A Simulation Study of Forest Dynamics Under Multiple Harvest Regimes and Wind Disturbances in Southern Mississippi

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Abstract

Forests of the coastal plain region of the southern United States are unique in their productivity, biodiversity, and economic value. However, natural and anthropogenic disturbances may trigger forest age structure and spatial distribution variation. Detecting and predicting tree species distribution patterns can help to understand the dynamics of disturbances in order to develop adequate forest management plans. In this study, we first integrated the spatially explicit forest landscape model, LANDIS 6.0, with Mississippi Institute for Forest Inventory (MIFI) data and simulated coastal forest dynamics under natural succession, forest harvesting management regimes (20-year and 40-year logging re-entry intervals), and wind disturbance for 100 years. Then, we analyzed loblolly pine (*Pinus taeda*) productivity, age structure and spatial distribution. After 40 years, most loblolly pines grow into a sawtimber product class. From potential productivity structure analysis, the productivity seems steadier in 20-year logging regime when compared to a short time seedling gap in the 40 year logging intervals. Spatial pattern characteristic analysis was performed using Fragstats 3.3 software to calculate number of patches (NP) and landscape shape index (LSI) for projected maps. The results suggest that wind has larger capacity to fragment habitats than harvests. Furthermore, t-test results show that there is a significant difference between natural succession and harvest regimes in productivity and landscape pattern indicators, while only the difference in landscape patterns is evident between...
with and without wind disturbance scenarios. This suggests that harvest influences are more obvious than wind disturbance. Thus, with the constantly changing forest landscape associated with human and natural disturbances, human elements should have more considerations in forest management planning.

**Keywords:** disturbance, loblolly pine, potential productivity structure, spatial distribution pattern, LANDIS

**Introduction**

Forests along the northern Gulf of Mexico play an important and unique role because of their high productivity, biodiversity, and economic values (Guntenspergen and Vairin, 1998). However, natural and human disturbances, such as hurricanes or tornados, harvesting, and fire (natural or prescribed), may trigger potential forest ecosystem health problems such as habitat loss for wildlife. On the other hand, because of hierarchical structures and complex patterns and processes of forest landscapes, using traditional on-site experiments is difficult for predicting forest succession at large spatial and long temporal scales (Gustafson and Crow, 1999; Klopatek and Gardner, 1999). In this case, landscape modeling becomes a useful tool for macro-ecological study, as well as for understanding the interactive effects of disturbances (Scheller and Mladenoff, 2005).

As a key representative of the conifers planted in North America, loblolly pine (*Pinus taeda* L.) has significant economic and ecological importance because it grows fast producing high-quality wood products (Mississippi Genome Exploration Laboratory, 2003). Some management strategies are specially formulated for loblolly pine, so it is important to investigate how forests will change in response to different forest management regimes and disturbances. In this study, we attempt to determine: (1) how harvest regimes and wind disturbance affect the productivity structure of loblolly pine; (2) how harvest regimes and wind disturbance shape the spatial distribution characteristics of loblolly pine; and (3) which disturbance (harvest or wind) has the most influence in landscape fragmentation.

**Methods**

**Study area**

Our study area is located in the southern part of Mississippi belonging to the outer Coastal Plain mixed province (Figure 1). According to Bailey’s description (Bailey and Ropes, 2002) of outer coastal plain mixed province (code: 232), the climate is moderate with average annual temperatures ranging from 15.6-21.1°C (60-70°F) and precipitation ranging from 1,020 to 1,530 mm (40 to 60 inches) per year. The land-surface form is gently sloping. Temperate evergreen forests are typical. The extensive coastal area is dominated by gum (*Nyssa* spp.) and cypress (*Taxodium* spp); most of the upland area is covered by pine forests which includes needle leaf evergreen or coniferous species, such as loblolly pine and slash pine (*Pinus elliottii*). The soils are mainly ultisols, spodosols, and entisols. This region also provides habitat for a variety of wildlife species (e.g., black bears, white tail deer, raccoons, rabbits, squirrels, etc.).
LANDIS simulation

