Forest Biomass Carbon Storage in Louisiana and its Sensitivity to Future Climate Change

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INTRODUCTION

Global Carbon Cycles

[Diagram showing the carbon cycle with labels and arrows indicating flows and stocks, such as Fossil fuels, Land-use, Photosynthesis, Plant respiration, Soil respiration, Atmospheric CO₂, Global Carbon Cycle, Vegetation, Soils, Ocean, and Net flux values.]
Projected Global Greenhouse Gas Emissions

Approximate CO₂ Equivalent Concentrations (ppm) in 2100:

- B1: 600
- A1T: 700
- B2: 800
- A1B: 850
- A2: 1250
- A1FI: 1550

Source: Climate Change 2007 - Synthesis Report
Carbon Balance of Terrestrial Ecosystems

Photosynthesis

- Uptake of carbon from the atmosphere by plants

Gross Primary Productivity (GPP)
- 120 Gt C y⁻¹

Plant respiration (CO₂)

Net Primary Productivity (NPP)
- 60 Gt C y⁻¹

SOM and litter decomposition (CO₂)

Net Ecosystem Productivity (NEP)
- 10 Gt C y⁻¹

Fires, drought, pests, human activities, etc. (CO₂)

Net Biome Productivity (NBP)
- 0.7±1 Gt C y⁻¹

Source: IPCC (2000)
The Community Climate System Model (CCSM3)
Climate Change in Louisiana Simulated and Predicted with CCSM3

Source: CCSM3 outputs
Forests in Louisiana

- Carbon stock was increased from about 300 Mt in 1950 to about 460 Mt in 2000.
- No watershed scale quantification
- Facilitate the examination of the carbon biogeochemical cycle and budget at natural boundary.
- Provide insights in effects of watershed features on forest growth and carbon storage.
- The climate changes may have significant effect on forest ecosystems.

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>Forest Area</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>*10^3km^2</td>
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<tr>
<td>Deciduous</td>
<td>2.2</td>
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<tr>
<td>Evergreen</td>
<td>20.0</td>
</tr>
<tr>
<td>Mixed</td>
<td>3.7</td>
</tr>
<tr>
<td>Woody wetlands</td>
<td>25.8</td>
</tr>
<tr>
<td>LA state</td>
<td>51.7</td>
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</table>
OBJECTIVE

- To quantify current forest biomass carbon storage at watershed scale.

- To assess potential climate change effects on forest net primary productivity across Louisiana.
METHODS

Quantification of Carbon Storage on Watershed

: Plot
: Thiessen Polygon
: Watershed
: Evergreen

Forest Groups
- Deciduous
- Evergreen
- Mixed
- Woody Wetlands

FIA Plot 2006

Thiessen Polygon

Watershed

Louisiana
Modeling of Future Forest NPP

- PnET –II (net photosynthesis / evapotranspiration) is a canopy-to stand-level model, simulates forest ecosystem processes (C and Water cycles) at month time step using simplified algorithms that describe key biological and hydrologic processes.
- Climate scenarios: A2, A1B, and B1
- Time period: 1960-2050
- Spatial scale: 5 by 5 km
- Cells: 2711
Model Calibration

- Model calibration at the parish level under the assumption:

\[ \text{NPP2005} + \text{Mortality9105} + \text{Removals9105} = \text{NPP1991} + \text{PnETNPP} \]
Sensitivity Analysis

Monte Carlo Simulation:

- **Forests:**
  1. Foliage N concentration
  2. Slope of the relationship between maximum net photosynthesis rate and foliage nitrogen concentration
  3. Fraction of daily maximum photosynthesis
  4. Specific leaf weight at the top of canopy

- **Environmental:**
  1. Maximum and minimum temperature
  2. Precipitation
  3. Radiation
RESULT: FOREST BIOMASS CARBON

Distribution of Forest Biomass Carbon Density
Carbon Storage on Watersheds

Forest Biomass Carbon (ton)
- 0 - 47075
- 47075 - 972811
- 972811 - 1898546
- 1898546 - 7674568

Data Sources: Forest Inventory and Analysis 2006
National Land Cover Dataset 2001
Carbon Density on Watersheds

