WOOD ADDITIONS, STREAM MORPHOLOGY, AND BROOK TROUT POPULATION DYNAMICS IN HEADWATER STREAMS OF THE SACO RIVER WATERSHED

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INTRODUCTION

Anthropogenic alterations to the landscape can have long-lasting impacts on the ecological integrity natural systems. Forest harvest can strongly influence the structural characteristics of headwater stream habitat (Hauer et al. 1999). The logging history the northeastern United States has changed the geomorphological and biological properties of streams, deteriorating their quality as habitat for eastern brook trout (*Salvelinus fontinalis*) (Nugent and Carpenter 2015).

The native range of the eastern brook trout covers most of the northeastern United States and extends along high-elevation areas of the Appalachian Mountains. Populations have been reduced or eliminated across much of this area, particularly in southern reaches (Hudy et al. 2008), so northern New England is the most intact part of the native range at this time (Eastern Brook Trout Joint Venture). Despite the relatively high quality of habitat in the area, New Hampshire's brook trout were far more abundant in the past than they are today (Noon 2003). Though they are still distributed throughout most of New Hampshire (Figure 1), brook trout and their habitat are threatened by a variety of human impacts, such as historic land use, habitat fragmentation, and runoff (Nugent and Carpenter 2015).

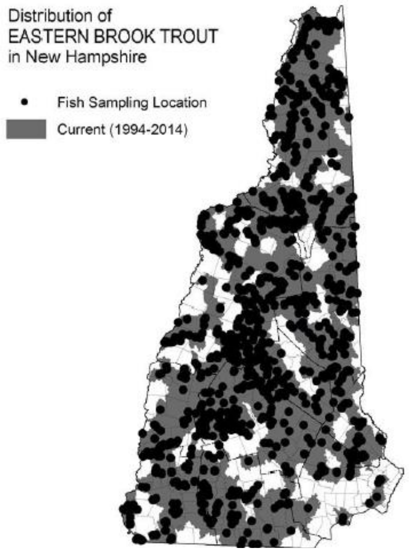

Figure 1. Present distribution of the eastern brook trout in New Hampshire from the NH Wildlife Action Plan (Nugent and Carpenter 2015)

Habitat improvement through wood addition has been shown to have a positive impact on trout abundance and density (Berg et al. 1998, Sweka and Hartman 2006, Antón et al. 2011). Many streams are channelized and flanked by relatively young forests, so natural recruitment of woody material is slowed and structural diversity is lacking. The presence of coarse woody material in streams strengthens their ecological integrity. Wood improves habitat quality by influencing stream flow, sediment, and the amount of pool habitat present in addition to playing a key role in the availability of nutrients and prey (Valett et al. 2002, Sweka and Hartman 2006). Augmenting the structural complexity of streams through wood additions can dampen the impact of year-to-year fluctuations in stream flow by providing refuges from both high- and low-flow conditions (Harvey et al. 1999). Wood addition also improves retention of sediments and organic matter, influencing trophic interactions by providing habitat for a diversity of the benthic macroinvertebrates on which fish feed (Raikow et al. 1995).

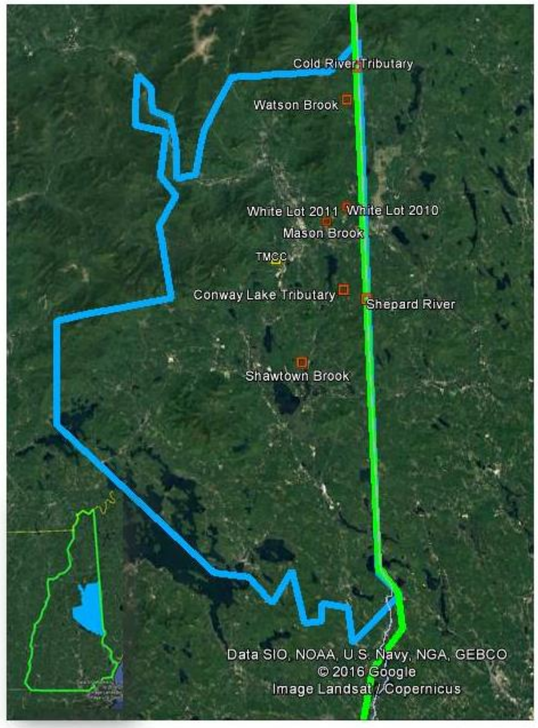

Figure 2. Location of Sample Sites. Mason Trib is located in the same area asMason

Through a partnership with the Natural Resource Conservation Service (NRCS), Tin Mountain Conservation Center (TMCC) began treating and monitoring headwater streams in Carroll County, New Hampshire in 2010 (Figure 2). The goal of this project is to better understand how and why wood additions affect brook trout distribution, abundance, and productivity and identify stream characteristics that may be associated with the potential of a stream for successful habitat restoration. The results will inform efforts to allocate resources and improve brook trout habitat more efficiently and effectively.

