Evaluating the influence of riparian forest structure on stream ecosystems across the northern forest

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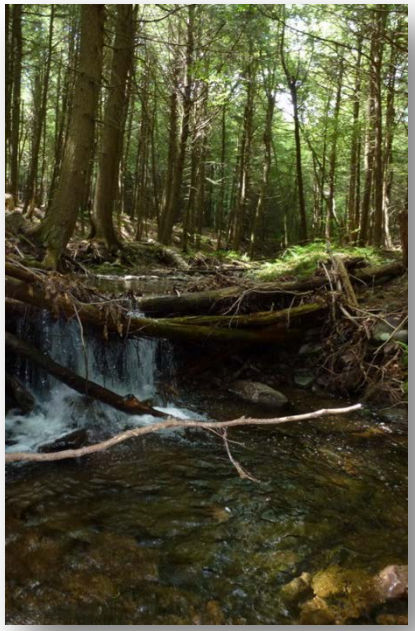
We found whole-stream ecosystem function increased with forest age/structure. Across a gradient of forest age, there was greater available light, biofilm chlorophyll a, whole stream metabolism and demand for organic carbon in streams with older riparian forests. However, in-stream nutrient uptake was not correlated with riparian forest age. Our findings suggest that stream ecosystem functions respond differently to riparian forest structure and specifically that GPP may be more sensitive than nutrient uptake to changes in forest structure.

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

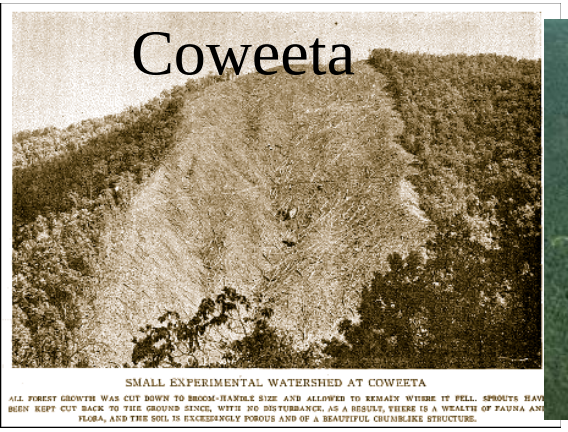

Project Summary

Because terrestrial and aquatic ecosystems are intrinsically linked, disturbances in forest canopies can influence nutrient flux (Sabater et al. 2000, Warren et al. 2007), organic matter input and export (Bernhardt et al. 2003), and large woody debris (Hollein et al. 2012) in adjacent streams. In addition, the complexity of the forest canopy, which is in part related to forest age, may also influence instream ecosystem function (Valett 2002, Warren et al. 2007). We investigated the relationship between riparian forest structure and three integrated measures of stream ecosystem function (nutrient uptake dynamics; gross primary production (GPP) and community respiration (CR) rates).

We measured metabolism and nutrient uptake at 13 sites in June, August, and October. Six streams were measured in 2011 in the Adirondack Mountains of NY, seven additional sites were measured in 2012, with four in the White Mountains, NH (Hubbard Brook Experimental Forest) and three located in Nash Creek watershed in Northern NH. Sample locations span a gradient of riparian forest structure and forest age (80-400 years old) at both the NY and NH locations.

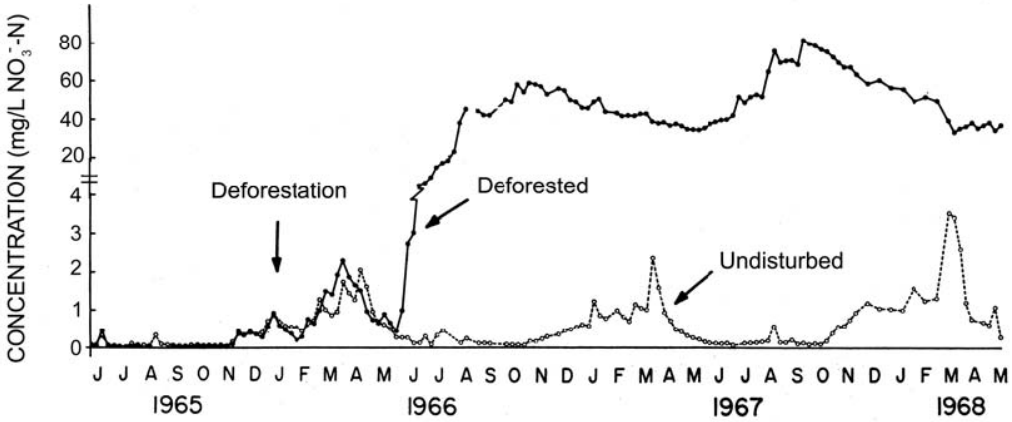
We found whole-stream ecosystem function was influenced by the age/structure of riparian forests. Specifically, we found greater light availability, stream biofilm chlorophyll a and whole-stream metabolism in streams with older riparian forests. In contrast, nutrient demand/uptake was not influenced by forest age/structure. Our findings suggest that stream ecological functions may respond to forest structure in different ways, such that GPP may be more sensitive than nutrient uptake especially to changes in forest structure. The results from this work have implications for stream and forest management throughout the northern forest region where current impacts and the legacies of historic land use continue to alter the composition and structure of riparian forests and their adjacent stream ecosystems.

