Late-Successional and Old-Growth Forest Carbon Temporal Dynamics in the Northern Forest (Northeastern USA)

Principal Investigator(s): (PI) John S. Gunn, Ph.D. [1], (co-PI) Mark J. Ducey, Ph.D.[2], and (co-PI) Andrew A. Whitman[1]
Affiliations/Institutions:[1]Manomet Center for Conservation Sciences;
[2] University of New Hampshire
Email: jgunn@manomet.org
Mailing address:14 Maine St., Suite 410, Brunswick, ME 04011

Completion date: September 30, 2012

- Late-successional (LS) and Old-growth (OG) aboveground live carbon (C) stocks are very high relative to regional mean, LS plots accumulating aboveground live C at positive rate (0.61 Mg/ha/yr) while live C stocks on OG plots are declining (-0.54 Mg/ha/yr). This is likely driven by beech bark fungus (*Nectria* sp.) targeting a single species leading to mortality in large diameter American beech (*Fagus grandifolia)* trees.
- The Northeast Variant of the Forest Vegetation Simulator is not a reliable predictor of aboveground live carbon accumulation rates in Northeastern LS and OG stands.

Funding support for this project was provided by the Northeastern States Research Cooperative (NSRC), a partnership of Northern Forest states (New Hampshire, Vermont, Maine, and New York), in coordination with the USDA Forest Service.
http://www.nsrcforest.org

Project Summary

- Comprehensive data on the capacity and rates of change for carbon pools in managed and unmanaged forests is essential for evaluating climate change mitigation options being considered by policy makers at regional and national levels. We currently lack real and long-term data on forest carbon dynamics covering a wide range of forest management practices and conditions. Because of this, selecting the best policies for conserving forest carbon must rely on forest growth and yield models such as US Forest Service Forest Vegetation Simulator (FVS) to predict the future forest carbon impacts of management actions. FVS may underestimate the capacity of older stands to accumulate carbon because the model relies on US Forest Service Forest Inventory and Analysis data that lack data from late-successional and old-growth (LSOG) stands. Improving these models will increase the likelihood of selecting policies that successfully use forests to reduce atmospheric carbon.
- From 1995 to 2002, Manomet conducted research on 65 10m by 50m permanent plots to evaluate forest structure (standing live and dead trees, and down coarse woody material) in LSOG stands across northern Maine. These plots were re-measured in 2011 to assess long-term carbon sequestration trends in LSOG stands of common forest types in the Northern Forest region for above ground alive, standing dead, and coarse woody material carbon pools. Late-successional (LS) and Old-growth (OG) aboveground live carbon (C) stocks were very high relative to regional mean (2.4-2.6 times the mean), LS plots were accumulating aboveground live C at positive rate (0.61 Mg/ha/yr), while C stocks on OG plots are declining (-0.54 Mg/ha/yr). This change is driven by the presence of beech bark fungus (*Nectria* sp.) that is leading to mortality in larger diameter American beech trees. We also found that the Northeast Variant of the Forest Vegetation Simulator is not a reliable predictor of aboveground live carbon accumulation rates in Northeastern LS and OG stands.
- This work provides important baselines for understanding the role of older forests and forest management within climate change mitigation strategies in the northeastern US. Northeastern LSOG forests can play an important role in mitigating climate change, but understanding and quantifying natural disturbance risk to forest carbon stocks is critical for successful implementation. Further, regional forest carbon models will need further calibration to accurately predict carbon accumulation rates in older forests.

Background and Justification

- Forests play a critical role in global storage and emission of biogenic carbon (C).
- Contrary to previous scientific thinking, recent research suggest that old forests may continue to serve as “carbon sinks” (Luyssaert et al. 2008); hence, the common assumption that northeastern late-successional and old-growth (LSOG) forests are net emitters of C deserves reexamination.
- Very little “old-growth” forest remains in the northeastern United States and long-term data on C dynamics and storage capacity of older forests is lacking.
- In Wisconsin, a region with similar forests and history, the current forest C stocks have only recovered to 49% of pre-settlement levels (Rhemtulla et al. 2009). A similar conclusion likely could be made for the Northern Forest, given an historically older age-class distribution than current day (Lorimer 1977).

Figure 1a. Example of an old-growth (OG) study plot in a hardwood-dominated stand in northern Maine, USA.

