Nitrogen controls on detrital organic matter dynamics in the Northern Forest: Evidence from a 26-year nitrogen addition experiment at the Bear Brook Watershed in Maine

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Completion date: 30th June 2021

In light of reported C and N pools, woody debris deserve increased inventory efforts for purposes of forest C accounting as well as for biogeochemical studies in a changing climate.

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

Rationale

Woody debris play an important role in forest carbon (C) and nitrogen (N) cycles. However, little is known about the factors that control its dynamics. Leaf litter decomposition studies have shown that initial litter quality, especially N concentration, plays a critical role in its persistence. It is currently not well-understood if N additions in the field also lead to increased C and N storage in woody debris.

Project objectives

The project goal was to investigate the influence of ecosystem N status on C and N storage in woody debris. The associated objectives were:

1. Determine the C and N pools, and ^{15}N composition of woody debris in two ecosystems differing in N status.

2. Compare sugar maple and red spruce wood decay stake decomposition in two ecosystems differing in N status.

3. Evaluate the influence of environmental and decay stake characteristics on decay stake decomposition.

Methods

The study took place at the Bear Brook Watershed in Maine (BBWM), a long-term paired-watershed whole ecosystem N enrichment experiment with a treated watershed (WB) having received N additions for 26 years and a reference watershed (EB).

Project Summary

Methods

- The Line Intercept Method was used to inventory woody debris by decay class and species in both BBWM watershed (i.e. at two ecosystem N status).
- The mass method was used to sample fine woody debris (FWD, diameter ≤ 10 cm).
- FWD and coarse woody debris (CWD, diameter > 10 cm) were analyzed for C, N and ^{15}N composition by species, decay class, and watershed. CWD density was determined on CWD disks.
- A decomposition experiment was initiated with sugar maple/red spruce standard decay stakes in both watersheds.

Major findings

- There was little evidence of higher CWD and FWD C and N pools under elevated N status.
- CWD C and N pools were consistent with other field studies in the region.
- CWD showed N isotope enrichment in advanced decay stages in the reference watershed.
- FWD N isotope composition differed between watersheds (treated > reference), indicating enhanced N transformations involving this component under elevated N status.

Implications for the Northern Forest region

Downed woody debris C and N pool sizes were quantified using chemical analysis and density by decay class for major species of the Northern Forest. Woody debris is a heterogeneous ecosystem component. Such detailed data sets are necessary to convert woody debris volume/mass per unit area to C and N pools and to scale up the contribution of woody debris to forest ecosystem C and N storage.

Background and Justification

- Forest C dynamics are closely tied to ecosystem N cycling via the role of N in detrital organic matter decomposition and plant productivity. As litter decomposes, it is known to accumulate N. Previous studies in the Northeast U.S. showed that experimental N additions leads to an increase in forest floor C presumably because of slower soil organic matter decomposition (Lovett et al. 2013, Frey et al. 2014).
- High N availability is known to decrease the lignin-degrading activity of fungi in soils with lignin-rich litter (Waldrop and Zak 2006, Eisenlord et al. 2013).
- However, it is not known if the effect of high N status holds true for woody debris decomposition and to what extent the dynamics of woody debris is contributing to soil C sequestration under elevated N in field settings.
- The Bear Brook Watershed in Maine (BBWM) consists of paired watersheds established as long-term research and monitoring ecosystems since 1987. The treatement watershed received ambient atmospheric N deposition plus ammonium sulfate additions (25.2 kg N ha^{-1} yr^{-1}) from November 1989 to August 2016, while the reference watershed received ambient N deposition only.

