

How Silvicultural Treatments Affect Carbon Storage in a Northern Conifer Forest: A 60-Year Perspective

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<http://www.nsrcforest.org>

Project Summary

Developing strategies for increasing carbon (C) storage in forests is one of the foremost challenges facing natural resource professionals today. However, knowledge regarding the impacts of alternative management strategies on C cycling in many forest types remains imperfect. The goal of this study was to evaluate total ecosystem and harvested wood product C stocks among alternative forest management strategies (selection cutting, shelterwood cutting, commercial clearcutting, and no management) in mixed-species stands in central Maine, USA. These strategies were initiated in the 1950s and have been maintained since, and ecosystem C pools were measured in 2012. When compared across managed treatments, the commercial clearcut had the lowest total ecosystem C stocks by 21%, on average ($P < 0.05$), while the selection and shelterwood treatments had similar total ecosystem C stocks. Including the C stored in harvested wood products did not influence observed differences in C storage among treatments. Total ecosystem C stocks in the reference stand were $247.0 \pm 17.7 \text{ Mg ha}^{-1}$ (mean \pm SD) compared to $161.7 \pm 31.3 \text{ Mg ha}^{-1}$ in the managed stands. When C stored in forest products was added to total ecosystem C stocks, ecosystem + products C stocks were $171.2 \pm 31.7 \text{ Mg ha}^{-1}$ for the managed stands. This study highlights the impacts of long-term forest management strategies on C storage and indicates that the timing of harvests and the species and sizes of trees removed influence C stored in harvested wood products.

Background and Justification

- Concerns about climate change have increased interest in developing management strategies to maximize carbon (C) storage in forests.
- A better understanding of how accounting for C stored in wood products influences comparisons of C storage among management strategies, particularly between managed and unmanaged stands, is needed to identify forest management strategies that are best suited for maximizing C storage.
- Comprehensive and long-term studies where all major ecosystem C pools are measured and compared are relatively rare, particularly in naturally-regenerated, mixed-species forests, which are relatively more common in the Northern Forest region when compared to single-species plantations.
- Site quality likely influences total ecosystem C storage. However, most studies of total ecosystem C storage have not included indicators of site quality in their assessments, which could influence treatment comparisons.

Methods

- The study was conducted on the Penobscot Experimental Forest in central Maine, where alternative management strategies were initiated in the 1950s.
- C pools were evaluated in stands managed according to three prescriptions (single-tree selection cutting on a 5-year cycle, three-stage shelterwood cutting, and commercial clearcutting) and an unmanaged reference stand.
- The selection stands had been cut 11 times prior to our sampling in 2012. In the shelterwood stands, the final overstory removals occurred during the 1970s, and no management activities have taken place since. In the commercial clearcut stands, merchantable trees were harvested in the 1950s and 1980s leaving undesirable trees scattered or in small patches.
- In 2012, live trees, dead wood, understory plants, and soils were measured on permanent plots to estimate total ecosystem C. Long-term data collected from the permanent plots were also used to determine C storage in below-ground dead root systems, and harvested wood products and landfills.
- In 2013, additional soil samples were collected and C concentrations were determined for herbaceous, O horizon, and mineral soil samples.

Methods

Reference



Selection



Methods



Results

Site quality

- This study was conducted on soils derived from glacial till parent material.
- The relative volume of coarse fragments in the mineral soil was negatively correlated with live tree, aboveground, and total ecosystem C stocks.
- Depth to the seasonal high water table influenced the coarse woody debris C pool and the relative volume of coarse fragments in the mineral soil influenced the mineral soil C pool, but the magnitude and direction of the relationships varied by treatment.