Background and Justification

- Comprehensive data on the storage capacity and rates of change of C in LSOG forests is essential for evaluating the full range of forest C mitigation and management options and as part of life cycle C accounting.
- We lack real, long-term data on forest C dynamics covering a wide range of forest management practices and conditions.

Figure 1b. Example of an old-growth (OG) study plot in a hardwood-dominated stand in northern Maine, USA.

Background and Justification

- The work presented here provides a long-term (>15 years) assessment on forest C stocks and rates of change using permanent sample plots in late-successional (LS) and old-growth (OG) stands in the Northern Forest of Maine (USA).
- These data can be used to inform forest growth and yield models such as US Forest Service Forest Vegetation Simulator (FVS) that are used to predict impact of management actions on future forest C levels.
- Emerging forest carbon offset protocols also require field-based benchmarks data to evaluate management trajectories and calculate a baseline and estimate the size of offset.

Figure 1b. Example of an old-growth (OG) study plot in a hardwood-dominated stand in northern Maine, USA.

Methods

- In 2011 we re-measured late-successional (n=23) and old-growth (n=35) permanent vegetation sampling plots at two sites in Maine.
- The original plots were marked with re-bar and PVC pipe and mapped using both GPS (± 10m) and reference landmarks (including directions from nearest logging road).
- Old growth plots (OG; >120 years old) were first measured in 1995. Late-successional plots (LS; 80-150 years old) were first measured from 1998 to 2002.

Figure 2. Plot locations. A) OG Plots in Big Reed Forest Reserve (owned by The Nature Conservancy). B) LS Plots in Kibby and Skinner Townships (owned by Plum Creek Timber Company, Inc.).

Methods

- LS plots were in ecologically mature stands and classified based on the Whitman and Hagan (2007) late-successional forest index and had evidence of historical logging.
- OG plots have no evidence of stand-replacing disturbance in the last 120-280 years (Fraver et al. 2009).
- We re-measured plots using the same methods used in the initial studies (e.g., Gunn and Hagan 2000): measuring diameter at breast height (DBH) and assessing decay stage of live and dead trees (> 8 cm DBH), and measuring length and diameters of downed CWD (> 10cm mid-point diameter and > 30 cm in length) and assigning each CWD to a decay stage, all within a 1/20th ha plot (10 x 50m).

Figure 3a. Re-establishing plot boundaries in a late-successional (LS) stand (softwood dominated) in northwestern Maine, USA.

Methods

- We compared aboveground C biomass stock changes between measurements by C pool type (aboveground live and dead standing). Coefficients from Jenkins et al. (2003) and Harmon et al. (2011) were used to convert species class, volumes, and decay class data to estimates of C volume per ha (MgC/ha).
- We used the Northeast Variant of the FVS growth and yield model to simulate growth from the initial measurement year to 2011. Aboveground live tree carbon stocks (MgC/ha) and growth rates (MgC/ha/yr) were compared with values from the field-measurements.

Figure 3b. Re-establishing plot boundaries in a late-successional (LS) stand (softwood dominated) in northwestern Maine, USA.

Results/Project outcomes

- In 2011, both OG and LS mean aboveground live carbon stocks were 2.4-2.6 times greater than the mean stocks for similar stand types in the region (Fig. 4). Individual stands exceed the mean carbon stocking by as much as 5.2 times.
- Dead standing carbon stocks represent 10% of total standing stocks in LS plots compared to 15% in OG.
- Dead and Down C Pools represented 9% of OG and 4% of LS aboveground total carbon volume in 2011 compared to 12% and 6% in the initial measurements.
- Dead and Down C Pools declined in both LS and OG from the initial measurements to 2011. Methodological differences are likely responsible for some of that difference.

