Future Forests – Future Steams (FuFor)

Full Project Title: Dynamic forest-stream interactions: experimental acceleration of late-successional stream functions and resistance to flood disturbance

Abstract

Secondary forested landscapes in the northeastern U.S. continue to recover from 19th century clearing and other land uses. With the majority of these forests still in a mature developmental condition, there are important questions about how forest processes and ecosystems will change as stands develop towards a late-successional condition. It remains poorly understand how stand development processes will interact with anthropogenic stressors and fine to intermediate-scaled disturbances, including wind and ice storms, that accelerate gap formation and patch diversification. And further, as gap-forming disturbances accelerate stand development, an important question becomes whether recovering late-successional forests will generate a different mix of ecosystem services (e.g., hydrologic regulation and water quality) compared to the younger, structurally simpler secondary forests we have today. Stream-side forest systems are an ideal place to explore these questions based on our previous work on riparian forests in the region. The findings will have important implications for predicting not only future forest dynamics, but also the associated ecosystem processes and biotic interactions in adjacent aquatic environments. From our earlier work in the few remaining primary (old growth) riparian forests in the eastern U.S., we can hypothesize that stand development and localized disturbances create intriguing and beneficial forest-stream interactions, including enhanced nutrient uptake and retention by stream biota, complex shifts in food webs and biological production, and potential increases in flood resistance related to woody debris inputs and channel roughness. Effects on streams of gap creation associated with invasive pests, including emerald ash borer and hemlock woolly adelgid, remain highly unclear. This is particularly true because spatial scale, species-specific mortality, and recovery dynamics are likely to differ significantly from natural gap formation processes.

We are proposing a new, collaborative, interdisciplinary study at Hubbard Brook. We will experimentally create complex riparian forest structure – particularly characteristics associated with late-successional development (canopy gap formation and large woody material recruitment) – influence stream ecosystem functions through effects on stream light and temperature, in-stream productivity and nutrient dynamics, as well as changes in channel geomorphic features and hydrology that relate to flood resistance in forested landscapes. We will address both theoretical questions about controls on productivity in streams and practical questions about how management promoting late-successional characteristics in the riparian zone will influence aquatic ecosystems and flood resistance.

We focus here on two controls on stream processes related to the structure and development of surrounding riparian forests: light availability and large wood loading in streams. Neither nutrient limitation nor top-down controls on primary production manifest when light is limiting. Therefore understanding controls on light dynamics and their influence on stream metabolism and Gross Primary Productivity (GPP) is of fundamental importance in understanding how nutrients and consumers function in stream ecosystems. We are particularly interested in how changes in forest structural dynamics influence light, and therefore we propose the creation of experimental canopy gaps (scaled on natural gap sizes and frequencies based on previous work) along selected stream reaches at Hubbard

Brook. Forested streams are widely acknowledged to be light-limited ecosystems. Previous studies have demonstrated that removal of all riparian vegetation changes stream ecosystem function, but the more complex question of how canopy gaps and associated hotspots of high light and concomitant elevated benthic GPP translate to whole ecosystem processes remains poorly understood.

We also propose manipulating wood loading in the selected stream reaches through direct wood additions to levels commensurate with those documented in the region's remaining old-growth forests. Wood loading has been shown to affect nutrient processing in streams, with retention and uptake increasing with greater wood levels in some cases. However, other studies have produced contradictory results, suggesting a key knowledge gap in relating wood loading to nutrient dynamics in eastern forest streams. Manipulations that explore mechanistic processes may help to determine factors driving different responses to wood addition and removal. And beyond wood alone, the critical interaction of light and wood loading – both expected to increase with late-successional structural development along stream reaches based on our previous work – in controlling in-stream nutrient processes have never been explored together in a manipulative experimental context, particularly as it relates to the developmental stage of riparian forests. Since wood loading also affects channel geomorphology, including erosional and depositional processes as well as "roughness" coefficients related to dissipation of flood energy and re-infiltration of stream flow in previous research, we will investigate relationships between channel planform adjustments and natural high precipitation events. Other sources of variation in stream processes related to anthropogenic stressors, such as climate change, airborne pollutants, and invasive pests and pathogens, will be addressed statistically and using simulation modeling, building on Hubbard Brook's extensive datasets. The individual tree-based landscape and disturbance simulator called "iLAND," recently parameterized and re-calibrated for the U.S. Northeast, will be employed for modeling purposes.