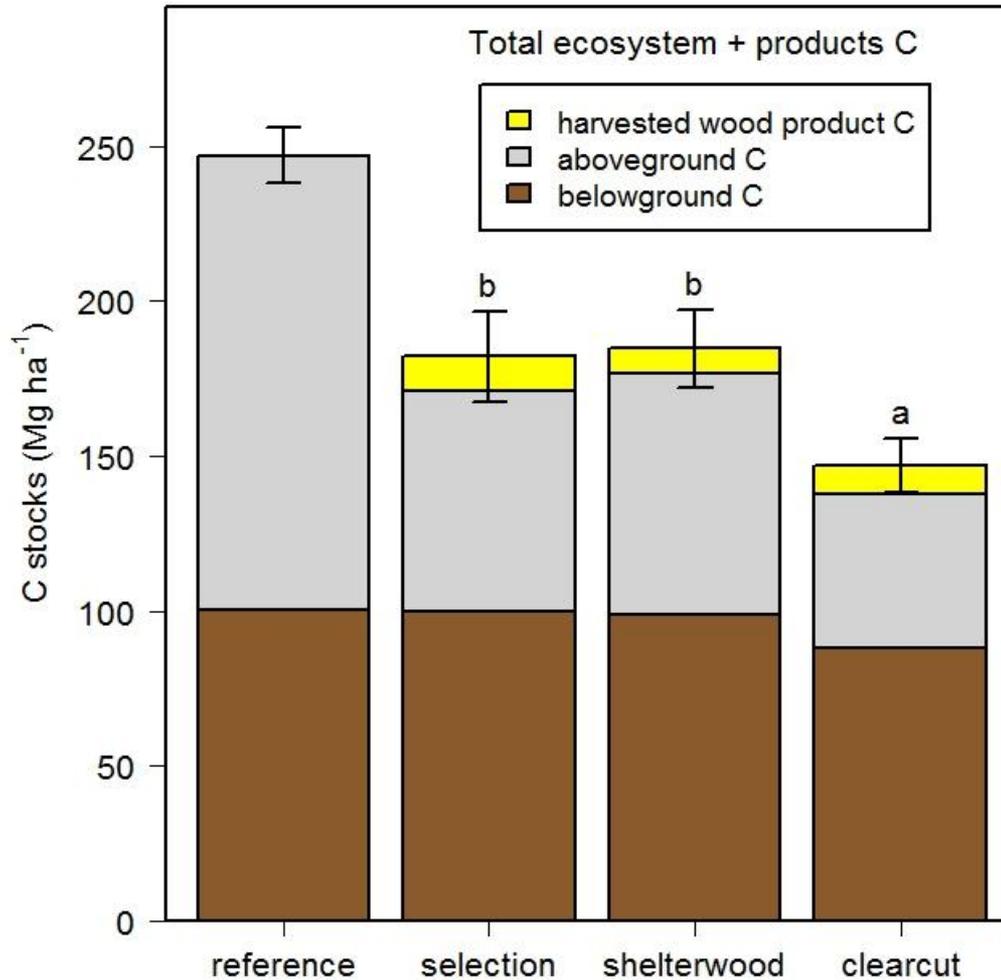
Results

Unmanaged vs. managed stands

C stock (Mg ha ⁻¹ ; mean ± SD)	Reference stand	Managed stands
Total ecosystem	247.0 ± 17.7	161.7 ± 31.3
Total ecosystem + wood products	247.0 ± 17.7	171.2 ± 31.7