Literature cited:
Eisenlord, S.D., Freedman, Z., Zak, D.R., et al. 2013.Microbial mechanisms mediating increased soil C storage under elevated atmospheric N deposition. Applied and Environmental Microbiology 79:1191-1199.
Frey, S.D., Ollinger, S., Nadelhoffer, K., et al. 2014. Chronic nitrogen additions suppress decomposition and sequester soil carbon in temperate forests. Biogeochemistry 121:305-316.
Lovett, G.M., Arthur, M.A., Weathers, K.C., Fitzhugh, R.D., Templer, P.H. 2013. Nitrogen addition increases carbon storage in soils, but not in trees, in an Eastern U.S. deciduous forest. Ecosystems 16: 980-1001.
Waldrop, M.P. and D.R. Zak. 2006. Response of oxidative enzyme activities to nitrogen deposition affects soil concentrations of dissolved organic carbon. Ecosystems 9: 921-933.

Background and Justification

- The experimental design at the BBWM allowed to investigate the influence of ecosystem N status on C and N dynamics and storage in woody debris.
- A ^{15}N tracer was added in 1991-1992 in the treatment watershed only, and a whole watershed ^{15}N pulse-chase labeling was started in June 2012 and conducted in both watersheds, allowing to follow the fate of the tracer in woody debris in this project.
- Woody debris decomposition relies in large part on the composition and activity of the wood decaying fungi. We hypothesized that the long-term N treatment at BBWM has decreased wood decomposer activity (fungi), slowing woody debris decomposition. To test this hypothesis, the project objectives were:

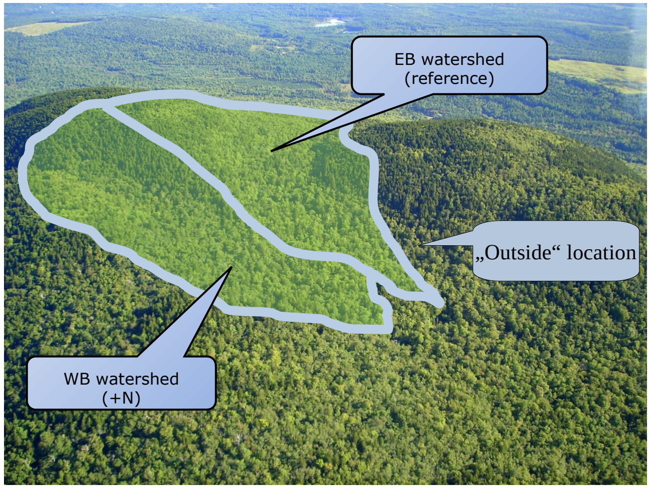
  1. Determine the C and N concentrations, C and N pools, and ^{15}N composition of CWD and FWD along a decomposition gradient in each watershed.

  2. Compare sugar maple and red spruce wood decay stake dynamics between watersheds in a field decomposition experiment.

  3. Evaluate the influence of environmental parameters and decay stake characteristics on wood decay stake decomposition.

Methods

- The research site BBWM (44°52' N. lat. and 68°06‘ W. long.) is located ~ 60 km northeast of Acadia National Park. It comprises a treated (West Bear, WB) and reference (East Bear, EB) watershed (10.3 and 11.0 ha, respectively, picture below). Lower elevations are dominated by mixed hardwoods and higher elevations by red spruce.
- Bi-monthly application of $(NH4)_2SO_4$ fertilizer (25.2 kg N $ha^{-1}yr^{-1}$) constitutes the long-term N treatment at the WB watershed and took place by helicopter between November 1989 and August 2016.
- Two ^{15}N tracer additions took place at WB (1991/92 and 2012) and one at EB (2012) with backpack sprayers on the forest floor.



Picture by Bruce Wiersma

Methods

- The Line Intercept Method was used to inventory woody debris along 3 transects of 40 m each at 10 locations in each watershed.
- Coarse Woody Debris (CWD) decay classes were determined following Sollins (1982).
- CWD volume per unit area were calculated following Fraver et al. (2018) per location.
- CWD were sampled at nearby locations in each watershed for C, N, and ^{15}N composition determination.
- A subset of CWD disks was measured and oven-dried to determine CWD density (kg m^{-3}) by watershed, species, and decay class.
- CWD with combination of watershed, species, and decay class with missing or erroneous values was replaced by CWD densities from the literature (e.g. Harmon et al. 2008).
- Fine woody debris (FWD, diameter ≤ 10.0 cm) on top of the forest floor was quantified using the mass method at 12/13 locations per watershed, sorted into 4 size classes, 2 species groups, and 2 decay classes then oven-dried and used for C, N, and ^{15}N composition determination.
- CWD and FWD were also sampled for isotope composition outside of the labelled EB and WB watersheds. Approximate „outside“ location is shown on slide 6.
- Non-parametric statistics were used to test for decay class and watershed effects on woody debris characteristics.