Whole watershed disturbances



Entire watersheds logged

Great potential of terrestrial disturbance to alter stream nutrient cycles



10-100 times higher than average nitrogen output

Likens et al. 1970

Partial watershed disturbances

In-stream uptake dampens effects of major forest disturbance on watershed nitrogen export

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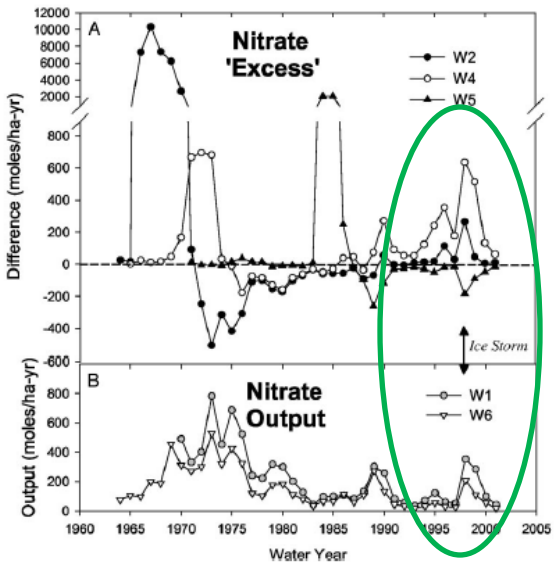
Contributed by G. E. Likens, June 13, 2003

Between January 4 and 10, 1998, a severe ice storm impacted large areas of northern New York, New England, and eastern Canada. This storm struck the Hubbard Brook Experimental Forest in New Hampshire on January 7–8, 1998, and caused extensive forest crown damage (>30%) in a narrow elevation band (600–740 m) rapidly attenuated (12–16); and (*iii*) that this attenuation is often the result of in-stream retention and processing, which are important regulators of nutrient export from watersheds (14, 15, 17–19).

1998, localized disturbance, destroyed 30% canopy crowns

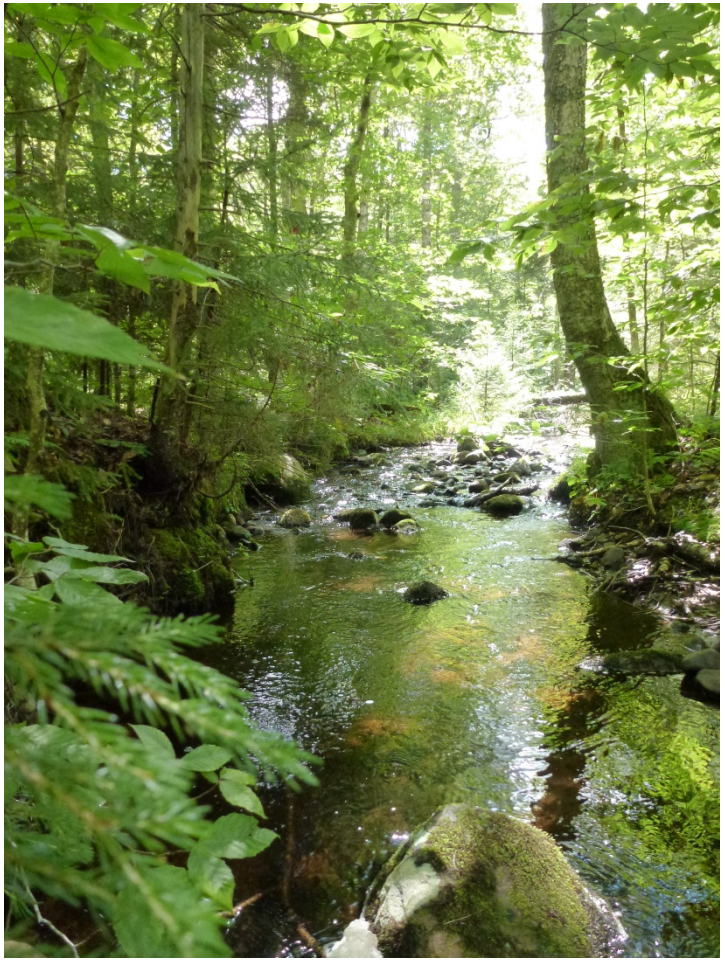


- Result in increased export of stream water N
- Stream processes rapidly attenuated N
- NO_3 export was reduced by 80-140%

Within forest changes

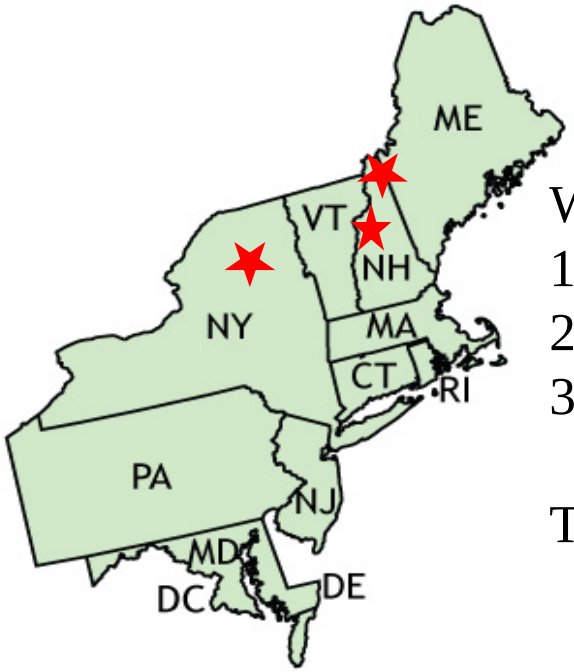
- Smaller scale disturbances can alter forest canopy
  - Movement of pests
  - Selective logging
  - Ex-urban development

- Stream function
    - Metabolism
    - Nutrient uptake/retention



How do changes in forest structure affect headwater streams?

