Land-Use and Land-Cover Change:

Land Management, Carbon Storage, and Policy Implications for the Southeast US Coastal Plain
Authors and Team: A Very Complex System

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• Henry Gholz (Terrestrial Ecosystem Ecologist)
• Scot Smith (Remote Sensing/GIS Specialist)
Objectives

(1) to determine the links between changes in land ownership, land management, land cover change, and carbon storage patterns within the southeastern lower coastal plain region of the United States;

(2) to determine the effects of land ownership patterns on the carbon storage and sequestration rates of a representative regional ecosystem at already established long-term intensive research sites.
Science Implications

• Regionalizing point measurements – scaling from towers to landscapes (bottom-up not top-down).
• Measuring human activity as a factor driving land-cover/land-use change.
• Developing empirical models of biomass/carbon in land cover classes in a large physiographic region (~ecoregion).
• Developing estimates of C storage change based on extensive and intensive measurements of biomass and carbon exchange in several major land-cover classes.
Study Area

Figure 2. Physiographic provinces of the southeastern U.S.
Study Area

~15-km square

Landsat WRS 2 P17 R39
Using eddy covariance for estimating NEE

Figure 2. Landsat TM imagery from 27 March 1997. A. "True-color" image using bands 3, 2, and 1 for red, green, and blue. B. Interpret results of an unsupervised land-cover classification.

Industrial Forestry – Slash Pine
Vegetation Dynamics and Carbon Sequestration in North Florida

Landsat TM/ETM 5,4,3 = R,G,B Composite
Alachua County Study Site
Landscape Dynamics

• Vegetation is Dynamic

• Ownership is Dynamic

• Management is Dynamic

Jan 1998

Jan 1999

Hamilton County

Clay County
Approaches to Linking Ecosystem Research with Satellite Data

• Land-cover classification, including age classes for plantation pine, linked to
  – Look-Up-Tables of Net Ecosystem Exchange measured by eddy-flux towers, and Total Ecosystem Biomass/C measured in many sites over many years.
  – LUT of C removal by Fire and Harvest

• Continuous field
  – Statistical relationships between RS data and C storage
  – Artificial Neural Network approaches to estimating C storage from RS data

• Ecosystem modeling (Biome-BGC) expressed spatially by forest age
  – Accounting for climate variation
Method

- **Time-series (1972-2002) Landsat data for study area.**
- **Preprocessing, Classification to Known Land-cover Classes.**
- **Time-series maps of Land-cover (forest age group) classes.**
- **Combine and Extract**
  - Tables of NEE, Fire Losses, Cutting Losses for each Land-cover Class.
- **Overlay and extract**
  - Time-series maps of Land-ownership.
- **Table and Graph of Net Ecosystem Carbon Exchange 1976-2000**

- **20+ years of ecosystem research.**
- **Table and Graph of Net Ecosystem Carbon Exchange 1976-2000 as a Function of Land-ownership.**
Land-Cover Change is Continuous
Land-cover From-To Analysis

Change Matrix 1998 - 1999 (after the great Waldo fire of 1998)

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Total</th>
<th>Burned hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-3 yr plantation_Clearcut</td>
<td>1</td>
<td>681</td>
<td>1042</td>
<td>1413</td>
<td>592</td>
<td>146</td>
<td>535</td>
<td>546</td>
<td>4955</td>
</tr>
<tr>
<td>4-8 yr plantation</td>
<td>2</td>
<td>291</td>
<td>2013</td>
<td>843</td>
<td>838</td>
<td>49</td>
<td>447</td>
<td>183</td>
<td>4666</td>
</tr>
<tr>
<td>8+ yr plantation</td>
<td>3</td>
<td>0</td>
<td>270</td>
<td>1756</td>
<td>122</td>
<td>0</td>
<td>269</td>
<td>1</td>
<td>2417</td>
</tr>
<tr>
<td>Cypress and other wetlands</td>
<td>4</td>
<td>19</td>
<td>685</td>
<td>315</td>
<td>1533</td>
<td>5</td>
<td>201</td>
<td>52</td>
<td>2810</td>
</tr>
<tr>
<td>Agricultural crops</td>
<td>5</td>
<td>395</td>
<td>90</td>
<td>28</td>
<td>46</td>
<td>886</td>
<td>6</td>
<td>374</td>
<td>1825</td>
</tr>
<tr>
<td>Older/natural regenerated pine forest</td>
<td>6</td>
<td>4</td>
<td>406</td>
<td>743</td>
<td>198</td>
<td>0</td>
<td>538</td>
<td>10</td>
<td>1901</td>
</tr>
<tr>
<td>Urban (ignore)_road</td>
<td>7</td>
<td>170</td>
<td>348</td>
<td>14</td>
<td>187</td>
<td>98</td>
<td>31</td>
<td>649</td>
<td>1497</td>
</tr>
<tr>
<td>Total</td>
<td>1560</td>
<td>4855</td>
<td>5112</td>
<td>3516</td>
<td>1185</td>
<td>2026</td>
<td>1815</td>
<td>20071</td>
<td>2835</td>
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</tbody>
</table>