Literature cited

Fraver, S., Ducey, M.J., Woodall, C.W., D’Amato, A.W., Milo, A.M., Palik. B.J. 2018. Influence of transect length and downed woody debris abundance on precision of the line-intersect sampling method. Forest Ecosystems 5: 39.

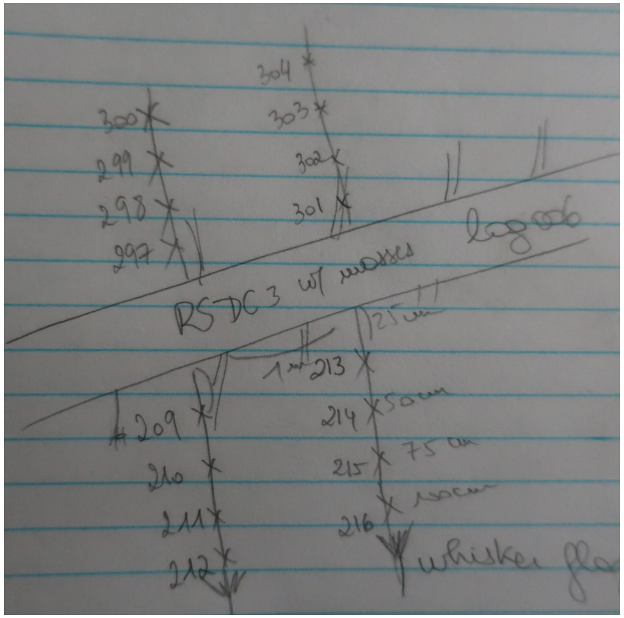
Harmon, M.E., Woodall, C.W., Fast, B., Sexton, J. 2008. Woody detritus density and density reduction factors for tree species in the United States: A synthesis. United States Department of Agriculture, Forest Service, Northern Research Station, General Technical Report NRS-29, 90 p.

Sollins, P. 1982. Input and decay of coarse woody debris in coniferous stands in western Oregon and Washington. Canadian Journal of Forest Research 12: 18-28.

Methods

- In the scope of a standard wood decay stake decomposition experiment, 320 sugar maple and red spruce standard decay stakes (dimensions: 2.5 x 2.5 x 20 cm, see picture) were installed in 4 transects around sugar maple and red spruce CWD logs of decay class 3 in July 2016 in both watersheds (see schematic representation).
- Little evidence of wood stake decay existed during this contract timeframe, so collection timelines have been extended to beyond this contract period to fulfill objectives 2 and 3. Half of the decay stakes will be collected in August 2021 and processed for mass loss determination and comparison between watersheds as per project objectives 2 and 3.