Our proposed study will bring together two lines of previous research in which our group has participated: namely studies of in-stream processes and channel geomorphology in relation to forest age and development; and silvicultural studies in which experimental manipulations has been proven capable of accelerating rates of stand structural development. The former includes both descriptive and experimental work throughout the Northeast, while the latter includes the P.I.'s ongoing 18-year study at two research forests in Vermont. In this study we integrate both with the goal of better understanding forest-stream linkages and how those will change in the future, potentially yielding important ecosystem services. We anticipate the results will inform both our understanding of the basic ecology of forest-stream interactions and critical aquatic ecosystem processes, while also enhancing our ability to predict future shifts in ecosystem service provisioning and resistance to disturbance in relation to forest development and stresses.

We propose a factorial Before-After-Control-Impact experimental design implemented at stream reach scales (roughly 300 linear meters along streams). In this design there will be four factorial treatments: no manipulation, gap creation, wood addition, and gap creation + wood addition. These will be implemented along three replicate reaches per treatment. Forest manipulations will extend to a distance equivalent to three site potential tree heights on either side of stream channels, which is the distance over which forest canopies have been shown to most strongly regulate below-canopy microclimate and low angle light attenuation in previous research.

We are in the early stages of project design. Therefore, we propose implementing this study in two stages. In stage one (6 months to 1 year), we will invite potential collaborators, broaden the team of terrestrial and aquatic ecologists with relevant expertise and interests (including modeling), conduct design and planning workshops, and engage stakeholders around goal development. The latter is particularly important to ensure stakeholder input and the public's engagement with the science throughout the project, including initial design. We will also make final site matching and selection decisions from candidate reaches in north-facing and western portions of the experimental forest during the first stage, determining also the level of feasible treatment replication. In stage two, the experimental manipulations will be implemented. Intensive sampling is planned for both forest attributes and in-stream processes over two growing seasons pre-treatment and at least three seasons post-treatment. A wide array of stream process response variables will be of interest to the investigators, and we propose focusing these through the planning process in stage one.

Objectives and Hypotheses Objectives

In this study, which emphasizes both basic and applied research science, our first set of objectives are phrased as series of testable hypotheses. Collectively these represent a highly interdisciplinary study, integrating multiple sub-disciplines within terrestrial ecology and stream ecology. The objectives are as follows:

- **Forest development and effects on stream productivity**: Accelerated late-successional forest structural development will alter stream productivity, nutrient processing, and channel complexity.
- **Wood loading and nutrient uptake**: Enhanced wood loading will increase in-stream nutrient retention and uptake rates as new dams retain fresh organic material and increase hyporheic flowpath length. As wood jams age and accumulate inorganic sediment and organic material with lower C:N ratios, their function in stream nutrient retention will decline.
- **Gaps, light, and nutrient demand:** Canopy gaps will alter localized stream light availability, leading to greater primary production and nutrient demand. Patches under canopy gaps will have larger standing stocks (biomass) of periphyton and invertebrates in mid-summer.
- **Wood + light interactions:** Strongest nutrient and productivity responses will occur where light is not limiting and wood additions result in the highest nutrient processing rates.
- **Wood and channel roughness**: Wood additions will result in greater channel geomorphic complexity and in-stream structures (e.g. debris dams, bank deposits, pools, etc.) that will, in turn, increase channel roughness.
- **Channel geomorphology and flood resistance:** Increased roughness and channel complexity will reduce rates of planform adjustment in response to high precipitation events.

Additional applied objectives include: A) informing forest and watershed managers of options for managing riparian forests for enhanced late-successional functions, including habitat, flood resilience, and nutrient processing; B) information transfer to range of stakeholders interested in water quality and stream habitat enhancement; and C) experimental development and validation of models that will improve predictive capacity for understanding ecosystem service generation with shifting landscape dynamics, forest development, and global change influences (e.g. climate change and invasive species).

Public Engagement with Science (PES) will be a key objective and outcome of the proposed study. We will not simply disseminate or publish information, but rather engage stakeholders directly from the outset (i.e. project design through implementation) to derive stakeholder driven questions and interests. This will include early engagement with federal and state agency personnel and k-12 educators. There will also be a heavy emphasis on application of the science to real world forest and watershed management concerns. This will include development of silvicultural guidance, based on our findings, for those interested in managing riparian corridors for enhanced functionality and flood resistance. The HBRF will assist with PES for the study.