Total Unchanged = 8057
Percent Unchanged = 40
Land-Cover – Carbon Dynamics: Linking Ecosystem Research with Satellite Data

Fire Effects

<table>
<thead>
<tr>
<th>Age Classes</th>
<th>Biomass Removal (T ha-1)</th>
<th>std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>4-8</td>
<td>4.3</td>
<td>3.3</td>
</tr>
<tr>
<td>&gt; 8</td>
<td>38.2</td>
<td>15.7</td>
</tr>
</tbody>
</table>

Positive values indicate net C uptake by the ecosystem, negative values indicate net C output from the system.

Total Landscape $C_{exc} = \Sigma \text{(Class area \times C}_{exc} \text{ area}^{-1})$

NEE estimates for age classes:

<table>
<thead>
<tr>
<th>Age Class</th>
<th>NEE (g C m$^{-2}$ y$^{-1}$)</th>
<th>NEE (T C ha$^{-2}$ y$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3 yr plantation Clearcut</td>
<td>-850</td>
<td>-8.50</td>
</tr>
<tr>
<td>4-8 yr plantation</td>
<td>145</td>
<td>1.45</td>
</tr>
<tr>
<td>8+ yr plantation</td>
<td>575</td>
<td>5.75</td>
</tr>
<tr>
<td>Cypress and other wetlands</td>
<td>60.5</td>
<td>0.61</td>
</tr>
<tr>
<td>Agricultural crops</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Older/natural regenerated pine forest</td>
<td>180</td>
<td>1.80</td>
</tr>
<tr>
<td>Urban (ignore)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>water (ignore)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
One Part

- 20+ years of ecosystem research.
- Tables of NEE, Fire Losses, Cutting Losses for each Land-cover Class.
- Overlay and extract Time-series maps of Land-ownership.

Table and Graph of Net Ecosystem Carbon Exchange 1976-2000 as a Function of Land-ownership
### Regional Annual Carbon Budgets 1976-2000 (T landscape\(^{-1}\))

<table>
<thead>
<tr>
<th>Year</th>
<th>NEE</th>
<th>Fire</th>
<th>Harvest</th>
<th>Total C Exchange</th>
<th>Total C Exchange without harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>10289</td>
<td>-5719</td>
<td>4570</td>
<td>10289</td>
<td></td>
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<tr>
<td>1981</td>
<td>25306</td>
<td>-16164</td>
<td>9143</td>
<td>25306</td>
<td></td>
</tr>
<tr>
<td>1982</td>
<td>14155</td>
<td>-16235</td>
<td>-2080</td>
<td>14155</td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td>26710</td>
<td>-295</td>
<td>-8043</td>
<td>18372</td>
<td>26415</td>
</tr>
<tr>
<td>1986</td>
<td>13651</td>
<td>-17288</td>
<td>-3637</td>
<td>13651</td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>6196</td>
<td>-22187</td>
<td>-15991</td>
<td>6196</td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>256</td>
<td>-4299</td>
<td>-4043</td>
<td>256</td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>11795</td>
<td>-11218</td>
<td>577</td>
<td>11795</td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>7287</td>
<td>-15539</td>
<td>-8252</td>
<td>7287</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>980</td>
<td>24723</td>
<td>-25703</td>
<td>-980</td>
<td></td>
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<tr>
<td>1992</td>
<td>17588</td>
<td>-9698</td>
<td>7890</td>
<td>17588</td>
<td></td>
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<tr>
<td>1993</td>
<td>8952</td>
<td>-148</td>
<td>-6300</td>
<td>-9307</td>
<td>-3007</td>
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<tr>
<td>1994</td>
<td>15005</td>
<td>-5319</td>
<td>9686</td>
<td>15005</td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>34243</td>
<td>-4440</td>
<td>29802</td>
<td>34243</td>
<td></td>
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<tr>
<td>1996</td>
<td>25272</td>
<td>-2221</td>
<td>23050</td>
<td>25272</td>
<td></td>
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<tr>
<td>1997</td>
<td>28950</td>
<td>-11066</td>
<td>17884</td>
<td>28950</td>
<td></td>
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<tr>
<td>1998</td>
<td>-16332</td>
<td>-51187</td>
<td>-43379</td>
<td>-110898</td>
<td>-67519</td>
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<tr>
<td>1999</td>
<td>-16332</td>
<td>-219</td>
<td>-343</td>
<td>-16894</td>
<td>-16552</td>
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<tr>
<td>2000</td>
<td>-33028</td>
<td>-15568</td>
<td>-48596</td>
<td>-48596</td>
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<tr>
<td>Average</td>
<td>8799</td>
<td>-12455</td>
<td>-6549</td>
<td>5250</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>167172</td>
<td>-67417</td>
<td>-224182</td>
<td>-124427</td>
<td>99755</td>
</tr>
</tbody>
</table>
Vegetation Dynamics and Carbon Sequestration in North Florida

