2019 Annual update of Soil Productivity Research

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We measure the impacts of our forest management practices on soil productivity by conducting research on our land and supporting peer-reviewed research at universities and through cooperatives. Weyerhaeuser has several research studies that investigate soil productivity and sustainability. These studies are located in our Southern and Western Timberlands and their study objectives help ensure that our quality timber products are produced from forests managed without compromising our commitments as a long-time steward of the environment.

Soil organic matter can serve as an indicator of soil "quality" and contributes to productivity. Changes in soil organic matter stemming from changes in management practices can influence long-term site productivity and sustainability. The current scientific literature shows effects of removing forest floor and logging residue ranging from no effect to negative effects. These effects or lack thereof are expected to vary by soil type, soil fertility and levels of biomass removal. Weyerhaeuser has installed several studies to investigate the effects of removing different levels of biomass during and after timber harvest.

WESTERN TIMBERLANDS
In Weyerhaeuser's ownership in the **northwestern United States** we have 3 major long-term soil sustainability studies underway:
Fall River Long-Term Soil Productivity (LTSP) – Tree age 20
Northwest Advanced Renewables Alliance (NARA)- LTSP – Tree age 6
Soil Carbon Change in Pacific Northwest Douglas-fir Forests after Harvest – Tree age 8

And one short-term study that was recently completed:

Tethered Harvesting Effects on Soil Disturbance

LTSP

The LTSP studies are designed to examine the effects of organic matter removal and compaction on planted-tree growth and other soil conditions. A broad network of LTSP sites exists across North America and is a collaboration among the United States Forest Service, Canadian forest management agencies, universities, and private timberland owners (see map below). Some locations in the network were installed as early as 1989. A summary of recent finding across the network can be found here:

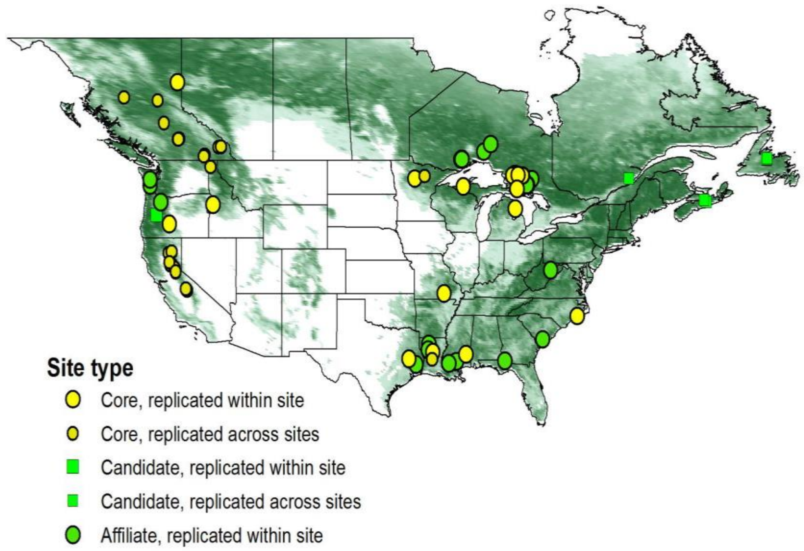

Figure 2.1 Map of Long Term Soil Productivity (LTSP) sites. Map Credit: Andy Scott, USFS

http://www.fs.fed.us/nrs/pubs/jrnl/2012/nrs_2012_Ponder_001.pdf

Fall River LTSP is the older of the two Weyerhaeuser owned LTSP sites and completed its 20th growing season in 2019, after which trees were measured but the age 20 data are not yet analyzed. Separate nitrogen fertilizer and calcium treatments have been applied. The latest tree measurements available are from the 15-year milestone. Through year 15, the Fall River LTSP study results indicate that severe biomass removal (beyond what would operationally be feasible) can have a small negative effect (-7%) on tree volume at this site after 15 years. Compaction, without displacement, showed no effect on tree growth at this highly productive site. Lower tree volumes also occurred where competing vegetation was not controlled in the early years (see figure below), but weed control effects are waning by age 15 compared to previous measurements. Other soil studies in collaboration with the University of Washington and National Council for Air and Stream Improvement (NCASI) are ongoing.