Methods



We measured three ecosystem functions :

1. Nutrient removal/uptake (nitrogen, phosphorus)
2. Primary production (GPP)
3. Respiration (CR)

These were measured in:

- 13 streams in 3 regions
  - NY (Adirondack Mountains)
  - NH (Hubbard Brook Experimental Forest)
  - NH (Nash Watershed Natural Area)

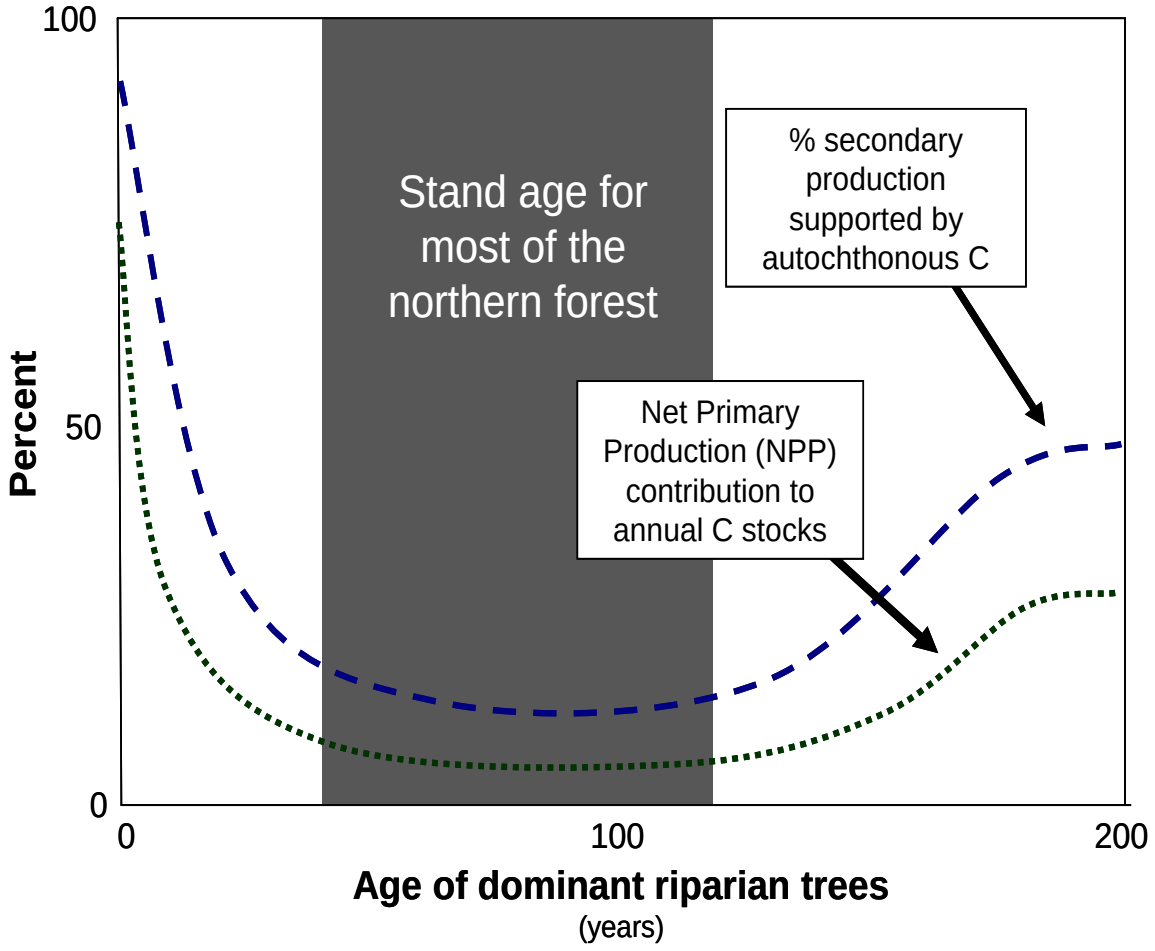
Which were conducted seasonally

- June, August, October

Previous data by PIs on riparian tree characteristics were also used.

Our sites span riparian tree complexity from simple to complex and have an age range between 30-300 years.