Picture by Shawn Fraver



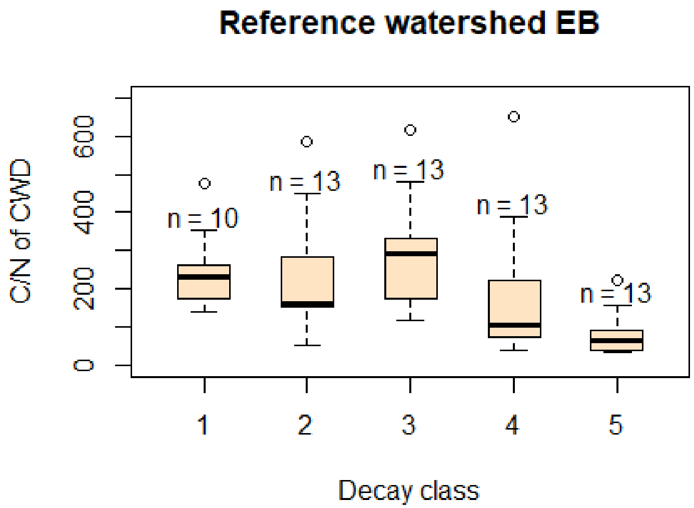
Picture by Marie-Cécile Gruselle

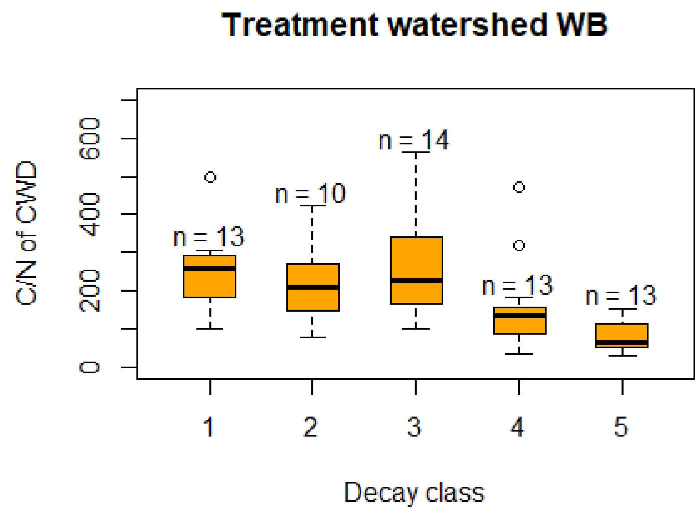
Schematic representation of 16 decay stakes (see 16 IDs) laid on the forest floor at fixed distances to a red spruce (RS) CWD log of decay class 3 as provider of inoculum of decomposer community.

Results

CWD characteristics

- 186 and 130 CWD pieces were inventoried in EB and WB, respectively, for volume determination. 62 and 63 CWD disks were samples in EB and WB, respectively, for C, N and N isotopic composition.
- CWD diameter (median) were larger in the reference watershed EB (16.0 cm) than in the treatment watershed WB (14.9 cm).
- In each watershed, significant C/N ratio differences existed among decay classes (species pooled, figures by watershed below).
- C/N ratio showed a typical decreasing trend with decay class. Values consistent with study by Currie and Nadelhoffer (2002) at the Harvard Forest, albeit under ambient N conditions.