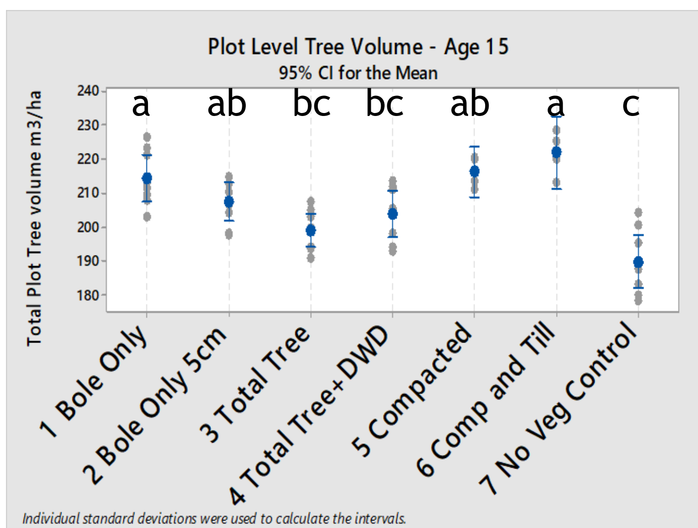

Figure 2.2 Fall River LTSP tree volumes at age 15 years.

The NARA LTSP study

The broader NARA study examines the entire supply chain of converting woody residuals to jet fuel and other co-products (http://www.nararenewables.org).

The new NARA LTSP study site east of Springfield, Oregon has had treatments applied and planted seedlings have been measured at tree age 5 years. Second year tree measurements have been analyzed and at this early stage removing slash at this site increases tree growth relative to slash covered plots. Soil temperature and moisture data indicate that early treatment differences are likely due to increased warming of the more exposed soil. Other collaborators on this site include researchers from Oregon State University who are studying soil carbon and nutrient cycling as well as monitoring pollinator pollinations and diversity.

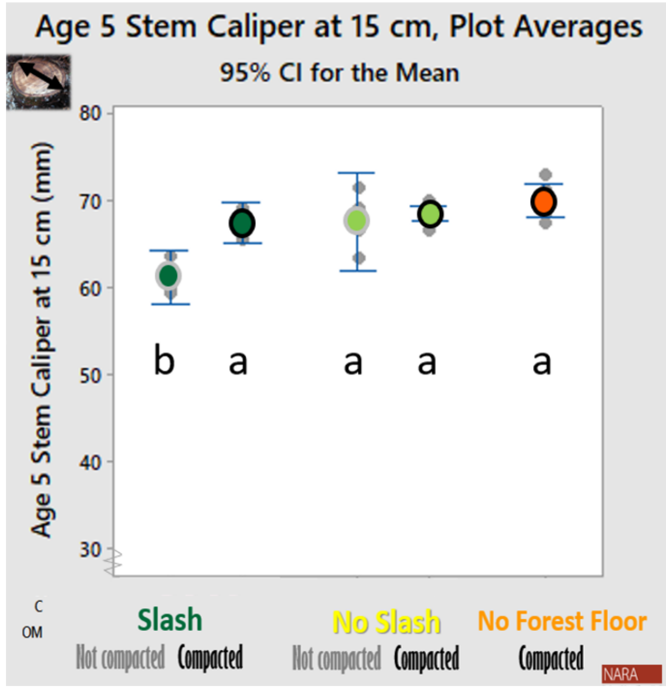

Figure 2.3 NARA LTSP Age 5 stem caliper.