We hypothesized that:



Complex riparian forest structure

Increased light patches

Increased autotrophic production leading to more in-stream carbon

May increase secondary production

Methods

At each of the 13 sites we measured:

1. Stream metabolism: Instantaneous change in dissolved oxygen

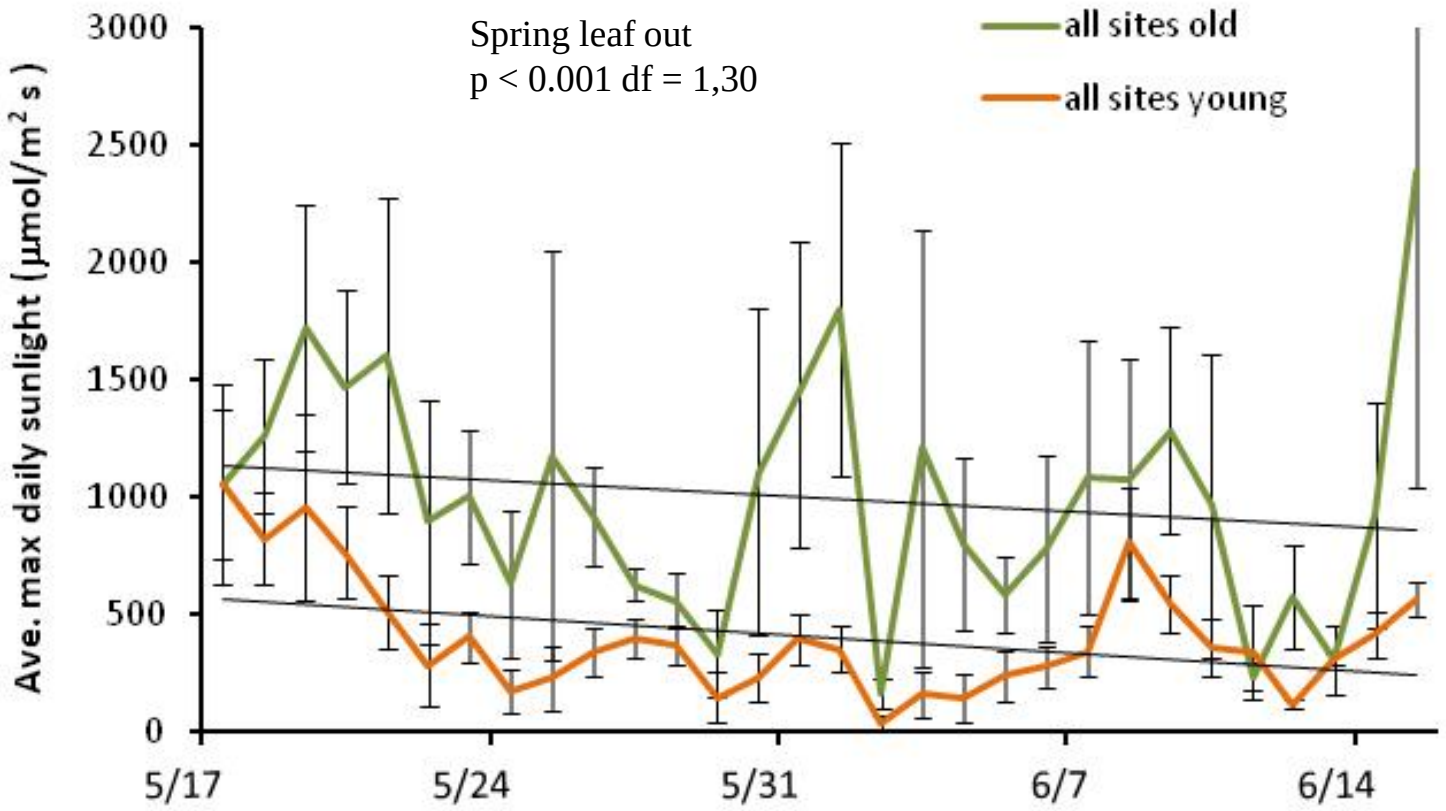
   Dissolved O_2 = GPP – CR ± E

   E= gas exchange of O_2 across the air-water

2. Nutrient uptake: was measured with short-term nutrient additions
   - N (NO_3), (NH_4) & SRP (PO_4)
   - Conservative tracer (NaCl) was brought to a stable plateau to account for differences in hydrology
   - Calculations of the downstream decay in stream water nutrient concentration
     - Nutrient loss (or decay) can be attributed to ecosystem production (GPP or CR)