LANDIS, a landscape level simulation model of forest succession, disturbance, and management, has been widely applied in both forest and shrub ecosystems in North America, Switzerland, and northeast China to simulate forest processes, such as forest succession, seed dispersal, wind, fire, harvesting, insect disturbance, and fuel management (Shifley et al., 2000; Franklin et al., 2001; He et al., 2002; Pennanen and Kuuluvainen, 2002; Mladenoff, 2004). In this project, we applied the LANDIS model to simulate succession, harvest, and wind throw processes with an aim of exploring the change in forest composition structure and spatial distribution characteristics. As the first trial using LANDIS to simulate forest dynamics in the southern United States, species parameters, such as vital biological traits and initial age cohort composition for the selected species were set up prior to the LANDIS simulation based on the importance values of tree species in the Mississippi Institute for Forest Inventory (MIFI) database. The definitions and formulas to calculate importance values are shown in the following table (Table 1).
Table 1. Formulas used to calculate the importance value to select dominant species.

<table>
<thead>
<tr>
<th>Index</th>
<th>Definition and formula</th>
</tr>
</thead>
</table>
| Relative frequency| Number of occurrences of a species as a percentage of the total number of occurrences of all species  
\[ \text{relative frequency} = \frac{\text{number of plots obtaining a given species}}{\text{total plot number}} \]  |
| Relative density  | Number of individuals of a species as a percentage of the total number of individuals of all species  
\[ \text{relative density} = \frac{\text{number of trees for a given species}}{\text{total number of trees for all species}} \]  |
| Relative dominance| Total basal area of a species as a percentage of the total basal area of all species  
\[ \text{basal area (BA)} = 0.005454 \times \text{DBH}^2 \]  
\[ \text{relative basal area} = \frac{\text{sum of BA for given species}}{\text{total BA for all species}} \]  |
| Importance value  | Importance value = \[ \text{relative frequency} + \text{relative density} + \text{relative basal area} \times \frac{1}{3} \]  |

Wind module parameterization

There are 15 parameters in initial wind module file. Three were selected because they play significant roles—minimum, maximum, and mean wind size determining the area of damage from wind disturbance. After a comprehensive literature review (Oswalt and Oswalt, 2008; Oswalt et al, 2008), we set the three selected parameters of the minimum, maximum, and mean wind size as 200, 50,000, and 3,000 hectares, respectively.

Harvest module parameterization

In the study area, most forest lands are owned by private landowners making it difficult to find an accurate logging census. We designed two practical harvest regimes in our LANIDS initial parameter setting according to the specifications of the “Best Management Practices for Forestry” in Mississippi (Husak et al., 2004).

First, we defined four management area based on elevation. In this case, the harvest target proportion can be set individually based on various management areas. The target proportions of harvest for each management area are shown in Table 2. The minimum stand age for harvest is
Table 2. Parameters setting for the harvest module in LANDIS.

<table>
<thead>
<tr>
<th>Management area ID</th>
<th>Elevation</th>
<th>Target Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-30m</td>
<td>0.1</td>
</tr>
<tr>
<td>2</td>
<td>31-60m</td>
<td>0.2</td>
</tr>
<tr>
<td>3</td>
<td>61-90m</td>
<td>0.5</td>
</tr>
<tr>
<td>4</td>
<td>&gt;91m</td>
<td>0.8</td>
</tr>
</tbody>
</table>

40 years. After logging, the sites should be regenerated by planting a new generation of trees. Two regimes, a 20-year and a 40-year re-entry interval, are set up for pulp-wood and saw-timber production, respectively.

**Design of simulation scenarios**

We executed a LANDIS simulation for 100 years with a five year time step (totalling 20 iterations on each run). In this case, we can obtain 20 output maps in one simulation operation for each selected species. The following six regimes were designed to examine both human (harvest) and natural (wind) disturbance effects. We consider the first three regimes as Scenario 1 (without wind scenario) and the last three as Scenario 2 (with wind scenario).

- Succession without wind or harvest
- Succession with 20-year harvest interval but without wind disturbance
- Succession with 40-year harvest interval but without wind disturbance
- Succession without harvest but with wind disturbance
- Succession with 20-year harvest interval and wind disturbance
- Succession with 40-year harvest interval and wind disturbance

**Analysis of LANDIS output**

Loblolly pine is a fast growing species and plays an important economic role in southeastern U.S. wood markets (Rauscher and Johnsen, 2004). According to LANDIS output maps, we calculated loblolly pine potential productivity structure and spatial distribution characteristics for each set of simulation.

