTHERN PINE BEETLE IN SOUTHERN APPALACHIAN FORESTS.

By: John D. Waldron, PhD
Postdoctoral Research Associate, Bent Creek Experimental Forest, 1577 Brevard Road, Asheville, NC 28806. Phone- (828) 667-5261 x 140. Email- jwaldron@fs.fed.us

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INTRODUCTION

The Southern Pine Beetle has caused severe damage to large extents of both commercial and recreational pine forests throughout the southern United States. In the latest outbreak (1999-2002), SPB activity has specifically thought to have increased in the mountain counties of Western North Carolina because of drought stress (NCDENR 2002). In addition to the destruction of yellow pines, SPB also turned to eastern white pine, Norway spruce, and eastern hemlock in this region (barkbeetles.org 2001). As a response to this unprecedented impact by SPB on forest structure in this region, the project “Restoration Planning and Evaluation Following Damage by the Southern Pine Beetle in Southern Appalachian Forests” began in July 2003 with the following objectives: (1) to adapt a computer forest simulation model (LANDIS) for use in SPB damage restoration, planning, and evaluation and (2) to apply this model to aid in developing SPB damage restoration plans. This report consists of three sections. Section 1 will review the problem and our general methodology. Section 2 will review the progress on the model that has been made to date. Section 3 introduces our plans for year two and calls for open discussion of our research plan.

SECTION 1: REVIEW OF PROBLEM AND METHOD

APPROACH

Our intent is to use the forest succession modeling capabilities of the LANDIS landscape disturbance and succession model along with the new biological disturbance agent (BDA) module to provide a landscape-scale assessment of revegetation of former pine forests in the Southern Appalachians of Western North Carolina. For this project, we will initially be investigating two restoration scenarios. The first scenario will be a simulation of natural succession. As a result of discussions with local land management practitioners, scenario two will consist of restoring native Table Mountain pine-pitch pine forests. The general approach for this project initially involves the compilation and analysis of data from the mountainous regions of Western North Carolina in the LANDIS modeling environment. Once the data have been collected and integrated into the LANDIS simulation environment, the model will simulate reforestation of SPB impacted landscapes under various management scenarios.

THE SOUTHERN PINE BEETLE

Introduction

The Southern Pine Beetle (Dendroctonus frontalis Zimmermann (Cleoptera: Scolytidae)) is a bark beetle that is indigenous to the Southeast and
Gulf Coast regions in the United States. Because of the realized economic damage and perceived scenic damage this species has caused to large extents of both commercial and recreational pine forests, *D. frontalis* has been considered a pest species. While *D. frontalis* generally colonizes loblolly pine (*Pinus taeda*) and shortleaf pine (*Pinus echinata*) and to a lesser extent slash pine (*Pinus elliottii*) and longleaf pine (*Pinus palustris*), it has been known to also colonize pitch pine (*Pinus rigida*), Virginia pine (*Pinus virginiana*), Table Mountain pine (*Pinus pungens*), eastern white pine (*Pinus strobus*), spruce pine (*Pinus glabra*), red spruce (*Picea rubens*), and Norway spruce (*Picea abies*) (Payne 1980, Coulson *et al.* 1999, Coulson and Wunneburger 2000).

**SPB Life History**

Newly emerged female adult pine beetles will fly from their host tree to a new tree where they begin to release a combination of pheromones and host tree odors upon boring into the bark (Borden 1974, Payne 1980, Flamm *et al.* 1988). These attractants result in the subsequent immigration of large numbers of pine beetles, especially male pine beetles, to the new host tree (Renwick and Vite 1969, Payne 1980, Flamm *et al.* 1988). The arriving males release their own attractant pheromone and as density of both male and female beetles increases, higher concentrations of pheromones create an inhibitory effect which instigates emigration to other host trees (Gara and Coster 1968, Payne 1980, Flamm *et al.* 1988). Mating takes place in the host tree and eggs are deposited in S-shaped egg galleries. Larvae hatch from the eggs within 2-9 days (Fronk 1947). Emergence of new adults is completed within 14-28 days (Coulson 1980). Within a single year, it is possible to have approximately 3-8 generations depending on environmental factors (Coulson and Witter 1984).