Results



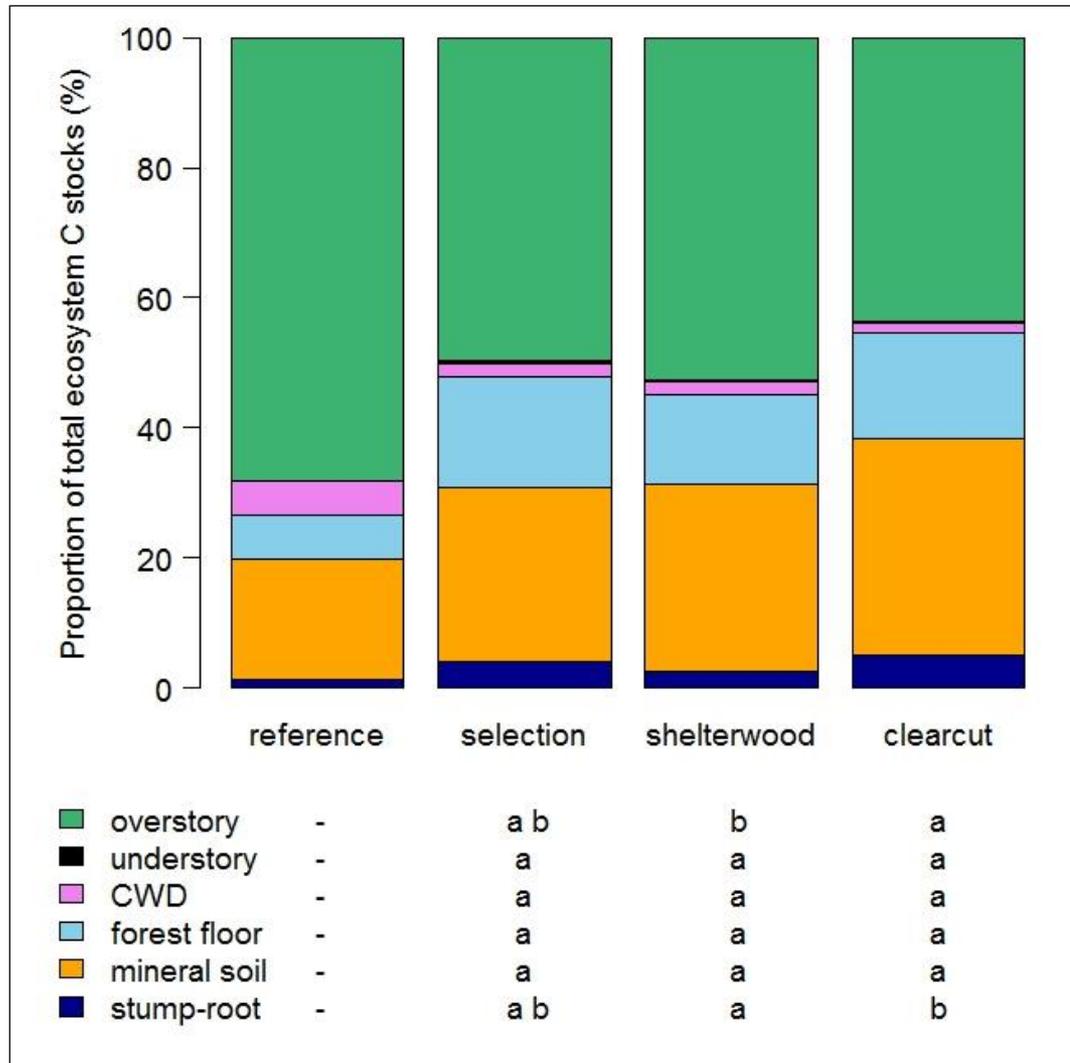
Mean and standard error of total ecosystem C (TEC) plus C stored in harvested wood products (Mg ha⁻¹). Different letters indicate significantly different least-squares means at the average relative volume of coarse fragments in the mineral soil (33.6%). Note that the reference was not included in pairwise comparisons tests.

Results



Mean and standard error of C stored in harvested wood products (Mg ha⁻¹) by forest management treatment. Pairwise comparison tests indicated no significant differences in least-squares means.

Results



C storage in ecosystem pools expressed as a proportion of total ecosystem C stocks. Different letters indicate significantly different least-squares means. Note that the reference was not included in pairwise comparisons tests, and the overstory C pool includes the aboveground and belowground portions of live trees and shrubs except for fine roots. CWD = coarse woody debris.