Potential productivity structure reflects the capacity of given species for wood stocking. Based on the output map of loblolly pine, we reclassified forest lands considering them as natural stands into four categories, seedling (age 1-10 years), sapling (age 11-30 years), pole (31-60 years), and sawtimber (age >60 years) for each five-year time step to generate the potential productivity structure for 100 years. For spatial distribution characteristics, we applied two landscape matrices, number of patches (NP) and landscape shape index (LSI), to describe spatial distribution and detect fragmentation. Spatial Pattern Analysis Program, FRAGSTATS 3.3, is used in landscape matrices calculation. Then, we applied t-test to compare the differences among succession, harvest regimes and wind disturbance scenarios.
Figure 2. Potential productivity dynamics for Scenario 1 (left three) and Scenario 2 (right three). Top down, the left three graphs are (a) succession without any disturbance, (b) with 20-year harvest interval, and (c) 40-year harvest interval, while the right three are (a) succession wind but without harvest, (b) with wind and 20-year harvest interval, and (c) wind and 40-year harvest interval, respectively.

Results

Potential productivity structure

The loblolly pine age cohorts were regrouped into four categories, seedling, sapling, pole, and sawtimber. Both scenarios (without and with wind disturbance) yielded similar patterns of potential productivity. However, the productivity varied with different harvest regimes. With no
harvest, no matter whether wind events take place, all loblolly pine stands will reach sawtimber product class after 40 years growth. Moreover, more over-aged forest has more forest risks, such as susceptibility to debris accumulation and wild fire.

Forest productivity under the two harvest regimes is different from no harvest situation (Figure 2). In the 20-year logging re-entry interval, there are short time gaps, in 45-50 year, 60-70 year, and 80-90 year, with more seedlings and saplings. In other simulation years, forest structure has a relatively stable state with about 60% in pole wood, around 35% sawtimber, and very small proportion of seedlings and saplings. In the 40 year reentry interval harvest regime, there is a 15 year unstable stage from year 25 to 40 in the simulation with too much old forest, and the forest needs a recovery stage in order to gain juvenile trees back from year 45 to 65. After that, the forest reached a similar pattern to the 20 year logging re-entry regime. This result indicates that for 40-year interval forest should spend almost 40 years in growing and restocking without output of timber products. Furthermore, severe disturbances during the wood re-stocking stage will result in large benefit loss in the long run. Thus, among the three cases of forest succession, the 20-year reentry interval will do more to achieve the sustainable use of forest resources.

Spatial distribution characteristics

The number of patches (NP) and landscape shape index (LSI) are indicators of landscape
fragmentation. In the *no wind* disturbance Scenario 1 (left two graphs in Figure 3), the results showed that succession without any disturbances cannot incur landscape fragmentation so in the graph it is a straight line. Once harvest begins, NP and LSI increase. When integrating wind disturbance with harvest, these matrices increase dramatically. These results suggest that wind may cause more fragmentation than harvest.

**Analysis of harvest effects**

The *t*-test results indicate that there is significant difference in both productivity structure (except seedlings) and landscape matrices between succession and both harvest regimes (Table 3). Thus, harvest management influences not only the age composition of forest land but also spatial distribution properties.

**Analysis of wind effects**

The statistical results indicated that there is no significant difference in forest potential productivity between *no-wind* (Scenario 1) and the *wind disturbance* (Scenario 2) scenarios, but that there is a significant difference in landscape properties (Table 4). It suggests that wind cannot significantly influence forest age composition but can shape spatial distribution patterns.

**Conclusion**

Mississippi’s forestland is dynamic and constantly changing (Mississippi Institute for Forest Inventory, 2006). Forest composition and distribution are affected by several processes of disturbances. Harvest, as the primary human influence, plays an important role in shaping forest structure. For our two harvest regimes, the 20-year logging interval is more suitable for forest age structure regeneration and reproduction than the 40-year interval. Under the 20-year reentry interval, the forest structure in southern Mississippi will maintain steadier condition, and supply more sapling and sawtimber wood than the 40-year reentry interval.
Regular wind disturbances are restricted to small areas and impact forest productivity at the landscape level. However, as a natural force, wind can shape landscape patterns and alter its structural characteristics by changing local habitats for the wildlife.

Comparing harvest and wind disturbance, harvest activities conducted by land managers and industrial landowners seems more deterministic, controllable and predictable, while wind disturbance is stochastic and more related to natural climatic conditions which are hard to predict. We will study natural disturbances caused by climate change in future studies.

Acknowledgement

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