**SPB Biogeography**

*D. frontalis* is thought to be spread throughout Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia and has been found in parts of eastern Texas and Oklahoma, south central Arizona, southern New Jersey, Pennsylvania, Ohio, Indiana, Illinois, and Missouri, as well as in parts of Mexico, Honduras, and Nicaragua (Figure 1). However, what we might term the “core range” for southern beetle includes Alabama, Arkansas, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia. While Florida has become an important center of SPB
activity, this has only occurred in recent years concomitant with the construction of large tracts of densely-spaced even-aged loblolly pines. Before this period, SPB distribution in Florida was minimal if present at all.

In addition to the expansion of *D. frontalis* in previously unoccupied regions of the South, the species has also been pushing its northern range limits as evidenced by the unprecedented large-scale outbreak in Kentucky in 1999-2001. The Northern range limit of SPB roughly corresponds with the isoline representing a 90% probability of reaching the lower lethal temperature of the species (-16 °C) (Ungerer *et al.* 1999). Global climatic warming trends may be responsible for raising the northern limit of this isotherm. It has been estimated that an increase of 3 °C in minimum temperature would result in an extension of the northern limits of *D. frontalis* by 170 km (Ungerer *et al.* 1999).

In recent years, beetle activity has been severely damaging pine ecosystems in the Southern Appalachian region. The beetle does have a history of activity in the area, although its presence has been somewhat erratic. Large Outbreaks of Southern Pine Beetle had been reported in the area in the mid-1950s and then again in the early 1970s (Ward *et al.* 1973, 1974). However, beetle activity was also present well before this as Figure 2 illustrates.

**Within Stand Spatial characteristics of SPB**

While there is certainly some stand variation depending on stand location, there does exist a generally understood and expected behavior of beetles at the stand scale. In non-outbreak years, small populations of beetles will colonize stressed or disturbed trees, particularly those that have been struck by lightning (Coulson *et al.* 1983, Coulson *et al.* 1986, Flamm *et al.* 1993). As populations rise within disturbed trees, beetles will begin to sequentially inhabit neighboring trees by degree of host attractiveness. Thus, directionality of outbreak is largely determined by the patterning of trees on the landscape possessing the highest levels of desirability. If no trees meet a certain undefined level of attractiveness, the adult beetles will disperse and outbreaks will generally not occur.

One factor to attractiveness is tree density within stands. It has long been held that dense spacing will lead to infestation (Gara and Coster 1967, Bennett 1968, Bennett 1971, Lorio and Bennett 1974, Leuscher *et al.* 1976, Hicks *et al.* 1978). Gara and Coster (1968) asserted that undesirable trees would be those that are spaced greater than about 6-7.5 m away from the host tree. This
assertion was improved upon by Schowalter et al. (1981) who discovered reemerged beetles traveled an average of about 8 m and emerged beetles traveled an average of around 18 m. Another factor of desirability is age. Trees greater than 40 years old seem to be most desired by pine beetles (Hicks 1980). Finally, in addition to age alone, size (dbh) may be an important factor. It is also important to note that in the mountainous regions of the South, another important criterion is the situation of pines on southerly facing slopes (Porterfield and Rowell 1980).

Between Stand Spatial characteristics of SPB

Even less understood than within stand dynamics, are between stand or landscape scale dynamics. In regards to SPB behavior, landscape scale studies deal with networks of habitats and population centers which occur in heterogeneous areas characterized by multiple interacting ecosystems (Coulson et al. 1996) (Figure 3). At the landscape scale, there are basically two ways of viewing the interaction between landscape pattern and beetle behavior. The first way is to look at how SPB actively structure landscape pattern in a cause/effect relationship. That is to say, what is the resultant pattern from the process of infestation? The second way of investigating the relationship between SPB and the landscape is to look at how landscape pattern affects beetle behavior. In other words, how are SPB process dynamics affected by landscape pattern? Coulson et al. (1996) surmise that the epidemiology of SPB at the landscape scale involves a network of high hazard stands, lightning-struck hosts, and existing population centers that are connected through insect dispersal behavior.