The spatial and temporal scope of this study could present a unique perspective on the benefits of wood additions for trout. Although extensive research has examined the impact of wood additions on freshwater salmonid populations, many published studies have only monitored sites for a few years. According to Sweka and Hartman (2006) the full influence of wood additions may take more than 3 years to take effect. Additionally, an increase in wood does not necessarily mean an increase in fish due to the high variability of stream characteristics. We have an opportunity to replicate experimental manipulation of habitat over multiple streams within a region as part of a long-term study, and for this reason can potentially address questions that remain after the completion of shorter-term research projects.

In addition to the overarching goals of the project, we aim to answer several more specific questions: (1) Which functions of wood additions have the most significant influences on trout abundance, and what other factors contribute to the impact of habitat restoration on suitability for trout? (2) How can we tell if a stream will be a good candidate for restoration? (3) How effectively do wood additions increase the amount and area of pools in streams with different geomorphological characteristics? (4) How do trout biomass, age structure, and abundance differ in streams with varying habitat characteristics? (5) How do changes in climate, water, and substrate characteristics relate to wood additions and changes in trout populations? Answering these questions will help us better understand the value of old growth riparian forests to stream habitat.

This report addresses these questions based on the dataset available after the summer of 2016. Further analysis will be needed after additional data is acquired to examine patterns in more detail.

METHODS

Field Methods

Sites were selected by NRCS in cooperation with TMCC for restoration between the years of 2010 and 2016. First order streams with a known eastern brook trout population and landowner permission were chosen as candidates for wood addition. Both sides of each stream are on the property of a single landowner to prevent conflict due to the effects of habitat treatment on the surrounding landscape.

We conducted habitat surveys of the stream and surrounding riparian areas along a 1000-foot reach of each stream before treatment. We measured wetted and bankfull width, depth, and existing wood in addition to visually estimating substrate type. We divided the 1000-foot sample into 100-foot sections and recorded habitat characteristics and the number and size of pools and riffles at one randomly selected pool-riffle combination in each section. We determined stream gradients using a transit and stadia rod and inventoried variable radius prism plots at the focal pool-riffle interface in each 100 foot sampling section and measured herbaceous vegetation by walking a 15-foot wide sample at each side of the 1000 foot reach of the stream.

We completed wood surveys within the 1000-foot sample sites at each stream. Each piece of coarse woody material (CWM) greater than 1 inch in diameter and over 3 feet long was measured and the location, habitat type, orientation, stability, wood type and decay class were recorded. Additional information about the geomorphological function of each piece of CWM was also taken, including whether it formed a pool, stored sediment, provided cover, or influenced stream structure in some other way. The percent of the log within bankfull width of the stream was also estimated at most sites.

Electrofishing took place during the last week of July annually at each site. We used a Smith-Root LR24 backpack electrofishing unit starting at 700 volts and 40 Hz and adjusted slightly according to conditions at the site. We weighed each captured fish using an analytical balance, measured their length using a box-and-ruler apparatus, and returned them to the stream. If known, we also recorded the number and species of fish seen but not captured.

We took water quality measurements monthly between June and August of each year. Temperature, pH, conductivity, dissolved oxygen, and flow rate were recorded within a 24-hour period in all streams and at consistent locations within the streams.

We made wood additions in early August of each year. The goal was to add enough wood to increase cover to between 6% and 8%, though 15% cover is a generally accepted amount to mimic the amount of wood that would be present in an old-growth stream (John Magee, personal communication). Using hand tools, logs from the surrounding riparian area were harvested and placed in the streambed. Additions were made with a variety of wood types, configurations, and orientations. To maximize stability of added wood, logs were placed next to downstream stumps or between natural features such as rocks or trees. Many logs were left at full length, and larger logs were placed on top of smaller ones. Some logs were marked with numbered metal tags at the White Lot sites to track wood movement over time.