Implications

Total ecosystem C pools

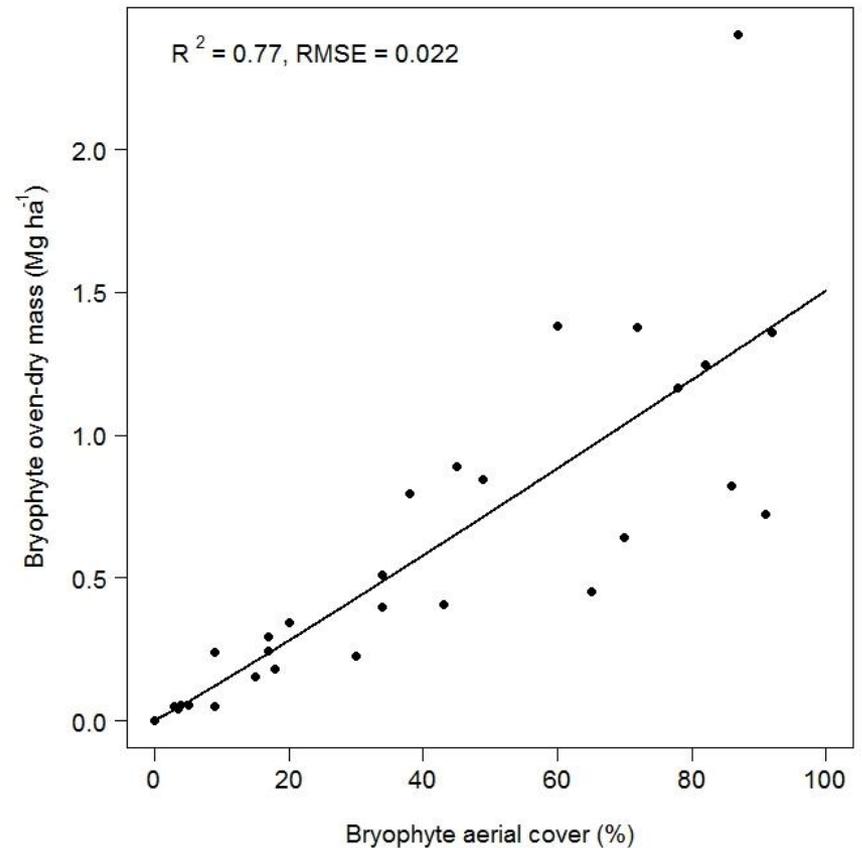
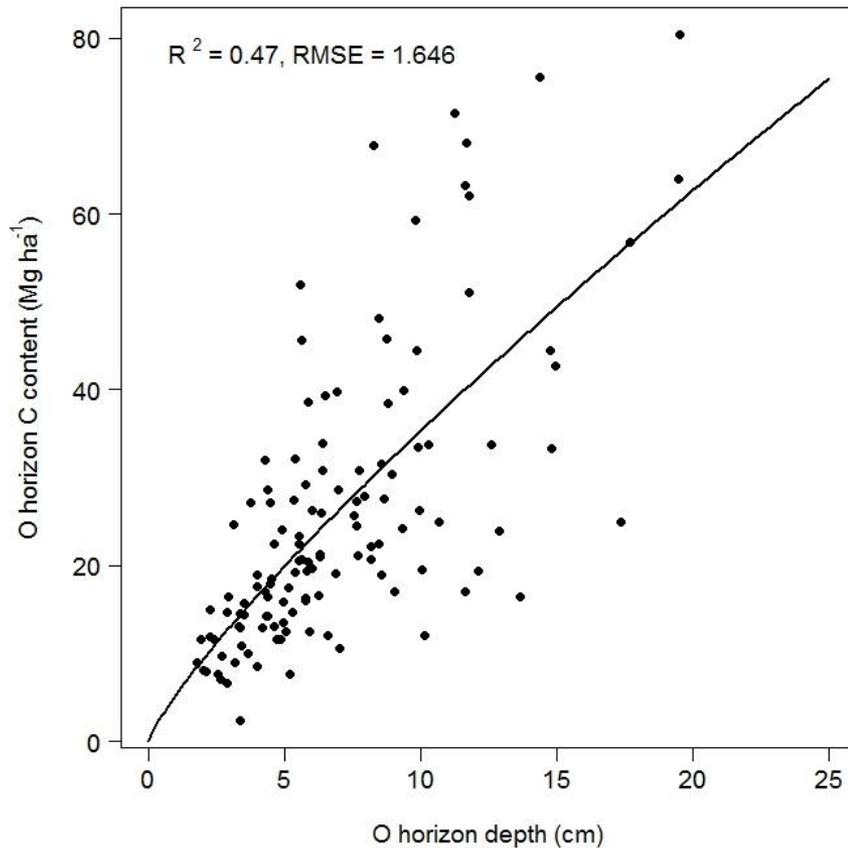
- Certain management practices may be better alternatives than commercial clearcutting when objectives include maximizing C storage in forests.
- Site selection is important where objectives include C storage.
- The timing of harvests and the species and sizes of trees removed influence C stored in harvested wood products.
- Site quality and C stored in wood products should be considered when comparing C storage among forest management treatments.

Dead wood C pools

- The timing of harvesting in relation to natural disturbance events influences the amount, type, and quality of dead wood biomass and should be considered when planning forest management activities.

Implications

- Alternative methods for quantifying bryophyte biomass and organic horizon C stocks could reduce inventory costs.