Soil Carbon Change following Harvest

The main goal of the "Soil C Change" study is to determine the effect of conventional timber harvest on ecosystem carbon stores with particular emphasis on soil carbon sequestration, since soils are a large pool of stable carbon and can hold over 50% of the carbon in a forest. The storage of carbon in forests has been studied, but rarely with the intensity to detect the small changes in soil C that might be expected due to harvest. In this study 9 sites stratified across the Coast Range and Cascades in Oregon and Washington were randomly selected to be intensively sampled for soil C, and other carbon pools. In 2010, we randomly selected nine harvest units from Weyerhaeuser's 2012 harvest plan. At each non-harvested unit, a uniform, non-rocky area of about 7-15 acres was selected for the study (Fig. 1). Pre-harvest soil samples were collected at 300 sample points from each unit on a fixed grid (Fig. 2), targeting an intensity that would allow detection of >5% change in soil carbon stores. These samples were spatially grouped into 25 12-sample composites for chemical analysis to 1 m depth. We measured soil carbon concentration and soil bulk density to allow for the calculation of total soil carbon per acre. Other ecosystem pools of carbon, such as trees and downed wood, also have been measured to complete the whole-site carbon budget.

All units were harvested from late 2011 through mid-year 2012. In 2015, 3-3.5 years post-harvest, we resampled the same areas in an identical manner as the pre-harvest collection to evaluate changes in soil carbon following harvest.

Across all sites combined, we estimated a +2% change (-2% to +6% 95% confidence interval) in mineral soil carbon following harvest, which is consistent with small-to-no change. Individual sites varied in direction of response; only one site showed evidence of a slight decrease in soil carbon, while two sites showed slight gains. (Fig. 2.4)

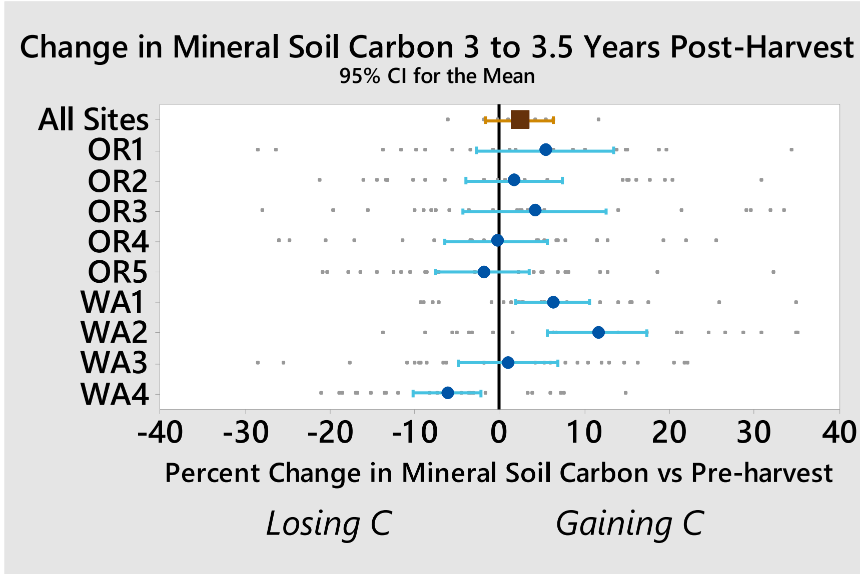

Figure 2.4 Change in mineral soil C 3-3.5 years after harvest. (overall/site mean, composite values, error bars=95% CI)

These early results indicate that Weyerhaeuser's conventional timber harvesting methods in the Pacific Northwest do not cause substantial short-term losses in soil carbon. Continued monitoring is necessary, however, to document the longer-term trajectory of soil carbon levels through stand development.

Tethered Harvesting Effects on Soil Disturbance Study

The tethered harvesting study compares soil and stream-adjacent disturbance between conventional hand falling and cable yarding, and tethered machine harvesting practices on steep slopes in the Pacific Northwest (Figure 1).