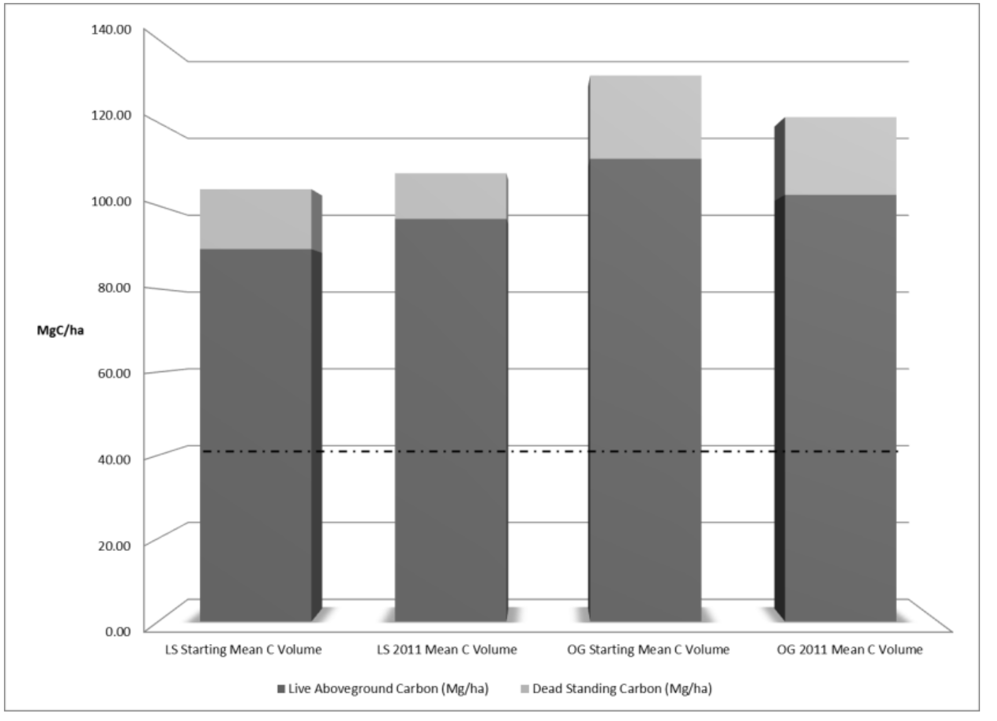

Figure 4. Mean aboveground live and dead standing carbon stocks for LS and OG plots (starting inventory and 2011). Dotted line represents the White Mountains Ecoregional Supersection mean carbon stocking (from: Appendix F, Climate Action Reserve Forest Project Protocol Version 3.2).

Results/Project outcomes

- Mean LS aboveground live C stocks have increased since the initial inventories (1998-2002 to 2011, Fig. 5a). However, mean 2011 OG aboveground live C stocks have declined since the initial inventory in 1995 (Fig. 5b).
- Mean dead standing C stocks decreased on LS plots from 14.44 Mg/ha (SD=15.78) to 11.02 Mg/ha (SD=7.32). OG dead standing C also declined slightly from 20.10 Mg/ha (SD=17.6) in 1995 to 18.71 Mg/ha (SD=13.01) in 2011, but remained constant as an overall percentage of the total standing C volume (~15%).