Carbon Density (ton/ha)
- 0 - 8.8
- 8.8 - 26.3
- 26.3 - 43.8
- 43.8 - 61.3
- 61.3 - 103.4

Data Sources: Forest Inventory and Analysis 2006
National Land Cover Dataset 2001
## Carbon Storage in LA Forests

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>Forest Area *10³km²</th>
<th>Forest Area %</th>
<th>Carbon Density ton/ha</th>
<th>Carbon Storage ton*10⁶</th>
<th>Carbon Storage %</th>
</tr>
</thead>
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<td>4.2</td>
<td>33.6</td>
<td>7.2</td>
<td>3.1</td>
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<tr>
<td>Evergreen</td>
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<td>39.4</td>
<td>77.4</td>
<td>35.3</td>
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<tr>
<td>Mixed</td>
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<td>7.2</td>
<td>37.2</td>
<td>13.8</td>
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<tr>
<td>Woody wetlands</td>
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<td>49.9</td>
<td>47.8</td>
<td>120.8</td>
<td>55.1</td>
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<tr>
<td>LA state</td>
<td>51.7</td>
<td>100.0</td>
<td>43.2</td>
<td>219.2</td>
<td></td>
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</tbody>
</table>
RESULT: FOREST NPP IN RESPONSE TO CLIMATE CHANGE

Model Calibration

\[ \text{NPP2005} + \text{Mortality9105} + \text{Removals9105} = \text{NPP1991} + \text{PnETNPP} \]
Predicted NPP by the Three Climate Change Scenarios

Blue: A1B
Green: A2
Red: B1
Predicted NPP at Grid Scale

Legend

- LA State Boundary
- CCSM3 Climate Data Grid
- NPP (gm^-2)
  - 719 - 824
  - 825 - 936
  - 937 - 1,180
  - 1,181 - 1,243
  - 1,244 - 1,278
  - 1,279 - 1,725
  - 1,726 - 1,753
  - 1,754 - 1,781

Numbers are climate grid ID

Maps show predicted NPP for different years and scenarios.
Sensitivity of FolNCon (A), AmaxB (B), AmaxFrac (C), and SLWMax (D)

- **A**: Mean NPP (gm$^{-2}$)
  - Blue: 1088±246
  - Green: 1121±246
  - Red: 1089±243
  - Black: 1030

- **B**: Mean NPP (gm$^{-2}$)
  - Blue: 1094±247
  - Green: 1126±247
  - Red: 1094±243
  - Black: 1030

- **C**: Mean NPP (gm$^{-2}$)
  - Blue: 1023±122
  - Green: 1060±121
  - Red: 1026±119
  - Black: 1030

- **D**: Mean NPP (gm$^{-2}$)
  - Blue: 1024±54
  - Green: 1060±53
  - Red: 1027±51
  - Black: 1030

Legend:
- Blue: A1B
- Green: A2
- Red: B1
Sensitivity of maximum (A) and minimum (B) temperature, precipitation (C), and radiation (D)

Red: add 1Std
Blue: subtract 1Std
CONCLUSIONS

- Spatial distribution of forests is the main factor affecting spatial patterns and the quantity of standing biomass stock of carbon.
- Among the three climate change scenarios, the predicted NPPs differ mainly among the years, and show apparently trends. However, the average NPP by the scenarios over the years are not significantly different.
- Spatial variability of NPP appears to be primarily a function of temperature.
- Afforestation and reforestation would be a management strategy to accumulate carbon in forest ecosystems for remaining the LA forests as a carbon sink.
THANK YOU
Date Sources

- Forest Inventory and Analysis (FIA) datasets (1991 and 2006)
- The Community Climate System Model (CCSM3) outputs
- National Land Cover Data (1991 and 2001)
- Soil Survey Geographic (SSURGO) Database
- National Hydrography Dataset (NHD)
- Basin Subsegment Layer
- DEM
FIA Plots

- 2899 plots in LA
- Each plot occupies 1 acre forest land, and represents 6,000 acres of land.
- The forest biomass carbon in each FIA plot was computed as half of the sum of dry biomass of all trees with diameter 1 inch or larger in the plot.