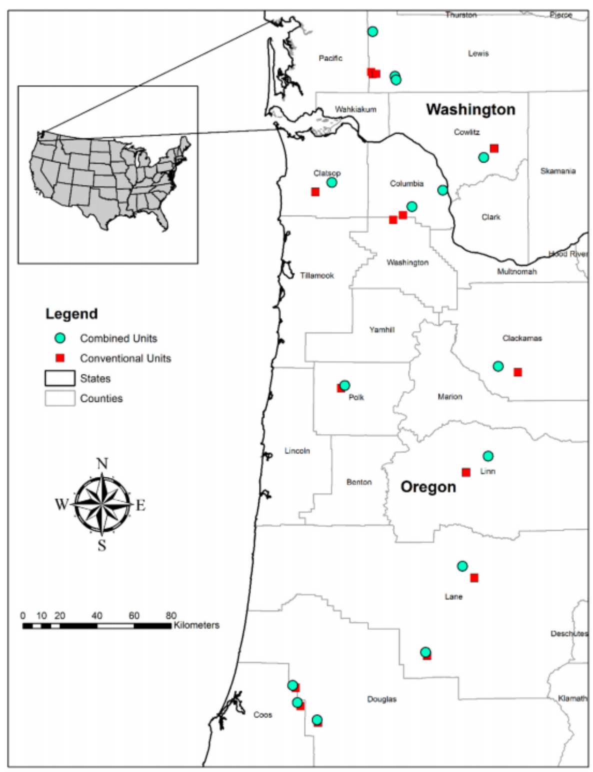

Figure 1. Map of study locations across Oregon and Washington

This study was a collaborative study between Western Environmental Research and Western Production Forestry and has been published in Forest Ecology and Management.

Both soil and stream-adjacent disturbance increased from tethered harvesting (labeled "Combined-Tethered" below) compared to conventional steep slope (labeled "Conventional-Hand cut") harvesting practices and were similar to other ground-based operations (Table 1). Although an increase in soil and stream-adjacent disturbance can be expected from cable-assist harvesting over conventional steep slope harvesting, the amounts were still below the examined regulatory thresholds and BMP's. While not specifically examined in this study, the increase in soil disturbance likely impacts forest productivity overall, but many of the negative impacts can be mitigated during planting (avoid heavily disturbed areas).

Table 1
Mean estimates and 95% confidence intervals for each response variable and harvest method.

Study scale	Method	Mean Stream-Adjacent Disturbance (%)	Mean Soil Disturbance (Class 3 + 4) (%)
Harvest unit operations (site-level)	Conventional	0.5 (0.3, 1.0)	3.0 (1.6, 5.5)
	Combined	1.1 (0.8, 1.6)	13.4 (10.2, 17.3)
Within-unit harvest method	Conventional – Hand cut	0.2 (0.1, 0.7)	0.3 (0.1, 1.5)
	Conventional – Other	1.4 (0.6, 3.4)	9.7 (5.9, 15.6)
	Combined – Tethered	1.2 (0.6, 2.2)	12.2 (8.8, 16.8)
	Combined – Other	1.0 (0.6, 1.7)	13.8 (10.2, 18.4)

LTSP Presentations/Publications Since 2017:

Martin, K. 2019. Response of soil microbial activity and community composition to timber harvest in an Oregon Douglas-fir forest. OSU master's thesis (with David Myrold).

Holub, S.M. 2019. Organic matter removal and forest soil compaction influence tree growth early in a Douglas-fir rotation in the Oregon Cascades – NARA LTSP. Oral presentation at Northwest Forest Soils Council Winter Technical Meeting, Lincoln City, Oregon. March 21, 2019.

Holub, S.M. 2019. Organic matter removal and forest soil compaction influence tree growth early in a Douglas-fir rotation in the Oregon Cascades. Poster Presentation: January 8, 2019, SSSA Meeting, San Diego, CA

Holub, S.M. 2019. Organic matter removal and forest soil compaction influence tree growth early in a Douglas-fir rotation in the Oregon Cascades – NARA LTSP. Oral presentation at Northwest Forest Soils Council Winter Technical Meeting, Lincoln City, Oregon. March 21, 2019.