While there has been little research performed at this scale, there are a few exceptions which are mostly descriptive in nature. Mawby and Gold (1984a, b) use a regression-based stochastic simulation model based on reference curve analysis to describe the regional population dynamics of SPB using regional blocks of data derived from county-level data. Pye (1993a,b) provides some general characteristics of regional level outbreaks at the state level based on the same data source used by Mawby and Gold. These characteristics include a) host characteristics define risk of SPB outbreak, b) outbreaks occur across multiple, adjoining states, c) outbreaks are initiated simultaneously at multiple locations in adjoining states, d) outbreaks expand from multiple epicenters in multiple states. Pye also discusses the need for more information on shape and directionality of SPB spot growth, beetle preference for edges versus interiors, and information regarding the shape and connectivity of pine stands before adequate modeling of SPB can be performed.
Coulson et al. (1996, 1999) provide a framework for looking at landscape-scale heterogeneity for generating SPB hazard ratings of landscapes; however, this model is still in its infancy. More recently, Gumpertz et al. (2000) provide a marginal logistic regression for estimating mean probability of SPB outbreak at the county level using elevation, longitude, sawtimber volume per ha, area of national forestland, precipitation in summer and fall, proportion of xeric and hydric land area, and average daily maximum temperature in fall, winter, and summer. In essence, while there are good beginnings to researching this problem, a definite gap in the literature still exists that is past due to be filled.

**SOUTHERN APPALACHIAN TABLE MOUNTAIN PINE-PITCH PINE FORESTS**


From the late 1800s to the 1930s, extensive anthropogenic landscape disturbance from logging added to fuel loads and resulted in intense fires (Ayres and Ashe 1905, Frothingham 1931). As a result of this disturbance activity, Table Mountain pine-pitch pine forests (Figure 4) were able to expand far beyond their pre-settlement range (Williams 1989, Williams and Johnson 1990, Harmon et al. 1983, Barden and Woods 1976). From the 1930s to the present, changes in land use, policy, and management have led to a reduction in the abundance of native Table Mountain pine-pitch pine forests (Williams 1998).
It has been proposed that Southern Pine Beetle outbreaks have been a key factor in driving the succession of Table Mountain pine-pitch pine forests (Harrod et al. 2000, Harrod et al. 1998, Williams 1998, Harmon 1980). This successional process involves a cyclic process whereby non-fire disturbances both create regeneration niches and add to fuel loads. The presence or absence of fire will then determine the successional trajectory of the forest (Figure 5).

This process can be unnaturally altered through silvicultural practices by allowing pines to continue to grow without the presence of fire. This creates older, denser stands of pines that would promote large-scale infestations of Southern Pine Beetle.

Some potential problems should be recognized with the attempt to restore Table Mountain pine-pitch pine forests. The first of these problems is maintaining the proper fire regime. Current research suggests that fires of medium intensity are most suitable for regenerating these forests (Waldrop et al. 2002, Randles et al. 2002, Welch and Waldrop 2001, Brose and Waldrop 2000, Waldrop and Brose 1999). Another question, in addition to intensity, is periodicity of burning. Randles et al. (2002) indicate that burning Table Mountain pine-pitch pine forests every 3-4 years with medium-intensity fires will not only lead to regeneration, but will also keep shrub density down. This type of burning will then promote the types of open Table Mountain pine-pitch pine forests one might have encountered at the time of Euro-American colonization.

Other potential problems with restoring Table Mountain pine-pitch pine forests include anthropogenic activity both within and near the restoration zone. This can include, but is certainly not limited to:

- Management practices,
  - fire suppression
  - harvesting
  - treatments
- Unintentional burning, and
- Land use conversion.

Lastly, it is important to note that other potential problems may exist due to changes in species from pre-colonial conditions in the form of invasive exotics.
such as Paulownia tomentosa and Gypsy moth that might impact these forests as well as potential shifts in the range and/or composition of native species due to climatic change.