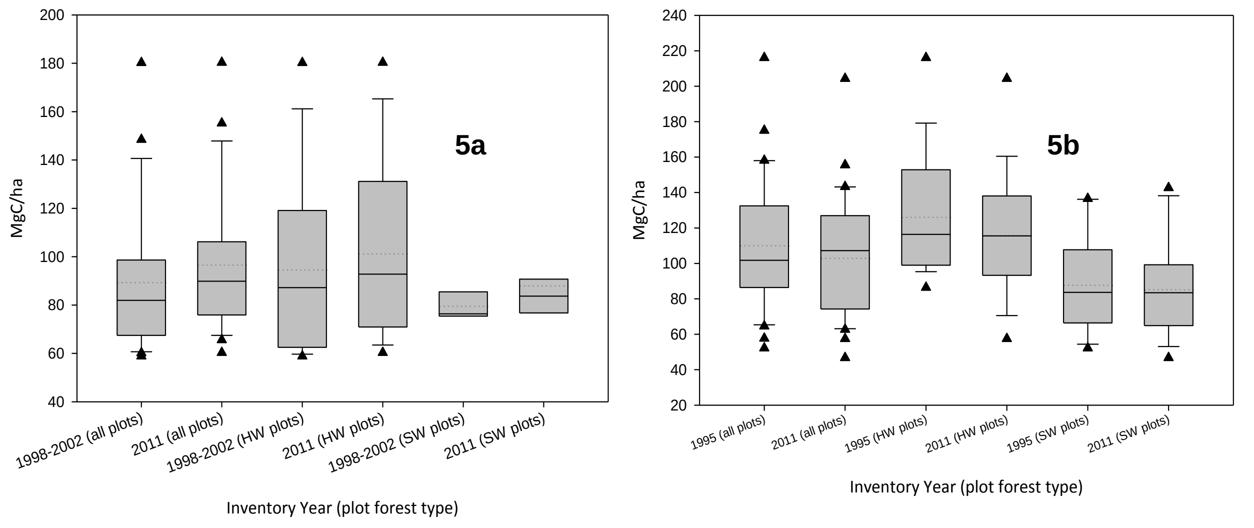

Figure 5a. Box plots showing aboveground live C stocks on LS plots. Solid line is the median and the dotted line represents the mean. The box represents the 25th to 75th percentiles and the bars represent the 10th and 90th percentiles. Outliers are shown as solid triangles. (HW = hardwood basal area >50%; SW = softwood basal area >50%).
Figure 5b. Box plots of aboveground live C stocks on OG plots.

Results/Project outcomes

- We fit linear models to predict annual change in C storage (see Fig. 6) using the following variables: stand age (LS vs. OG), stand type (softwood vs. hardwood), initial carbon stocks (total live C per hectare), initial beech basal area, trees/ha, and mean DBH. Backward selection using AIC led to a final model including only initial carbon stocks and initial beech basal area as predictors (both terms were significant at $p<0.01$).

  The resulting model is:

  Annual C change, Mg/ha = 1.237-0.008*(initial carbon, Mg/ha)-0.1249*(initial beech basal area, m^2/ha), $R^2=0.368$, $p<0.0001$

- Mean annual change in LS aboveground live C was positive (0.61 MgC/ha/yr, SD=0.69, Fig. 6), while OG generally lost C from the aboveground live stocks (mean = -0.54 MgC/ha/yr, SD=1.31, Fig. 6). Change in OG Aboveground Live C was largely being driven by American beech (*Fagus grandifolia*) decline (from 15% to 7% of total C volume).

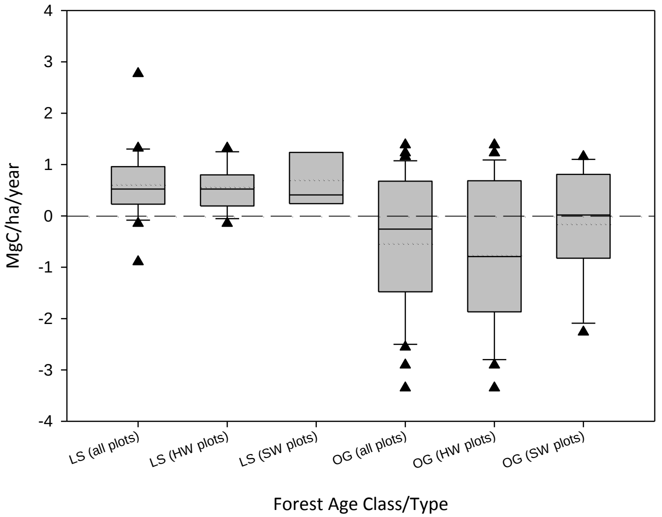

Figure 6. Box plots showing annual aboveground live C stock change on LS and OG plots.

Results/Project outcomes

- FVS modeled growth was were poorly correlated with observed changes in carbon stocks for both LS and OG stands
- The FVS model greatly overestimated increases in carbon stocks in OG stands, probably because the model does not accurately account for *Nectria*-related mortality of beech.
- FVS also over predicted increases in carbon stocks on average in LS plots