Design overview:

1. **Building on previous research; design workshop**

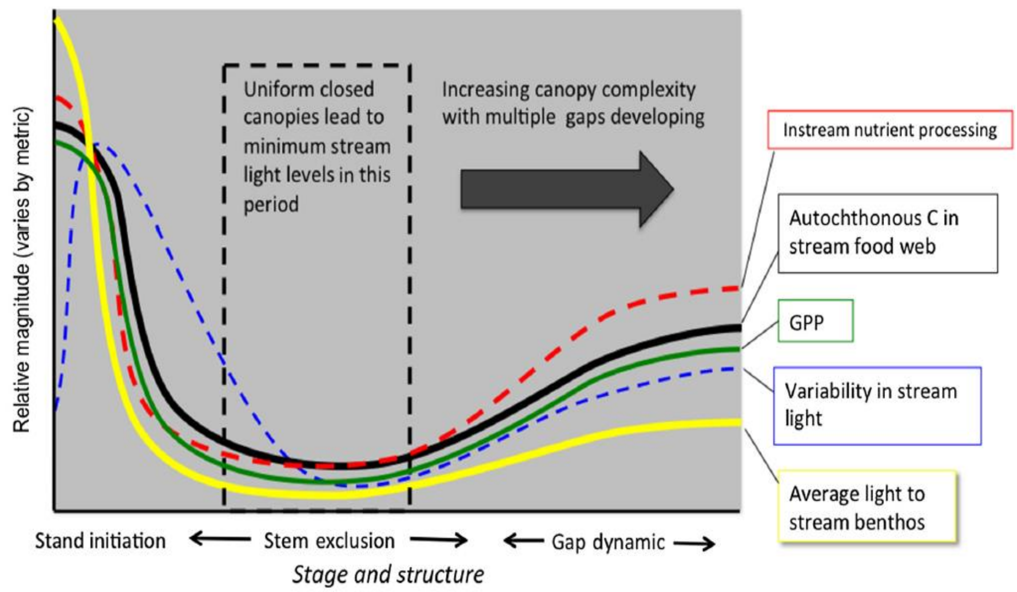
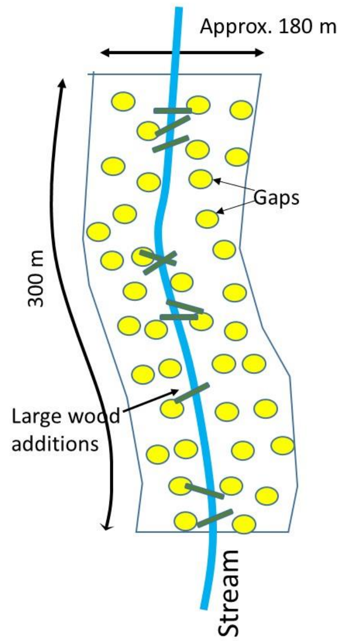


Figure 1. Conceptual model to be tested experimentally in this study. Figure reprinted from: Warren, Keeton, et al. (2016, Ecosphere).

2. **Replicated BACI design along 12 stream reaches at HBEF**

	No manipulation	Large wood addition
No manipulation	Control: 3 Stream Reaches	Wood only: 3 Stream Reaches
Gap creation	Gaps only: 3 Stream Reaches	Wood + Gaps: 3 Stream Reaches

Figure 2. Experimental design and replication by treatment for the proposed study at HBEF. The experiment will employ a Before-After-Control-Impact design, replicated along 12 stream reaches (N = 3 per treatment).



Artificial gaps:

- Area of each study reach: approx. 300 m x 180 m = 54,000 m^2
- Total area per reach: 5.4 ha or 13.3 acres
- Area in harvested gaps: 20% of each site = 2.7 acres or 1.08 ha
- Gaps will average 1/8 acre or 0.05 ha in size based on Seymour et al. (2002)
- About 22 gaps per site
- Total area harvested at HBEF = 6.48 ha.
- Total number of gaps at HBEF = 132 gaps

Wood additions:

- Harvested logs used for wood additions or left in gaps to emulate tree mortality
- Approx. 100 m^3/ha logs added to each of six stream reaches, distributed across range of logs sizes >30 cm median diameter
- Log placement based on geomorphic criteria

Figure 3. Proposed site layout and treatment specifications.