**METHODOLOGY**

LANDIS (LANdscape DIsturbance and SuCCeSSion) is a spatially explicit computer model designed to simulate forest succession and disturbance across broad spatial and temporal scales (Mladenoff et al. 1996, He et al. 1996, He and Mladenoff 1999a,b, He et al. 1999a,b, Mladenoff and He 1999). Originally developed to simulate succession as well as harvesting, windthrow, and fire disturbance in the Lake States, LANDIS has been successfully adapted for use in the Missouri Ozarks (Shifley et al. 1998, 2000), the southern California foothills (Franklin et al. 2001, Franklin 2002), northeastern China (He et al. 2002), and Fennoscandia (Pennanen and Kuuluvainen 2002).

LANDIS 3.6 operates as raster-based system with a 10m x 10m maximum cell resolution. Tree species are simulated as the presence or absence of 10-yr age cohorts on each cell. Succession is simplified to the species level and is based on dispersal, shade tolerance, and landtype suitability. Birth, growth, and death subroutines are run in each iteration on each species cohort.

There are limitations to LANDIS that must be taken into account in terms of what sorts of output we can and cannot produce for this project. First, because of the landscape-scale size at which LANDIS is capable of operating, it cannot model process occurring between individual trees. Also, since LANDIS was designed to be able to make predictions at up to the century to millennium scale, it is presently unable to model process below ten-year intervals. Moreover, dispersal, while technically spatially-explicit, is based on radial distance-decay and does not include velocity or vector in its calculations. Lastly, while there is no direct consideration of certain environmental factors such as soil type, elevation (slope, aspect), and climate, many of these can be considered indirectly in terms of the creation of Landtypes.

LANDIS 4.0, which is due to be released in late 2004, expands on some of the features already incorporated in LANDIS 3.6 as well as adding a new Biological Disturbance Agent module (BDA). The LANDIS BDA is purported to be capable of modeling disturbance to tree species from both insects and disease. Other capabilities in LANDIS 4.0 and LANDIS II (release date unknown) will include enhanced modularity, unlimited species, biomass calculations, and finer temporal resolution.
SECTION 2: PROGRESS ON MODEL DEVELOPMENT

BEGINNINGS

This project began as a solicitation for proposal by Dr. Kier Klepzig, Project Leader of the Southern Pine Beetle: Ecology, behavior, and management unit of the USDA Forest Service Southern Research Station. Dr. Robert Coulson, Professor of Entomology and Forest Sciences and Dr. Maria Tchakerian, Research Associate of the Knowledge Engineering Laboratory at Texas A&M University heeded the call and submitted the proposal which was summarily funded. Upon receiving confirmation of the proposal acceptance, Drs. David M. Cairns and Charles Lafon of the Department of Geography at Texas A&M University were added as collaborators. This team of investigators soon set to the task of further development of the research plan and hiring a postdoctoral research associate to develop and implement the model for forest restoration following damage by southern pine beetle.

JULY 2003 – DECEMBER 2003

Research for this project officially began in July 2003 with the hiring of Dr. John D. Waldron as the postdoctoral research associate. With the full team now in place, it became apparent that a wide variety of skills and knowledges were now in place to ensure this project would be a success (Figure 6). Before model parameterization could begin, it was first necessary to conduct a literature on 3 separate, but interrelated areas; southern pine beetle, southern Appalachian forests, and LANDIS. This research is represented, in part, in the Section 1 review portion of this document.

During this time, at least some subset of our research group was present at the Southern Pine Beetle RD&A Workshop in Mt. Lake, Virginia, August 11-14 to participate in guiding the Planning, Evaluation, and Monitoring of a Southern Pine Beetle Research, Development, and Applications Program. Also during this period, our research plan was presented at the East Texas Forest Entomology
Conference, Kurth Lake Lodge, Texas, October 16-17, 2003. Once all the necessary background documentation had been synthesized, it was possible to begin parameterizing LANDIS to fit our study. Our team met in early November at Texas A&M University to discuss modeling issues and readdress our project plan. At this point in time, parameterization of the LANDIS model was in its initial stages and the plan to use Table Mountain pine-pitch pine forests as a restoration scenario was established.