3. Ancillary measures: Chlorophyll a, PAR, benthic organic matter

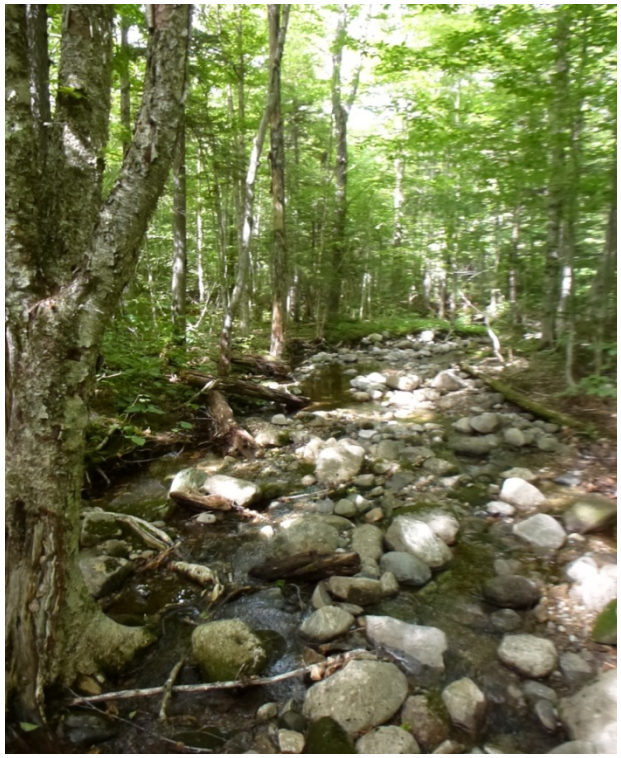
Available light: spring canopy closure

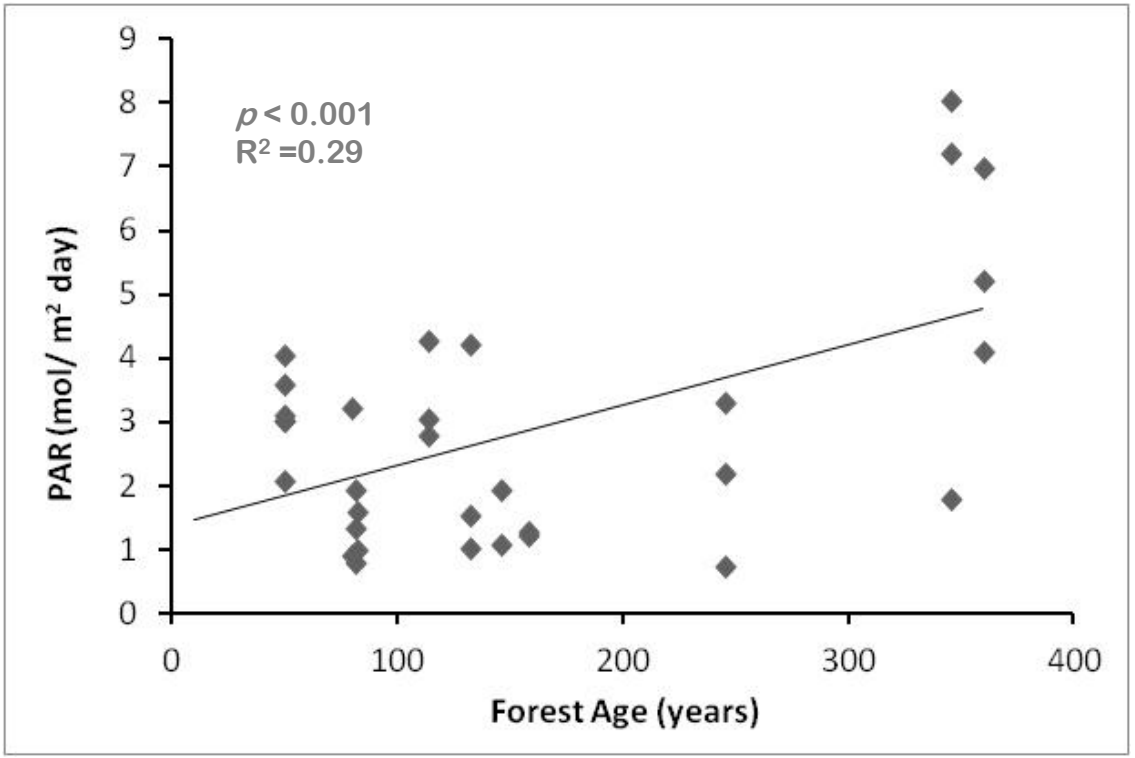


Older forests (green line) had more frequent and higher maximum PAR values compared to younger (secondary) growth forests (orange line).

Old growth forests remained brighter even after leaves developed on the trees during spring canopy closure.