3. Upscaling using the iLand model

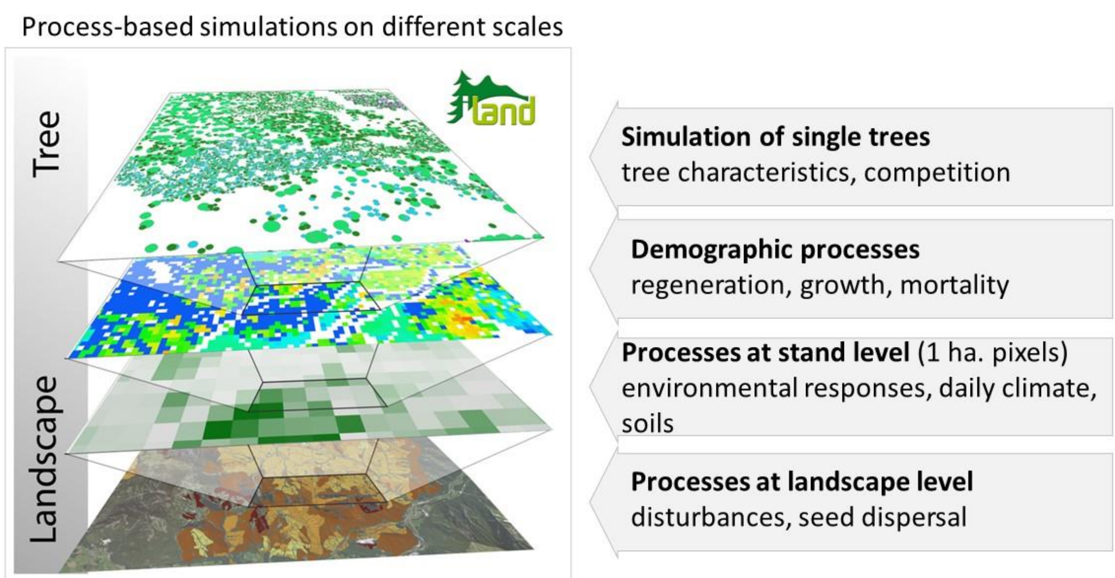


Figure 4. Structure and upscaling procedure in the iLand model, which we will use to simulate forest-stream interactions, as informed by experimental data, at the drainage basin scale for the HBEF. From Seidl et al. (2012) and Thom et al. (2017).

Other design elements:

- 3 replicates per treatment, including controls. Full or partial replication within HBEF depending on design preferences and limitations on "overall footprint."
- Mid elevation, hardwood dominated, previously un-manipulated
- Perennial 1st and 2nd order streams
- Northern and southeast facing watersheds in the western portion of HBEF
- Controls could include reaches above W7 and W8.
- Potential to manipulation reach above W7, depending on interest and coordination with HBEF community of scientists
- Each study reach (i.e. replicate) would be 300 meters of stream channel length by approximately 200 – 300 meters on each side of channel, depending on site potential tree height. Option to standardize or reduce widths of manipulated areas.