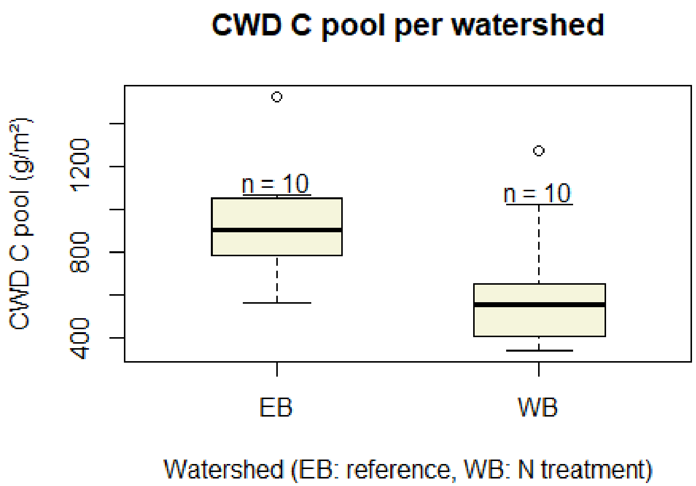


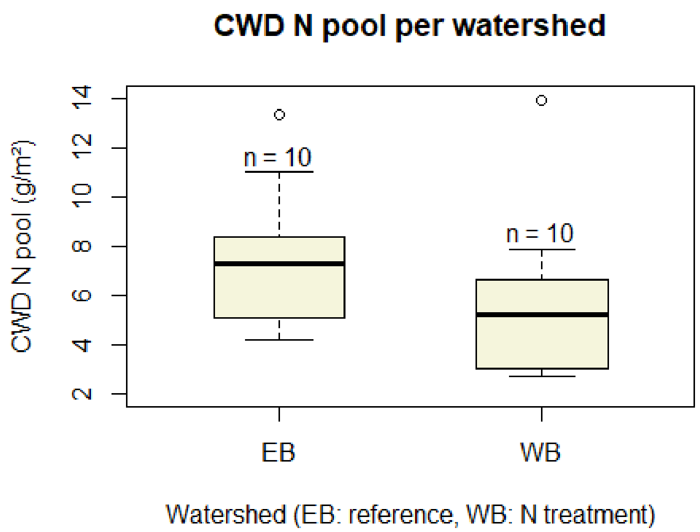
Currie, W.S. and K.J. Nadelhoffer. 2002. The imprint of land-use history: patterns of carbon and nitrogen in downed woody debris at the Harvard Forest. Ecosystems 5: 446-460.

Results

CWD mass, C and N pools

- There was a trend of higher total CWD mass (g m^{-2}, across species and decay classes) in the reference watershed, although not significant (data not shown).
- Significantly higher CWD C pool (g m^{-2}, across species and decay classes) was found in the reference watershed (figure below left).
- No significant difference in CWD N pools (g m^{-2}, across species and decay classes) was detected between watersheds (figure below right).