Older more complex forests have more sunlight

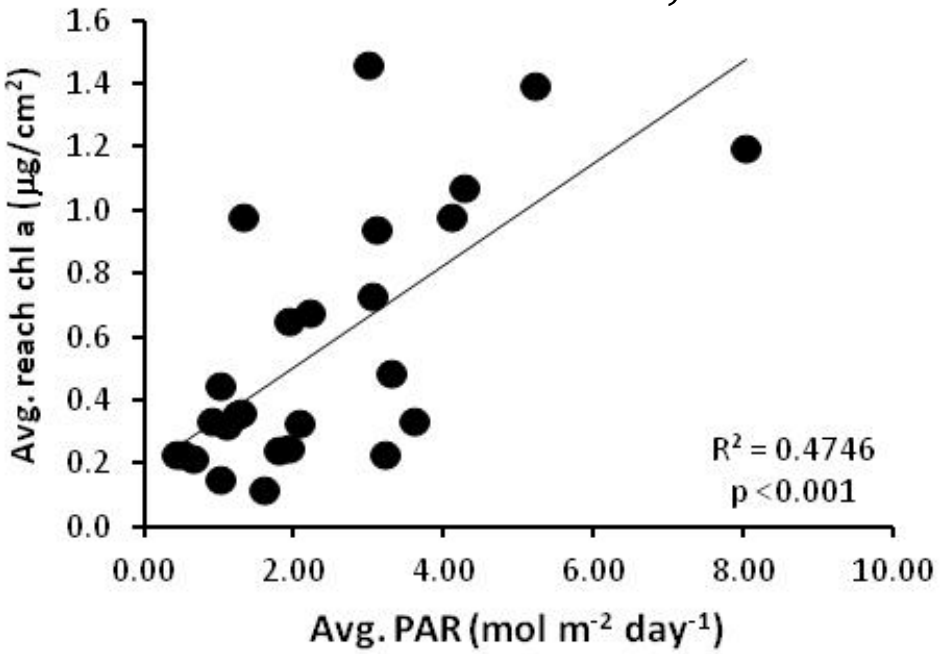




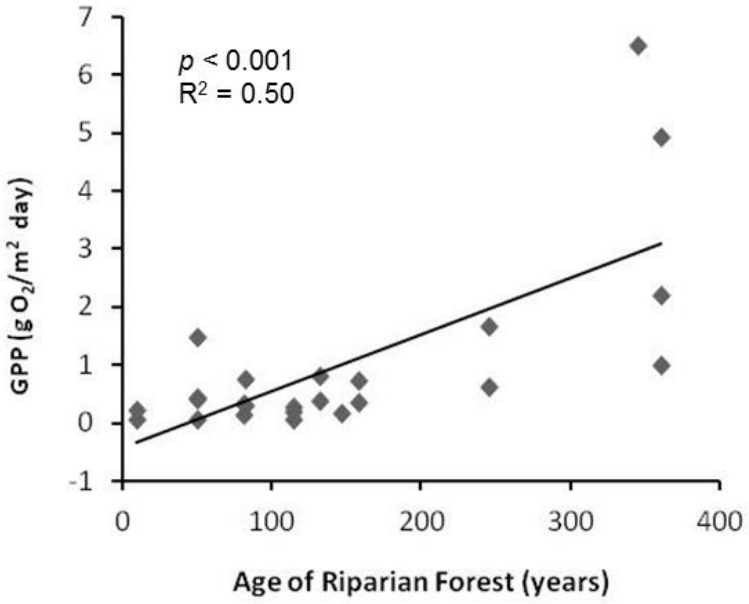
- Older riparian forests tend to have more “gaps” (and complexity) and create brighter conditions that are available to the streams draining them.
- Sunflecks created by gaps are highly variable in the canopy, but provide photosynthetically active radiation (PAR) to algal communities.
- Younger forests tend to be less complex in forest structure and darker due to small and less frequent gaps.

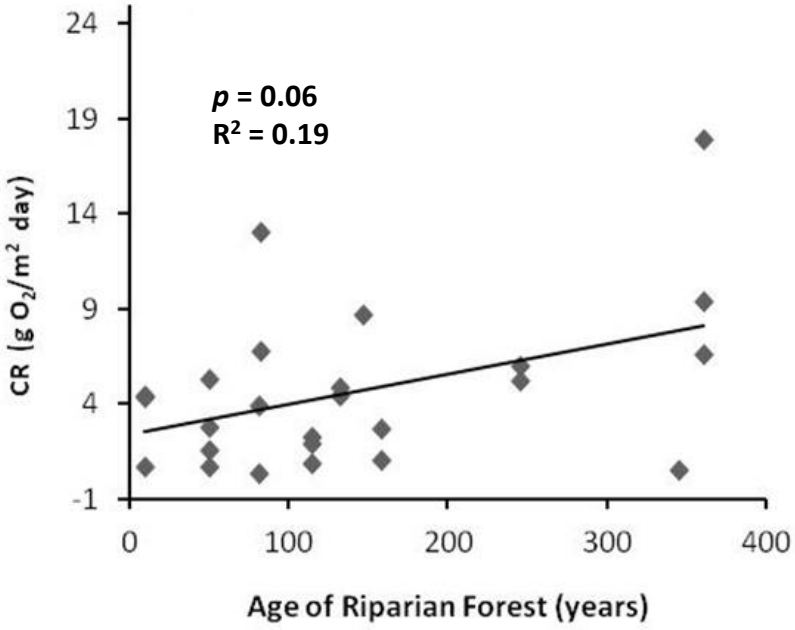
Light increases biofilm algal chl *a*

3 seasons, 14 sites



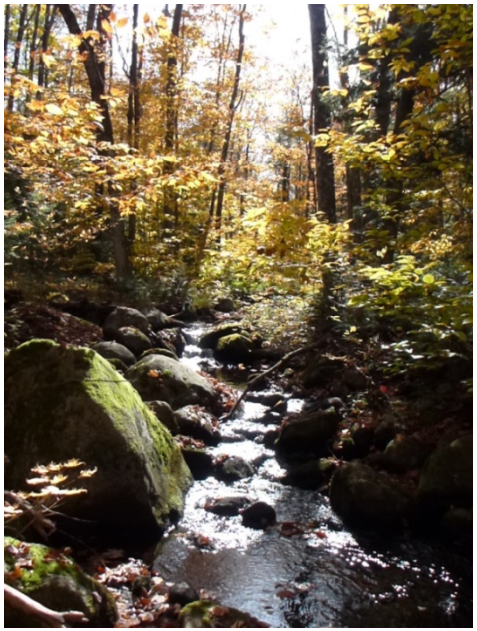
- Consistent pattern across all sites and seasons
- Algal biomass increased in brighter conditions