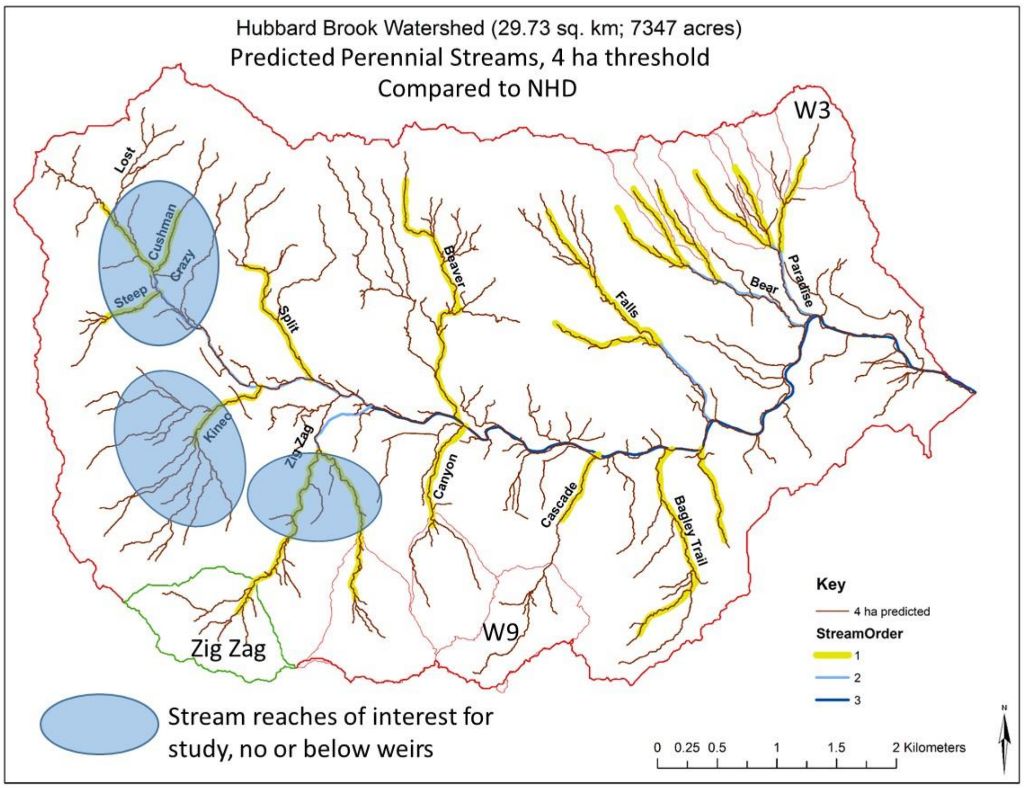


Figure 6. Location of potential study sites (stream reaches) in the western portion of the Hubbard Brook Watershed, NH. Only one gauged watershed will be employed and for control purposes only.