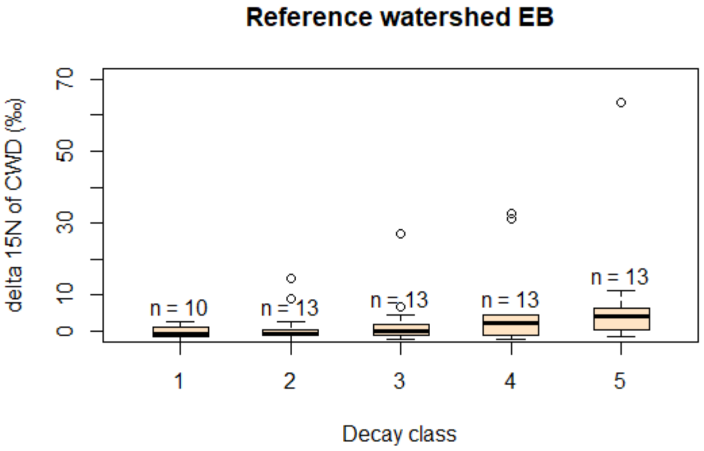


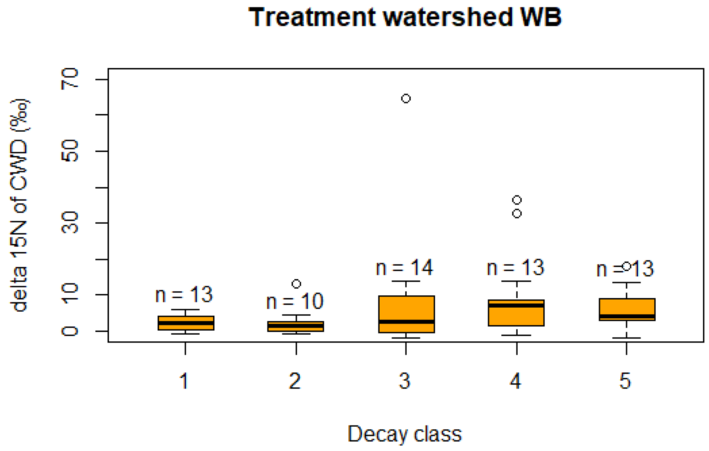


Results

CWD ^{15}N composition

- CWD disks were sampled five years after the latest ^{15}N tracer addition.
- CWD ^{15}N composition in both figures below show the fate of the tracer in this ecosystem component by ecosystem N status (with WB N status > EB N status, Patel et al. (2019)). Data were composited across species (American beech, red/sugar maple, and red spruce) by decay class for each watershed.
- No difference among decay classes was found in the treated watershed WB (Kruskal-Wallis test).
- Regarding the reference watershed EB, there was a trend of higher ^{15}N in advanced stage of decay (K-W test p value = 0.06). Note: samples > 70 ‰ (1 in decay class 4 and 1 in decay class 5) not displayed in EB figure.
- Isotopic composition of CWD sampled outside of the labeled watersheds ranged between -2.3‰ and +1.1 ‰ and did not differ among decay classes (data not shown).



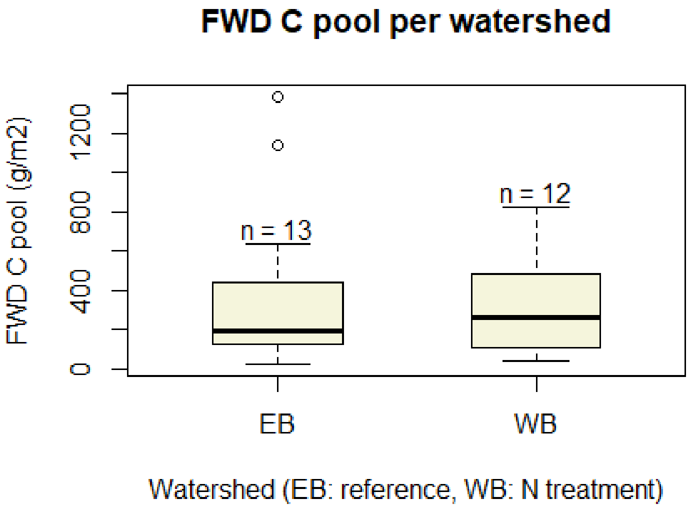


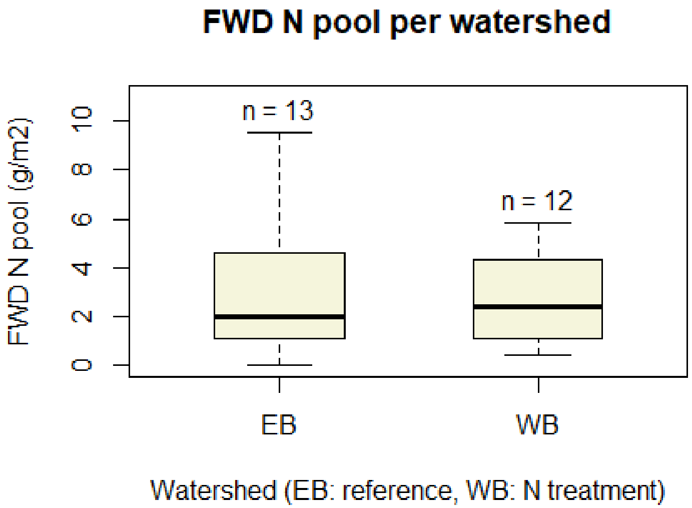
Patel, K.F., Fernandez, IJ, Nelson, S.J., Gruselle, M-C, Norton, S.A., Weiskittel, A.R. 2019. Forest N dynamics after 25 years of whole watershed N enrichment: The Bear Brook Watershed in Maine. Soil Science Society of America Journal 83: S161-S174.

Results

FWD C and N pools

- The FWD mass, C, and N pools (g m^{-2}) were summed across species group and decay class by location within watershed.
- Total FWD mass, C and N pools and C/N ratio were not significantly different between watersheds.
- FWD C and N pools were consistent with the few field studies available on N addition effects on FWD pools (e.g. Currie et al. (2002)).