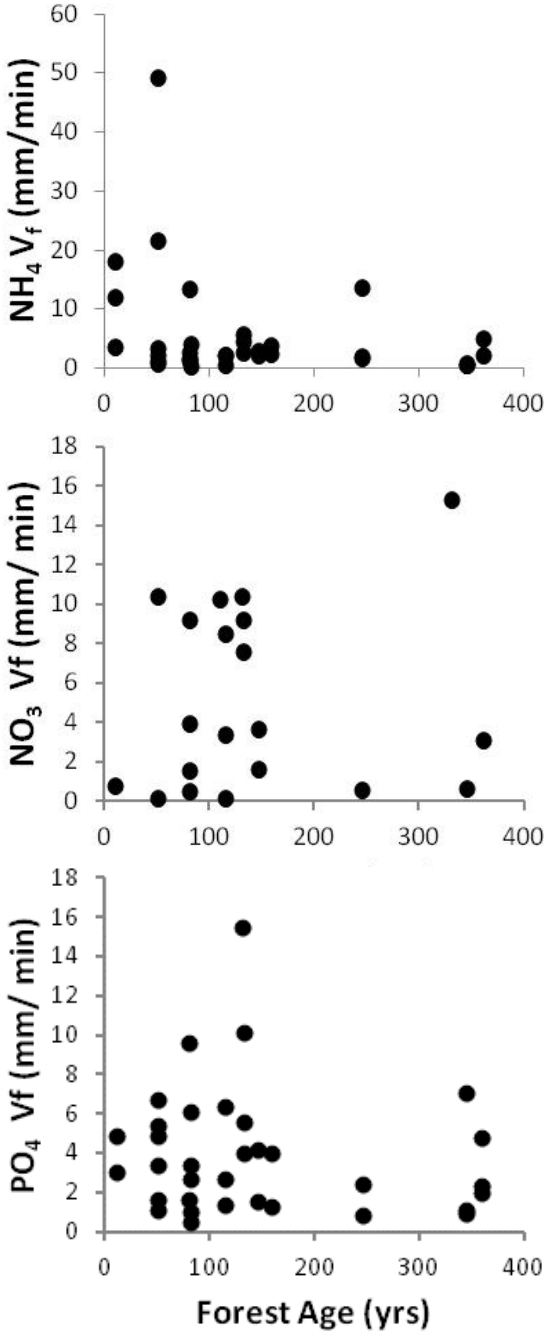




Whole-stream ecosystem function increased with forest age.

Gross primary production (GPP) significantly and community respiration (CR) marginally increased with forest age/complexity.

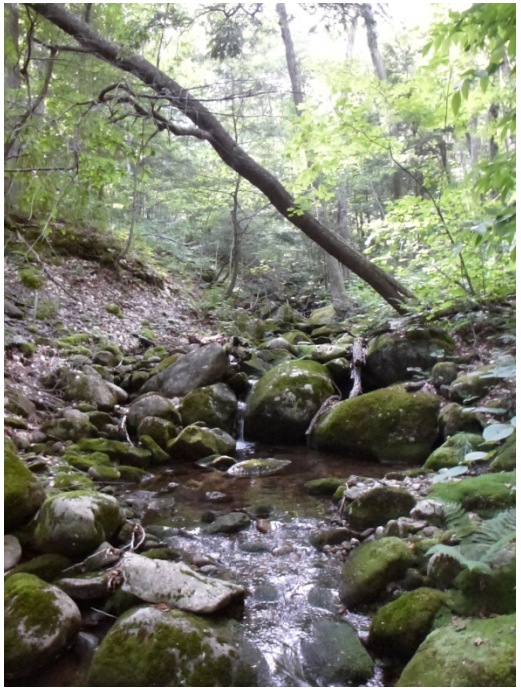




Although GPP increased with forest complexity, there was no relationship between forest complexity and nutrient uptake for any of the three nutrients studied (NH_4, NO_3, PO_4).

This lack of relationship might be due to site variability across 3 regions, and nutrient limitation status at these streams.