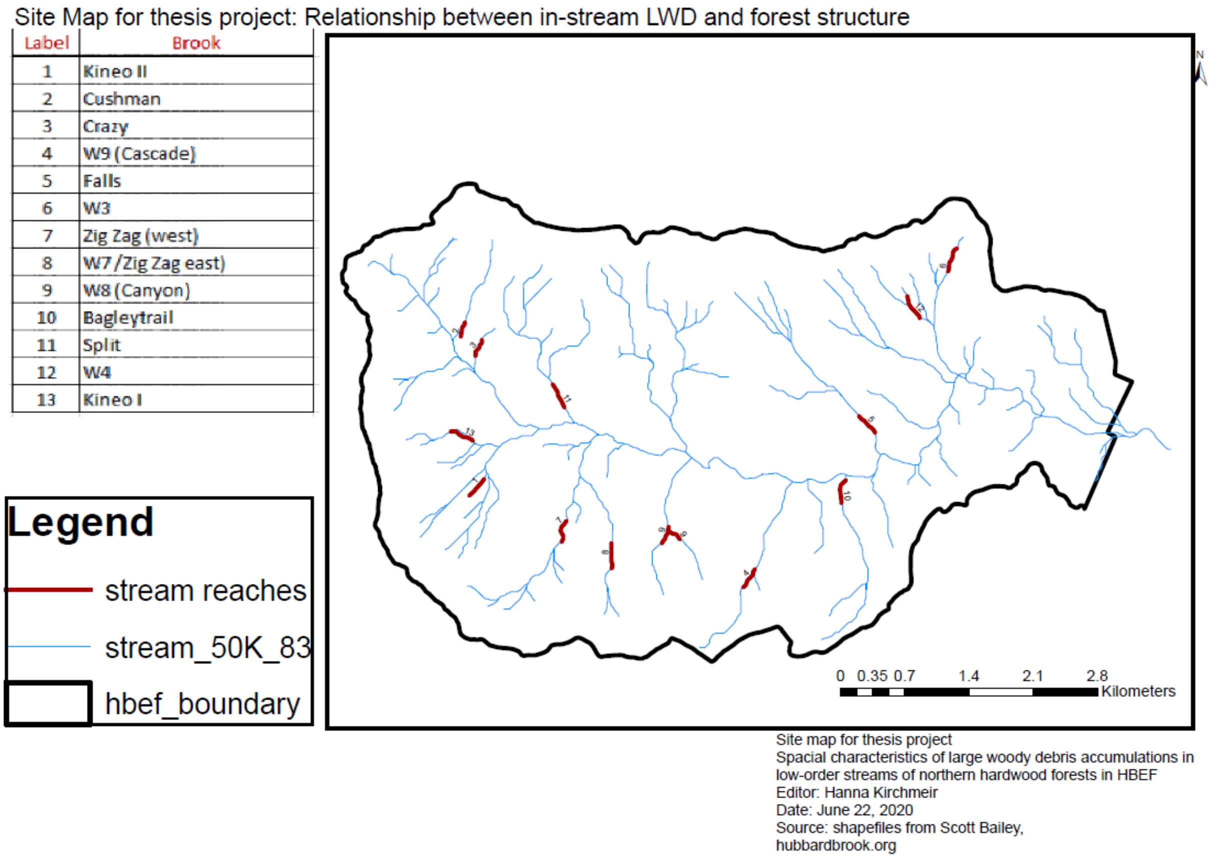


Figure 7. Location of surveyed candidate stream reaches

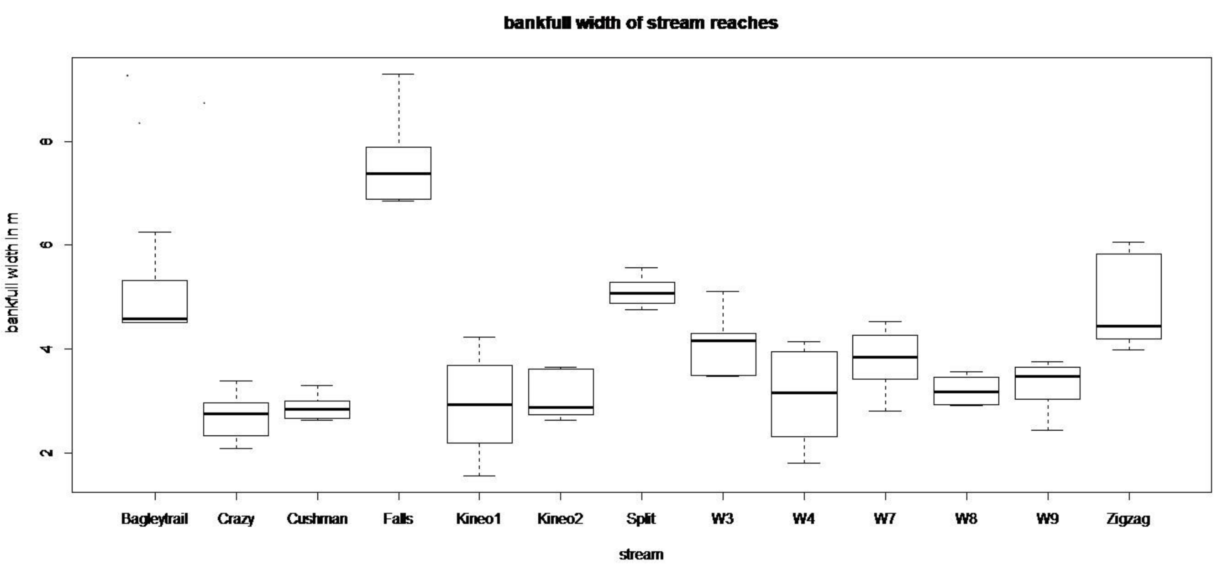


Figure 8. Bankfull widths of candidate stream reaches

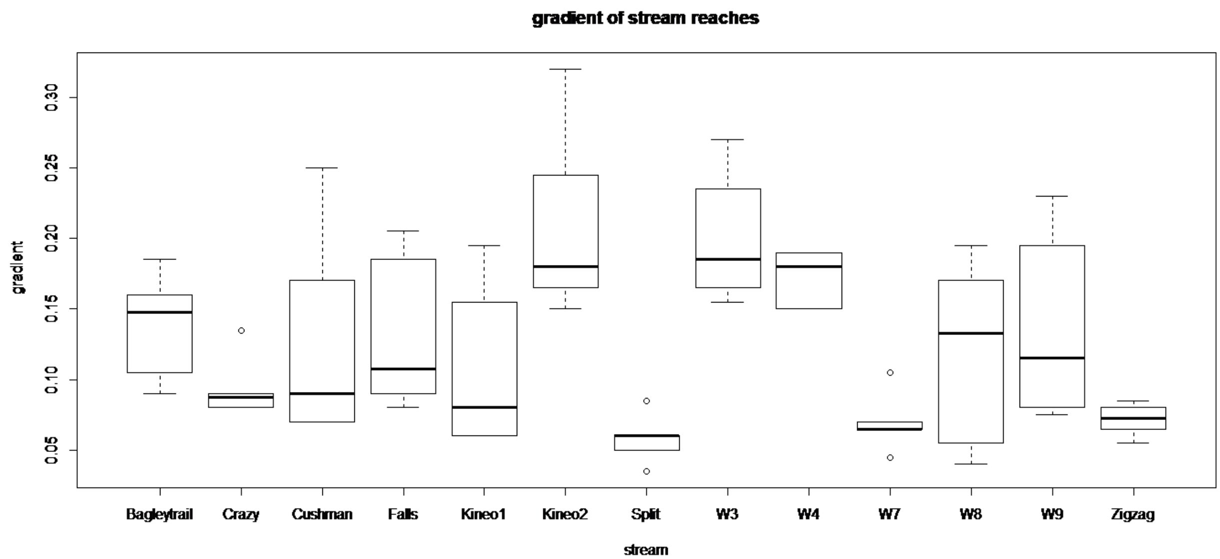


Figure 9. Gradient of candidate stream reaches

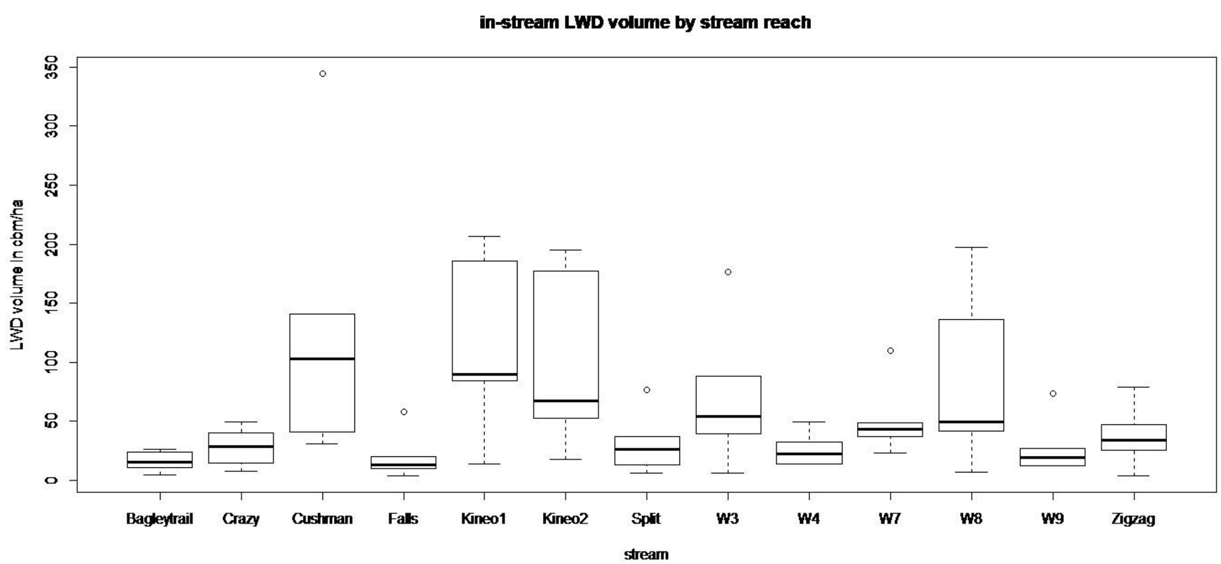


Figure 10. In-stream Large Woody Debris (LWD) volumes within candidate stream reaches

Potential Funding Sources:

- National Science Foundation, Division of Environmental Biology, Ecosystem Science Cluster.
- National Science Foundation, Dynamics of Coupled Natural and Human Systems.
- Northeastern States Research Cooperative (pending renewal of the program in FY19)
- USDA McIntire-Stennis Forest Research Program
- USDA, National Institute of Food and Agriculture, Agriculture and Food Research Initiative, Foundational and Applied Science Program

Diversity, Equity, and Inclusion

Our diversity, equity, and inclusion plan includes three key elements: 1) active recruitment of diversity hires (e.g. field crew and technical staff) and graduate students, 2) mentoring of all lab members to ensure that all achieve their fullest potential, and 3) creating a welcoming and inclusion work environment for all. At monthly lab and quarterly team meetings we will explicitly address issues of inclusion with an open roundtable format, in which team members will be asked to lead discussions issues of concern. Through the work of HBRF, the community of scientists at HBEF has been working actively to address issues of equity, diversity, and inclusion. This happens during special forums at the annual Cooperators Meeting as well as special events. As full members of this community, all of our team members (faculty and students alike) will participate in discussions of this theme.