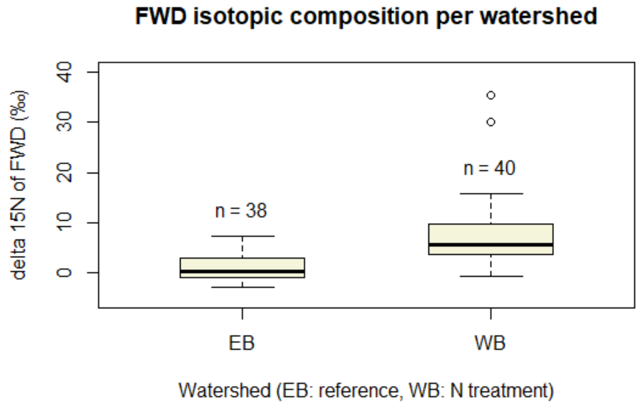


Currie, W.S., Nadelhoffer, K.J., Colman, B. 2002. Long-term movement of ^{15}N tracers into fine woody debris under chronically elevated N inputs. Pant and Soil 238: 313-323.

Results

FWD ^{15}N composition

- FWD ^{15}N composition is shown by ecosystem N status (treated WB > reference EB) five years after the latest ^{15}N tracer addition (figure below). Data were composited across species groups (hardwoods versus softwoods) and decay classes.
- FWD ^{15}N composition was highly significantly different between watersheds (treated WB > reference EB, figure below), indicating enhanced N transformations involving this component under elevated ecosystem N status.
- Isotopic composition of FWD sampled outside of the labeled watersheds ranged between -4.7 ‰ and +4.92 ‰ and did not differ among decay classes (data not shown).
- FWD ^{15}N composition within the watersheds showed enrichment compared to "outside" location, especially in WB, indicating a probable combination of legacy of tracer spraying on the forest floor, enriched woody litter fall, and enhanced N transformations in this component under elevated ecosystem N status.



Results

Outreach efforts

This project served the following students and early career scientists to learn and use a varied set of ecosystem research methods such as woody debris and forest stand inventory, and the standard decay stake decomposition method:

Michaela Kuhn, Elyse Daub, Maggie Mansfield, Jenna Zukswert, Jeanette Allogio, Emily Roth, and Erin Fien.

Implications and applications in the Northern Forest region

- This project facilitated the initiation of a multi-year field decomposition experiment to increase our understanding of local drivers of woody debris decomposition in un-managed stands of the Northern Forest.
- The forest at the BBWM, as in many parts of the Northern Forest Region, is dominated by small-scale disturbances periodically leading to coarse and fine woody debris inputs. Our study showed that both components are important C and N pools.
- Woody debris is an heterogeneous forest ecosystem component in time and space. Its components, such as fine woody debris and buried wood, are often overlooked in forest and soil inventories. In light of reported C and N pools and ^{15}N composition, woody debris deserve increased inventory efforts for forest C accounting as well as for biogeochemical studies.
- A strength of the present study is that downed woody debris was quantified in fine as well as in coarse size classes for C and N pool size determination using own chemical analysis by decay class for major tree species of the Northern Forest. CWD density was also determined. Such detailed data sets are necessary to convert inventoried downed woody debris in terms of volume or mass per unit area to C and N pools as well as to scale up the contribution of woody debris to forest ecosystem C and N storage.

Future directions

- Assess the influence of the wood-decay fungal community on wood decay rates, using the standard wood decay stake experiment
- Quantify the changes in macronutrient concentrations as wood decays, using the standard wood decay stake experiment.
- Test for differences in CO_2 flux (a measure of decay rate) from a set of maple CWD logs in each watershed, testing the effect of long-term N additions on this important process.

List of products

Poster presentation

Gruselle, M-C, Fraver, S., Puhlick, J.J., Fernandez I.J., Woodall, C.W. 2017. Buried dead wood: An often overlooked detrital pool in the Acadian Forest? New England SAF - 97th Winter Meeting, Northeastern Forest Pest Council - 79th Annual Meeting, Maine Chapter of The Wildlife Society – 41st Annual Meeting. Adapt, Adopt, Advance: Resiliency in Natural Resource Management. Bangor, Maine, March 8–10.