Dietzen, C.A., E.R.G. Marquez, J.N. James, R.H.A. Bernardi, S.M. Holub, R.B. Harrison. 2017. Response of deep soil carbon pools to forest management treatments in a highly productive Andisol. Soil Science Society of America Journal 81:(4) DOI: 10.2136/sssaj2016.09.0305

Holub, S.M. 2017. Lessons learned and best practices for sustaining site productivity of Pacific Northwest Douglas-fir. NCASI 2017 West Coast Regional Meeting, Vancouver, Washington, September 23, 2017. Invited speaker.

Soil Carbon Change Presentations/Publications since 2017:

Danielson, R.E., M.L. McGinnis, S.M. Holub, D.D. Myrold. 2020. Soil fungal and prokaryotic community structure exhibits differential short-term responses to timber harvest in the Pacific Northwest. Pedosphere 30(1):109-125. doi.org/10.1016/S1002-0160(19)60827-1

Holub, S.M., J.A. Hatten. 2019. Soil carbon storage in Douglas-fir forests of western Oregon and Washington before and after modern timber harvesting practices. Soil Science Society of America Journal (North American Forest Soils Conference Proceedings): 83(1):S175-S186. doi:10.2136/sssaj2018.09.0354

Holub, S.M. 2019. Forest soil carbon is minimally affected by conventional timber harvesting – 3 years post-harvest. Oral presentation at Northwest Forest Soils Council Winter Technical Meeting, Lincoln City, Oregon. March 21, 2019.

Myrold, D., R.E. Danielson, M.L. McGinnis, S.M. Holub. 2019. Harvesting effects on soil microbial communities and processes. Oral presentation at Northwest Forest Soils Council Winter Technical Meeting, Lincoln City, Oregon. March 21, 2019.

Holub, S.M., J.A. Hatten. 2018. Modern timber harvesting practices have little short-term effect on soil carbon stores in industrial forests of western Oregon and Washington, U.S.A. Poster presentation at North American Forest Soils Conference, Quebec City, Canada. June 13, 2018.

Danielson, R., M.L. McGinnis, S.M. Holub, D.D. Myrold. 2017. Harvesting Douglas-fir stands shifts soil microbial activity and biogeochemical cycling. Soil Science Society of America 81(4): 956-969. doi:10.2136/sssaj2016.09.0303

Harrington, C., S.M. Holub, C. Chen, E.A. Steel. 2017. Below-ground ecology of Douglas-fir forests in the Pacific Northwest: the distribution of tree roots, dead organic matter, and mineral fragments. Northwest Science 91(4): 326-343. doi:10.3955/046.091.0403

Holub, S.M., J.A. Hatten. 2017. Modern timber harvesting practices have little short-term effect on soil carbon stores in industrial forests of Western Oregon and Washington, U.S.A. Poster presentation at American Geophysical Union Annual Meeting, New Orleans, LA. December 14, 2017.

Tethered Logging Soil Disturbance Publication:

Chase, C.W, M. Reiter, J.A. Homyack, J.E. Jones, E.B. Sucre. 2019. Soil disturbance and stream-adjacent disturbance from tethered logging in Oregon and Washington. Forest Ecology and Management 454: (2019) 117672. https://doi.org/10.1016/j.foreco.2019.117672

SOUTHERN TIMBERLANDS

Southern timberlands has the following projects and studies to improve our understanding of how intensive forest management affects long term sustainability and forest carbon stores:

- Examining and identifying mechanisms that improve soil carbon sequestration under various silvicultural regimes and/or organic matter manipulations. Specific studies are:

  a. Lenoir 1 Intercropping and Sustainability Study

Goal: Determine the effects of intercropping and/or biomass management on site productivity and sustainability

b. **Pamlico / Millport OM Study**

Goal: Investigate soil effects from removing or adding additional pine needles.

c. **Parker Tract**

Goal: In collaboration with USFS and NC State University, evaluating ecosystem carbon fluxes