**DECEMBER 2003 – PRESENT**

The first step in this effort was to create a data needs assessment for the LANDIS SPB Restoration Project. This needs assessment involves the collection of six data input sources required to run LANDIS in general, and a seventh to run the portion of the model responsible for simulating disturbance by southern pine beetle. These steps are:

1. Determine the LANDTYPE CLASSES (LC) for the project area
   a. determine probability of various woody species occurring in each area

2. Create a LANDTYPE MAP (LM)
   - A raster map reflecting the location of the LC

3. Create COMMUNITY CLASSES (CC)
   - Listing of community types that are found within each LC

4. Create a COMMUNITY MAP (CM)
   - A raster map reflecting locations of communities in the CC

5. Create a SPECIES FILE (SF)
   - Contains information regarding attributes of each species included

6. Create a DISTURBANCE FILE (DF)
   - This contains information about FIRE, WIND, & HARVESTING

7. Create a SPB-BDA FILE (SBF)
   - Landtype modifiers, disturbance modifiers, temporal parameters, species vulnerabilities, neighborhood outbreak modifiers…

**Steps 1 - 4: Determining Landtype/Community Classes and creating Landtype/Community Maps**

Our first step in parameterizing the model was to determine the Landtype and Community Classes and create the associated Landtype and Community Maps. Landtypes, in LANDIS, define individual ecological units that have their
own set of characteristics regarding disturbance behavior and establishment. Within or between these Landtypes are community types that exist solely as an input file to determine where communities of species presently exist on the landscape. In order to develop these files for our study, we used a classified image and Digital Elevation Model of Great Smoky Mountain National Park. This information was processed through a Classification Tree algorithm to find the most important community classes that occurred on the landscape (Figure 7) and where these classes occurred in relation to elevation, slope, and aspect (Figure 8).

The Classification Tree algorithm revealed 14 Landtypes and 7 community types (Figure 9). This classification scheme was checked to determine its utility for the project area (Ulrey 1999, Simon et al. 2003, McNab personal communication). Once it was determined that the Landtypes and Community types were appropriate for the region, it was necessary to compile a list of species that occurred both in the landscape in general as well as within each community type. For testing purposes, we created hypothetical Landtype and Community maps. These raster, grid-based maps are two-dimensional representations of a hypothetical conical mountain that incorporate each of the 14 Landtypes and 7 community types (Figures 10 and 11).
Figure 7. Original classified map and resulting classes from Classification Tree process.
Figure 8. Locations of the seven classified community types by elevation, slope, and aspect.
<table>
<thead>
<tr>
<th>Landtype Class</th>
<th>Elevation</th>
<th>Slope</th>
<th>Aspect</th>
<th>Community Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Very High Elevation all Aspects</td>
<td>1671+</td>
<td>0-360</td>
<td>0-360</td>
<td>Spruce Fir</td>
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<tr>
<td>2. High Elevation All Aspects</td>
<td>1571-1671</td>
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<td>0-360</td>
<td>Northern Hardwood</td>
</tr>
<tr>
<td>3. Somewhat High Elevation N-W Slopes</td>
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<td>0-90</td>
<td></td>
<td>Cove Hardwood</td>
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<tr>
<td>4. Somewhat High Elevation W-N Slopes</td>
<td>1389-1571</td>
<td>270-360</td>
<td></td>
<td>Northern Hardwood</td>
</tr>
<tr>
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<td>1080-1389</td>
<td>0-360</td>
<td></td>
<td>Cove Hardwood</td>
</tr>
<tr>
<td>6. Mid Elevation SW-NE</td>
<td>937-1080</td>
<td>225-315</td>
<td></td>
<td>Cove Hardwood</td>
</tr>
<tr>
<td>7. Mid Elevation NE-SW</td>
<td>937-1080</td>
<td>45-225</td>
<td></td>
<td>Mesic Oak</td>
</tr>
<tr>
<td>8. Lower Mid Elevation SW-N Steep</td>
<td>684-937</td>
<td>&gt;15%</td>
<td>225-360</td>
<td>Cove Hardwood</td>
</tr>
<tr>
<td>9. Lower Mid Elevation E-S Steep</td>
<td>684-937</td>
<td>&gt;15%</td>
<td>90-180</td>
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<td>684-937</td>
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<td>11. Lower Mid Elevation E-S Gentle</td>
<td>684-937</td>
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<td>90-180</td>
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</tr>
<tr>
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<td>180-225</td>
<td></td>
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<td></td>
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<tr>
<td>14. Upper Low Elevation N-NE</td>
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<td>15. Upper Low Elevation NE-SW</td>
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<td>45-225</td>
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</tr>
<tr>
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<td>225-0</td>
<td></td>
<td>Pine</td>
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<td>0-360</td>
<td></td>
<td>Xeric Oak</td>
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</table>

Figure 9. Landtype classes with associated community types.
Figure 10. Community map.