Birdsey and Lewis, 2002
Predicted NPP by PnET-II at grid scale (4980 by 4980m) for four dates of 1980, 2000, 2025 and 2050 and three climate scenarios.
Changes in Temperature, Precipitation, and Sea Level

Source: IPCC Climate Change 2007 - The Physical Science Basis of Climate change
Climate change in the past 50 years is highly possible caused by significant increases of greenhouse gas concentrations in atmosphere.

Global-Average Radiative Forcing Estimates and Ranges in 2005

Sources: IPCC, the Physical Science Basis – Summary for Policymakers
US Forest Carbon Storage and Carbon Sequestration

- Total area: 302 million hectares
- Carbon in the forest ecosystem: 52.5 billion tons
The World Forests and Total Carbon Stock

World
3952 million hectares, 30% of the land area

United States
Source: Adapted from USEPA (2003a), and Heath and others (2003)
Figure 3. Percentage change in live vegetation carbon density for the period 2090–2099, as simulated by the MCI model under two future climate scenarios.

Aber et al. 2001. Forest processes and global environmental change: Predicting the effects of individual and multiple stressors. Bioscience, 51, 735-751

http://www.climatescience.gov/Library/stratplan2006/final/ccspstratplan2006-chap7.htm#Question7.1
Figure 1 shows a strong mid-latitude northern hemisphere sink in the three zones between latitude 37 and 64N, peaking between 44 and 53N. The trees and soils of the temperate/boreal forest are assimilating CO2 at a rate of up 2 Pg/year.

Figure 2. Nonfossil net surface sources (positive values) and sinks (negative values) of atmospheric carbon in Pg/year per zone of $18 \times 10^{12}$ m$^{-2}$, calculated taking the role of CO into account. Adapted from (Enting and Mansbridge 1991).
In the 2004 planting season, Louisiana landowners reforested the land with over 128 million seedlings, and at least 29 trees for each Louisiana citizen. Meanwhile, 1.2 billion board feet of sawtimber and 6.3 million cords of wood were harvested. However, the record also indicates, from 1988 through 1997, an average of 3,822 wildfires burned 18,606.64 hectares of forestland each year, by which vast amount of carbon dioxide is released through the forests fires. Quantifying and predicting carbon storage change and sequential potential in such Louisiana forest ecosystem can increase our understanding of the processes that regulate the transport and transformation of carbon within the forest ecosystem,
Main Components of 3-PG

Production of biomass – Based on environmental modification of light use efficiency and constant ratio of NPP to GPP.

Biomass partitioning – Affected by growing conditions and tree size.

Stem morality – Based on self-thinning rule.

Soil water balance – A single soil layer model with evapotranspiration determined from Penman-Monteith equation.

Stand properties – Determined from biomass pools and assumptions about specific leaf area, branch+bark fraction, and wood density.
The 3-PG model requires the following inputs (Landsberg and Waring 1997):

- **Weather data**: temperature, precipitation, humidity, radiation, subfreezing days
- **Initial biomass**: foliage, stems, roots
- **Variables**: maximum available soil water, initial stem number, stand age, maximum stand age
- **Parameters**: canopy photosynthetic efficiency, environmental responses, canopy leaf properties (area, mass, turnover & allometric equations), soil properties (texture, water holding capacity, & fertility index)
• PnET (net photosynthesis / evapotranspiration) is a nested series of models of carbon (C), water, and nitrogen (N) dynamics in forest ecosystems.

• It was built based on two principal relationships: 1) maximum photosynthetic rate is a function of foliar nitrogen concentration, and 2) stomatal conductance is a function of realized photosynthetic rate.
• **Site and soil variables**: latitude (degrees), water hold capacity (plant available water (cm))
• **Canopy variables**: canopy light attenuation constant (no units), foliar nitrogen (percent), foliage retention time (years), leaf specific weight (mg·cm-2)
• **Photosynthesis variables**: intercept/relationship-foliar N-max photosyn. rate, slope\((\mu\text{moles CO}_2\cdot\text{m}^{-2}\cdot\text{leaf}\cdot\text{sec}^{-1})\), half saturation light level (J·m\(^{-2}\cdot\text{sec}\))
• **Water balance variables**: constant for effect of VPD on photosyn. and transpiration, fraction of precipitation intercepted.