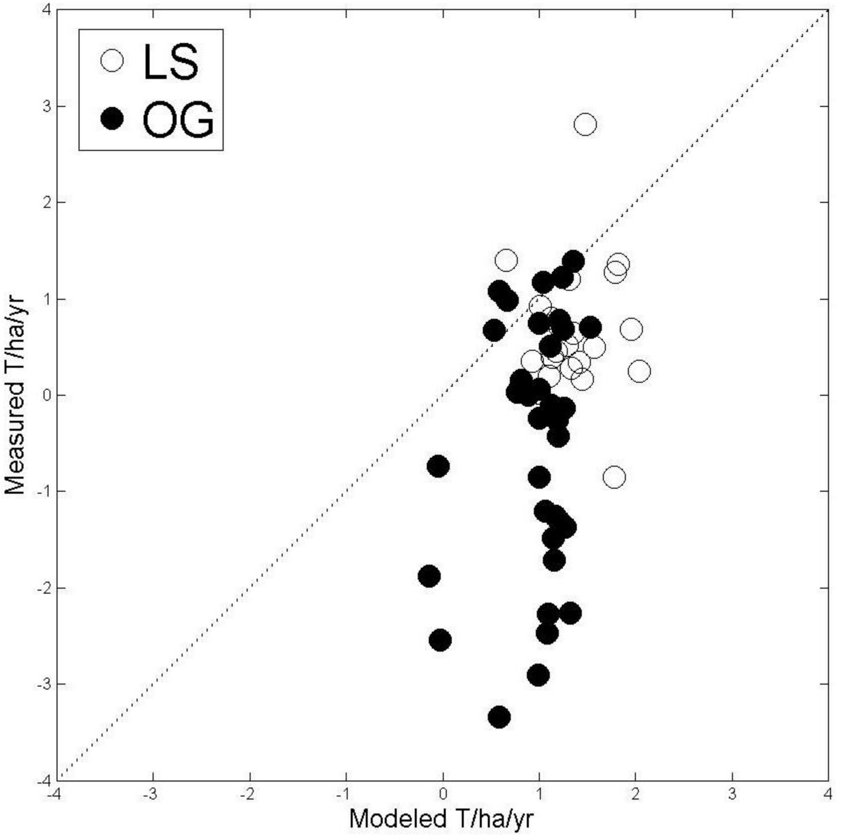

Figure 7. Scatterplot showing field-measured carbon stock change vs. FVS-predicted carbon stock change over time

Results/Project outcomes (outreach efforts)

- December 8, 2011. American Geophysical Union Fall Meeting, San Francisco, California. Presentation (poster). Late-Successional and Old-Growth Forest Carbon Temporal Dynamics in the Northern Forest (Northeastern USA)
- March 15, 2012. Invited Presenter. Carbon Potential of Maine's Forests. National Indian Carbon Coalition Workshop. Houlton, Maine 15 people.
- June 20, 2012. Invited Presenter. Earth Smart: Farming for the Future Workshop. Carbon Potential of Maine's Forests. Hallowell, Maine 30 people.
- Proposed presentation: 2013 New England SAF Spring Meeting, May 15 - 17, 2013 Bethel, ME
- Forest Ecology and Management peer-reviewed manuscript in preparation

Implications and applications in the Northern Forest region

- Late-successional and old-growth forests in Maine and the Northern Forest in general can store a large amount of carbon aboveground relative to regional means.

- However, understanding the risks posed by natural disturbance and exotic diseases (e.g., species-specific insect infestation and disease) to carbon stocks will be critical to selecting climate change mitigation strategies that result in long-term forest carbon storage.

Figure 8. Recent beech mortality in the canopy of an OG study plot, Big Reed Forest Preserve, Maine.

Implications and applications in the Northern Forest region

- Ability of LSOG stands in the northern forest to sustain prolonged carbon gain depends on abundance of beech.
- To accurately describe LSOG carbon dynamics, FVS would require modifications that include beech bark disease scenarios.
- Local calibration of FVS is needed to make it accurate for predicting forest carbon stocks of LSOG forest – but there is a paucity of “calibration” data available for LSOG forests.

Future directions

- Natural disturbance regimes and climate change will greatly influence the carbon storage capacity of Northeastern Forests. Quantification of this risk for different forest types and age classes will be an important area of climate change mitigation research.
- Calibration and structural improvement of existing forest growth and yield models will help us better predict possible carbon storage trajectories.
- Continued monitoring of LSOG forests using permanent plots will provide vital data for model calibration and evaluation, and for detecting impacts of disease and climate change on carbon sink potential.

List of products

- Gunn, J.S., Ducey, MJ, and AA Whitman (in prep) Late-Successional and Old-Growth Forest Carbon Temporal Dynamics in the Northern Forest (Northeastern USA) Intended for Forest Ecology and Management (expected submission November 2012)
- December 8, 2011. American Geophysical Union Fall Meeting, San Francisco, California. Presentation (poster). LSOG Carbon Dynamics.
- March 15, 2012. Invited Presenter. National Indian Carbon Coalition Workshop. Houlton, Maine 15 people.
- June 20, 2012. Invited Presenter. Earth Smart: Farming for the Future Workshop. Hallowell, Maine 30 people.
- Leveraged Grants: Davis Conservation Foundation ($10,000), Emily V. Wade Fund for Science ($12,500), Fox Family Foundation ($5,000), and Manomet Center for Conservation Sciences. Mark Ducey also made a significant in-kind contribution of time for FVS modeling and statistical analyses.