Total Carbon Exchange - Alachua Study Area

Carbon Exchange (T yr⁻¹)

Year

Continuous-Field C Estimates

Total Ecosystem Biomass \( (g \, m^{-2}) = -1298.90 + 1287.41 \times (SR) \)

Total Ecosystem C = Total Ecosystem Biomass / 2

\( R^2 = 0.88 \)

Jan 1998
Total C = 3,655,000 T

Jan 1999
Total C = 3,799,200 T

Jan 2000
Total C = 3,721,540 T
Climate Variation: Previous research showed that…

- Plantation pine growth is not affected by irrigation or impacted by water table depth under “average conditions”
- And that growth is primarily nutrient limited

So no further attention was placed on modeling interactions between $C$ and $H_2O$
But a “100 year drought” occurred in 1999-2002, altering our modeling strategy.
Mean NDVI time series (1972-2000), north Florida 15 x 15 km landscape

![Graph showing Mean NDVI time series (1972-2000), north Florida 15 x 15 km landscape. The y-axis represents Mean NDVI values ranging from -0.1 to 0.7, and the x-axis represents dates from 31-Dec-70 to 23-Dec-02. Error bars indicate the standard deviation within the 15 x 15 km site.]
Developing a Spatio-Temporal Cadastral Database

Original Rectangular PLSS Subdivisions

Current Cadastral Parcels (2000)
Definition

• Land Tenure

The social institution (rules, rights, restrictions) that controls the use and allocation of land and its associated resources
Cadastral Methods – Field Work

Extracting Cadastral Data from the Alachua County Property Appraiser’s Office
Typical Appraiser’s Tax Map
Reconstruction of Parcel Histories

2000 (4th Generation)
201
401 402
403 404 405
301 302 303
1990 (3rd Generation)
1980 (2nd Generation)
1975 (1st Generation)
201

1980 (2nd Generation)
1975 (1st Generation)

1990 (3rd Generation)
201

2000 (4th Generation)
201

1975 (1st Generation)
100

1980 (2nd Generation)
201

1980 (2nd Generation)
201

1990 (3rd Generation)
201

1990 (3rd Generation)
201

1980 (2nd Generation)
201

1975 (1st Generation)
100

1975 (1st Generation)
100
Object-oriented Parcel Data Tracking: Linking Location, Time, and Description
Ownership Evolution 1975-2000

Hamilton County

Clay County

1975 1990 2000
Ownership Classes of Clay County – 1975 to 2000

Year


% Area

Commercial
Government
Private
Timber Co
Urban/Other
Integration of Ownership and Land Cover – Hamilton County
Main Points

• The world in a grain of sand – 15 km square to represent the entire SE US Coastal Plain
• Exercise in inductive reasoning
• Link to regional scale (Turner)
  – Cause -> Outcome
• Linkage of \textit{in situ} observations to satellite data (Skole)
• Management usually ignored (Houghton)
Main Points 2

• Carbon dynamics
  – NEE fairly stable $\sim 10,000 \text{ T C yr}^{-1} \text{ landscape}^{-1}$
  – Variation mostly a consequence of harvesting
    • Cutting resets NEE, initially highly negative
    • Cutting removes C from landscape (but not necessarily adds to atmosphere)
  – Fire has immense effect
    • Huge loss of C to atmosphere
    • Periodic
    • Resets NEE level over large and small areas
Main Points 3

• Only now (after 2 years of study) linking to land ownership, but is very difficult.
• Will not explain land-cover or C dynamics, but is necessary first step.
  – Owners can conduct activities, make decisions
  – Owners can lease rights of land-cover activities to others who make decisions
• Land Tenure and Management Practices are proximate causes
  – Harvest rotation period, Fertilization, Thinning
  – Fire management
  – change in land use
Land Policy/Tenure provides the rules, rights, restrictions that control management and use of the land/resources (Rules of the Game).

Land Use/Management operates at local scale (Playing of the Game).

Tenure/Policy operates at national/state level.
Main Points 4

• Future:
  – Paper-products companies who do own land are increasingly quitting the lumber business to become land-development companies
    • St. Joe Paper Co. -> St. Joe Development Co.
    • Georgia-Pacific
    • Others?
  – Land owners are changing
    • Heirs selling off
    • Insurance companies (Holding companies)
  – Are these and other factors incorporated into landscape-change models?
Policy Implications

• Public policies
  – Land purchases
  – Conservation Easements

• Private interests
  – Land-use restrictions

• Research policies
  – Inherent complexity
    • Captured by modeling?
The End