Nutrient demand may also be less sensitive than GPP



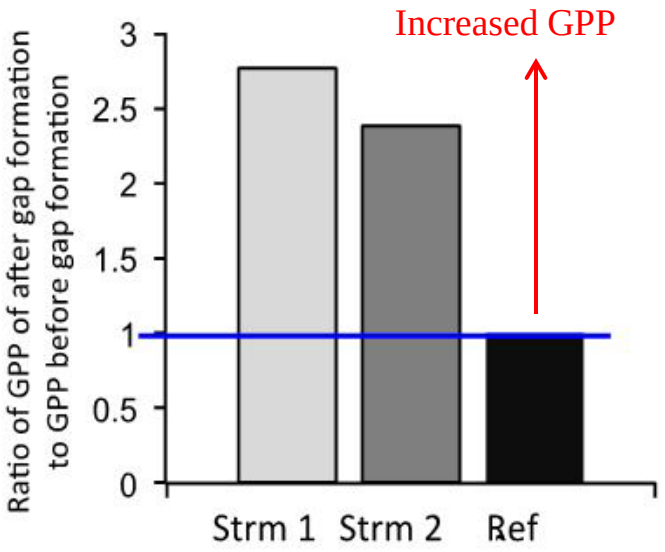
Outreach efforts

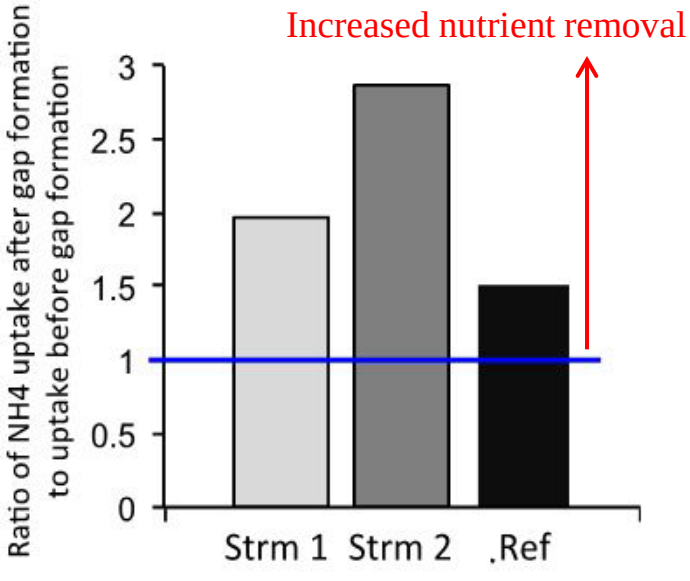
This work has been presented at multiple national and local scientific meetings, published in peer-reviewed journals and broadly disseminated to the scientific community. A Research Experience for Undergraduates (REU) student has participated in this research each year of the study. Outcomes of this work have also been shared with the Cary Institute of Ecosystem Studies Education Team who have used our findings to develop a plan to target non-scientist professionals. We also worked closely with New Hampshire Fish and Game throughout the second year of this project to develop methods to best monitor ecosystem functional response to the restoration efforts call “chop and drop”. This collaborative effort will continue to study the effects of small disturbances on trout habitat and stream function in the near future.

Implications and application to Northern Forest region

- Old-growth forests in the northeastern US are generally characterized by a lower density of trees, more forest gaps, multiple canopy layers, and more large trees dominating the canopy (Keeton 2006, D'Amato et al. 2009). Old-growth forests in the northeastern US are rare though and, when present, they are generally hard to access. The vast majority of research on stream ecosystem function in forested streams of the northeastern US has therefore been conducted in young and early-mature second growth forests; systems where we would expect the least amount of in-stream production and greatest net heterotrophy. Few studies have quantified nutrient uptake in old-growth forest streams, and we are aware of no studies quantifying ecosystem metabolism in streams with old-growth riparian forests. Missing old-growth forest ecosystems may have created a bias in our characterization of "forested" streams and influenced our understanding of how stream organic matter and stream metabolism change over time (Valett et al. 2002, McTammany et al. 2007).
- The structure of a forest is often linked with stand age; however, forest structure is not driven by stand development alone. Disturbances – both natural and anthropogenic – can influence the age structure, physical features, and community composition of riparian forests. Ice storms, hurricanes, and fire all kill trees and significantly restructure the physical characteristics of a forest. Aided by anthropogenic introductions and milder winters associated with a changing climate, invasive species such as the hemlock woolly adelgid (*Adelges tsugae*) and the emerald ash borer (*Agrilus planipennis*) are moving north into the northern forest region and are expected to alter forest structure.
- Our study suggests that increased small scale disturbance may have some positive effects on these heavily shaded stream ecosystems. This applies to increased primary production and chlorophyll a concentrations, however, nutrient uptake appears to be limited by some other factor besides light availability. The chronically low nutrient status of these streams combined with historical acidified conditions may have temporarily stripped the capacity of the streams to store or take up nutrients even when light increases.

Experimental removal of canopy enhances stream function





<u>Pilot study and future direction work from this research</u>

- We conducted a pilot study with NH Fish and Game at sites where restoration measures aimed to improve habitat for trout were put into place. These efforts created gaps in the riparian tree canopy in 2 of our study streams.
- We opportunistically measured the response of stream function before and after the restoration at these sites.
- We found both measures of ecosystem function to increase compared to before restoration and to reference streams (unaltered).
- Further investigation of these restoration methods could be used to mitigate effects of expected pest invasion or small scale disturbance to forest canopies.

Products

Conference Presentations:

•Bechtold, H.A., E.J. Rosi-Marshall, D. Warren, W. Keeton, J.J. Cole. 2013. Stream ecosystem function is linked to changes in riparian forest structure. Society for Freshwater Science, Gainesville FL.

•Bechtold, H.A., E.J. Rosi-Marshall, D. Warren, W. Keeton, J.J. Cole. 2012 Evaluating the influence of riparian forest structure on stream metabolism and nutrient uptake. Society for Freshwater Science, Louisville, KY.

•Bechtold, H.A., E.J. Rosi-Marshall, D. Warren, W. Keeton, J.J. Cole. 2012 Proposed work: Linking riparian forest structure to in-stream nutrient uptake and metabolism at Hubbard Brook. Cooperators Meeting, NH.

•Bechtold, H.A., E.J. Rosi-Marshall, D. Warren, W. Keeton, J.J. Cole. 2012.The effect of riparian forest structure on in-stream nutrient uptake and metabolism in the northeast. ECANUSA 2012, Durham, NH.

Peer-reviewed articles:

• Roales, J., J. Duran, H.A. Bechtold, PM Groffman, EJ Rosi-Marshall 2013. High resolution measurement of light in terrestrial ecosystems using photodegrading dyes.

•Warren, D.R., W. S. Keeton, Bechtold, H.A., E.J. Rosi-Marshall. 2013. Comparing streambed light availability and canopy cover in streams with old-growth versus early-mature riparian forests in western Oregon. *Aquatic Sciences* DOI 10.1007/s00027-013-0299-2

•Bechtold, H.A., E. Rosi-Marshall, D.R. Warren, J.J. Cole. 2012. A practical method for measuring integrated solar radiation reaching streambeds using photodegrading dyes. Freshwater Science 31:1070-1077.