Figure 11. Landtype Map.
Step 5: Creating a species file

The accompanying report to the classified vegetation map of Great Smoky Mountains National Park that we had used for our community types contained a list of 63 woody species present on the landscape (MacKenzie 1991). However, as a LANDIS species file can contain no more than 30 species, these species had to be pared down based first on their presence within our assigned landtypes, and second on the importance of the species in those landtypes reflected by mean basal area. Each species was then assigned data regarding its maximum age, age of sexual maturity, shade tolerance, fire tolerance, effective seeding distance, maximum seeding distance, probability of vegetative propagation, the maximum age of resprout, and a species importance percentage for the entire landscape (Figure 12). The probability of each of these species occurring on each Landtype was then calculated using the mean basal areas of the species per community type.

<table>
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Figure 12. LANDIS Species file.
Step 6. Creating the disturbance file

Presently, the disturbance file we are using contains only disturbances of wind and fire. For testing purposes, we have modified previously existing disturbance files to fit our general study region (Figure 13). Once we focus on specific study sites, more specific wind and fire history data will be used to further refine these processes.

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Figure 13. Wind and fire disturbance in LANDIS

Steps 1-6. Hypothetical test runs

Once steps 1-6 were complete, it was possible to run the model to test succession without the presence of southern pine beetle to determine if the model output resembled what we see on the landscape. After simulating 250 years of succession, it seems, at least for the pines landtype, that the major species remain fairly stable (Figure 14). As this is the case, we will assume for the present that the

![Species succession over 250 years in the "Pines" landtype](image-url)
model is valid enough to continue with simulations and begin adding the SPB components.

**Step 7. Creating the SPB-BDA.**

Under Development

**SUMMARY**

The first year of this program has been very successful in building a model to forecast vegetation types in the Southern Appalachians. It is important to note that this is the first time that LANDIS has been parameterized to fit this region. For a model that was originally designed to fit flat Boreal forests in Wisconsin, we could not be more pleased at how well the output seems to predict vegetation types. While parameterizing the model to fit the Southern Appalachians was a monumental undertaking in and of itself, our ultimate goal is to use this model to study potential restoration scenarios in the wake of Southern Pine Beetles. Now that the base model has been built for this ecoregion, it is possible to further parameterize the model to accept southern pine beetles as a disturbance agent. By doing this, we will not only be able to determine the best suited species for restoration on sites that have been damaged by southern pine beetle, but also be able to determine the potential impact of future outbreaks.

**SECTION 3: PROJECTIONS FOR YEAR 2**

In the second year of this project, we anticipate completing model development and testing the model on both hypothetical and real landscapes. At a minimum, we will be able to test the model in predicting vegetation from a natural succession scenario and from specifically restoring Table Mountain pine-Pitch pine communities. It is our goal to present the results of this research in peer-reviewed scientific journals as well as in presentation format to both academics and practitioners.

At the present time, it is necessary to elaborate on the specifics of the research questions we wish to answer with this model. Further discussion of the restoration scenario in terms of vegetation pattern, species composition, age composition, and management schemes are needed. It is also important that we discuss the viability of the restoration scenario we have chosen as well as the feasibility of implementing such a scenario. Finally, we need to discuss other options for restoration and develop a time-table for testing a suite of management options.
LITERATURE CITED


He, H.S., D.J. Mladenoff, and J.Boeder. 1996. LANDIS, a spatially explicit and stochastic model of forest landscape disturbance, management, and succession-LANDIS 2.0 user’s guide. Department of Forest Ecology and Management, University of Wisconsin, Madison.