Future Directions

- This study could serve as a baseline for future measurements of forest ecosystem C pools in this experimental forest and the data can be used to validate model projections of C storage.
- While our comparisons of C pools among forest management treatments were based on the quantification of stored C, it is also important to consider the influence of emissions during the harvest, transport, and manufacturing of wood products, or wood combustion for energy on treatment comparisons. Future studies based on model simulations could account for these factors.
- Studies of live tree C sequestration since the 1950s on the PEF would be informative, but including emissions from dead wood would be challenging because individual dead trees have only recently been tracked on permanent plots. Furthermore, repeat measurements of other C pools (e.g., the forest floor and mineral soil) were not made over time.
- Despite these constraints, a future analysis and projection of aboveground C sequestration at the PEF would improve our understanding of C dynamics in these and related forests.

List of Products

Peer-reviewed publications

Puhlick, J.J., A.R. Weiskittel, I.J. Fernandez, S. Fraver, L.S. Kenefic, R.S. Seymour, R.K. Kolka, L.E. Rustad, and J.C. Brissette. 2016. Long-term influence of alternative forest management strategies on total ecosystem and wood product carbon storage. In review.

Puhlick, J.J., A.R. Weiskittel, S. Fraver, M.B. Russell, and L.S. Kenefic. 2016. Assessing the role of natural disturbance and forest management on dead wood dynamics in mixed-species stands of central Maine, USA. *Can. J. For. Res.* Accepted pending revisions.

Puhlick, J.J., I.J. Fernandez, and A.R. Weiskittel. 2016. Evaluation of forest management effects on the mineral soil carbon pool of a lowland, mixed-species forest in Maine, USA. *Can. J. Soil Sci.* 96(2): 207-218. doi: 10.1139/cjss-2015-0136.

Puhlick, J.J., S. Fraver, I.J. Fernandez, A.R. Weiskittel, L.S. Kenefic, R.K. Kolka, and M.-C. Gruselle. 2016. Factors influencing organic-horizon carbon pools in mixed-species stands of central Maine, USA. *For. Ecol. Manage.* 364: 90-100. doi: 10.1016/j.foreco.2016.01.009.

List of Products

Other publications

Puhlick, J.J. 2015. How silvicultural treatments and site quality affect carbon storage on the Penobscot Experimental Forest: A 60-year perspective. Ph.D. dissertation, University of Maine, Orono, ME. 169 p.
<http://digitalcommons.library.umaine.edu/etd/2262>

Conference presentations

Puhlick, J.J., A.R. Weiskittel, I.J. Fernandez, S. Fraver, L.S. Kenefic, and R.S. Seymour. 2015. Comparisons of carbon pools among alternative management regimes on the Penobscot Experimental Forest. New England SAF Winter Meeting (poster presentation), Fairlee, VT, March 24-27, 2015.

Puhlick, J.J., A.R. Weiskittel, I.J. Fernandez, S. Fraver, L.S. Kenefic, and R.S. Seymour. 2014. How silvicultural treatments and site quality affect carbon storage in a mixed species forest in Maine, USA. IUFRO World Congress, special session for students and young scientists (oral presentation), Salt Lake City, UT, October 5-11, 2014.

List of Products

Conference presentations (continued)

Puhlick, J.J., A.R. Weiskittel, I.J. Fernandez, S. Fraver, L.S. Kenefic, and R.S. Seymour. 2014. How silvicultural treatments and site quality affect carbon storage in a mixed-species forest. SAF/CIF-IFC National Convention, technical session (oral presentation), Salt Lake City, UT, October 8-11, 2014.

Puhlick, J.J., A.R. Weiskittel, I.J. Fernandez, R.S. Seymour, S. Fraver, and L.S. Kenefic. 2013. How silvicultural treatments and site quality affect carbon storage on the Penobscot Experimental Forest. North American Forest Ecology Workshop (oral presentation), Bloomington, IN, June 16-20, 2013.

Puhlick, J.J., A.R. Weiskittel, L.S. Kenefic, I.J. Fernandez, S. Fraver, L.E. Rustad, R.K. Kolka, and J.C. Brissette. 2012. How silvicultural treatments affect carbon storage on the Penobscot Experimental Forest: A 60-year perspective. Eastern CANUSA Forest Science Conference (oral presentation), Durham, NH, November 1-3, 2012.