Yield decline and sustainability in Chinese Fir plantations – A simulation investigation to analyze the possible causes

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Plantations in China

- Forest plantations in China are managed to get many different forest products:
  - Timber
  - Resin
  - Mushrooms
  - Litter
  - Firewood
  - Game
  - Others

Chinese fir (Cunninghamia lanceolata (Lamb.) Hook.)

- Component of mixed subtropical evergreen broad-leaved forests.
- Moderate shade-tolerant, but it grows best in full sunlight.
- Moderate nutrient demanding. In unmanaged "natural" forests it normally grows on moist and fertile sites.
- Plantations are generally located on slopes of more than about 20%. Gentle lower slopes generally being used for agriculture.

Yield decline in Chinese fir plantations in China

- Farmers have reported yield declines in multi-rotation Chinese fir plantations since the 1960's, but there were few scientifically rigorous investigations until the late 1970's and the 1980's.
- Some examples of yield decline:

<table>
<thead>
<tr>
<th>Year</th>
<th>2nd rotation</th>
<th>3rd rotation</th>
<th>4th rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>100</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>1970</td>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1980</td>
<td>200</td>
<td>180</td>
<td>90</td>
</tr>
</tbody>
</table>

*Comparisons in the table*
1. Loss of soil fertility caused by short rotations with slash-burning;
2. Slower decomposition of litter and slower N cycle that results from the reduction in quality of litter when mixed species broadleaf forest is converted to intensively managed Chinese fir stands;
3. Increased activity of organic matter and nutrients due to loss in burning that results from slower decomposition of litter and the accumulation of a thin forest floor;
4. Increased erosion losses following burning of slopes;
5. Reduction in tree leaf area that slows tree growth and favors understory vegetation by reducing shading, which in turn increases competition for light and soil resources;
6. Increased competition from herbs and shrubs early in the rotation because they are regrowing as sprouts from rhizomes rather than from seed if the tree leaf area is insufficient to shade them out before the end of the rotation.

**Conceptual model implementation in FORECAST**

FORECAST
- A management-oriented, ecosystem-level modelling framework
- Site-specific, species-specific, and ecosystem condition-specific
- Uses the hybrid simulation approach: empirical historical bioassay + process simulation
- Modular structure designed to permit the addition or removal of complexity from a simulation
- Major focus is the projection of stand development and the assessment of biophysical indicators of sustainability under alternative stand management strategies

**Core ecosystem processes represented in FORECAST**
1. Plant growth and carbon allocation
2. Light limitation
3. Nutrient limitation
4. Moisture limitation
5. Competition for resources

**Evaluation of FORECAST**
- The performance of FORECAST has been evaluated several times:
  - A previous version of FORECAST (FORCYTE-II) was tested against 15 years of field data by Sachs and Trolldalen (1991) with acceptable results.
  - More recently, and after updating and improving the model, partial evaluations of the updated model FORECAST have been conducted (Sasai 2004; Sasai and Welham 2006)
  - The deepest evaluation of FORECAST has been carried out by Blanc et al. (2005) examining model outputs against 20 years of field data in a Douglas-fir plantation.
- Results from these tests show a good performance of FORECAST when calibrated with regional data. This performance is improved by using site-specific data.

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Acknowledgments:
Forecasts:

Simulation runs

- Calibration for low, medium and high quality sites
  - Data from literature of biomass-age, mortality-age, height-age curves
  - Direct samples of nutrient concentrations in soil, trees and understory and litter decomposition rates

- Management scenarios
  - Stand density: 3000 trees ha⁻¹
  - Rotation length: 20, 30, 40 or 60 years
  - Slash burning: no simulation or after harvest and before planting
  - Minor vegetation: no simulation, growing from seeds or growing from rhizomes

Simulation results

- Stand development over 120 years of simulation in fast site with different quality and combinations of slash burning and minor vegetation (simulation data at the end of each rotation)

- Stand development over 120 years of simulation in fast site with different quality and combinations of slash burning and minor vegetation

Conclusions

- Slash burning is the most important determinant in yield decline and site degradation, followed by rotation length.
- Understory vegetation can improve site quality under long rotations but it also can make site productivity decline more serious if slash burning occurs.
- The simulation results coincide reasonably with empirical data on yield decline, but appear to underestimate the problem on poor sites, possible because of the failure to represent erosion.
- The ecological notion for Chinese fir plantations appear to be to 40-60 years if slash burning is not applied. However, this rotation length may be unacceptable to farmers and forest managers from a shorter-term social and economic perspective.
- Yield decline in Chinese fir is an ecosystem-level rather than a population-level phenomenon and simulation of this requires ecosystem-level models that explicitly represent all the major determinants.