Statistical Methods

Nine original sites treated in 2010 or 2011 were used for this analysis because of their large sample sizes and the completeness of their initial habitat data. Additional streams will be examined over time as more data is collected. The first year of electrofishing in each stream acts as a control because sampling was done before wood addition.

Past TMCC summer interns ran Kolmogorov-Smirnov and Shapiro-Wilk normality tests ($p > 0.05$) to determine that trout size and abundance data were normally distributed. We used two-tailed, one-sample T-Tests and ANOVAS to identify significant changes in fish length, age structure, and biomass, and linear regression was used to examine relationships between habitat variables and characteristics of the fish population.

Due to the large scale of this project and the involvement of volunteers, some error in the data was expected. To minimize bias caused by human error, we ran all electrofishing data through a quantile range outlier analysis (tail=0.1; Q=3), and a minimal number of outliers were identified and excluded from statistical analyses.

We determined age class of fish for each year after the completion of the field season based on a length frequency distribution for each stream. Fish were categorized into young of the year (YOY) and one or more years (Adult) based on the location of the largest break between the less frequent and more frequent size classes. Because growth rates vary between years and sites due to environmental factors, each year of electrofishing at each site was analyzed separately.

Biomass was calculated as grams of fish per 100 square meters of stream, and density was calculated as fish per square meter of stream. Both were calculated using a conservative estimate including fish missed obtained by using the number, the percentage of all fish caught that were eastern brook trout, and average weight of eastern brook trout in the sample. We estimated area by multiplying the average bankfull width of the stream by the electrofishing sample length.

RESULTS

For this report, data was analyzed from nine sites: Watson Brook, Mason Brook, Mason Tributary (Mason Trib), Conway Lake Tributary (Conway Lake Trib), White Lot 2010, Cold River Tributary (Cold River Trib), Shawtown Brook, White Lot 2011, and Shepard River.

Habitat and Environment

Average air temperature in the Saco River Watershed area, where all nine focal streams are located, remained relatively constant through the years (Figure 3; U.S. Climate Data), but total precipitation varied substantially (Figure 4; U.S. Climate Data). Biomass was not significantly correlated with total precipitation (F=0.2883) or average temperature (F=0.4715).

Percent YOY was significantly correlated with total precipitation (F=0.0003), but not with average temperature (F=0.8814).

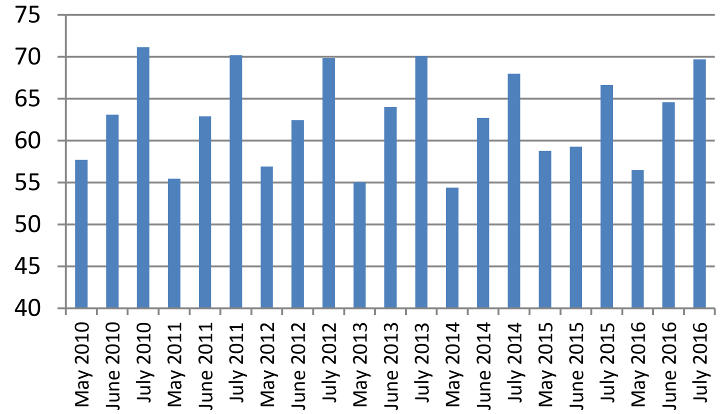

Figure 3. Average monthly temperature (F) of the months of May – July for each year of the study

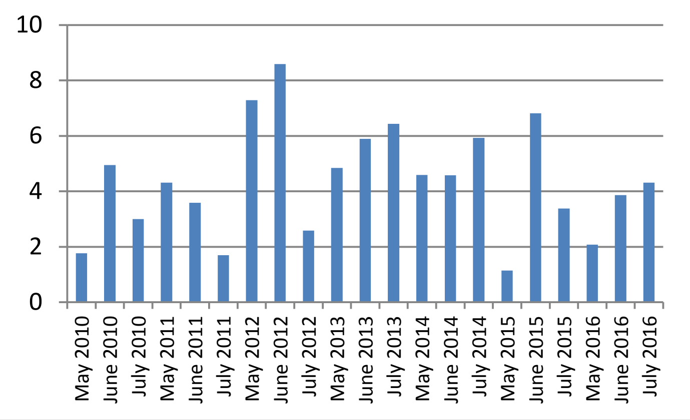

Figure 4. Total monthly precipitation (in.) of the months of May – July for each year of the study

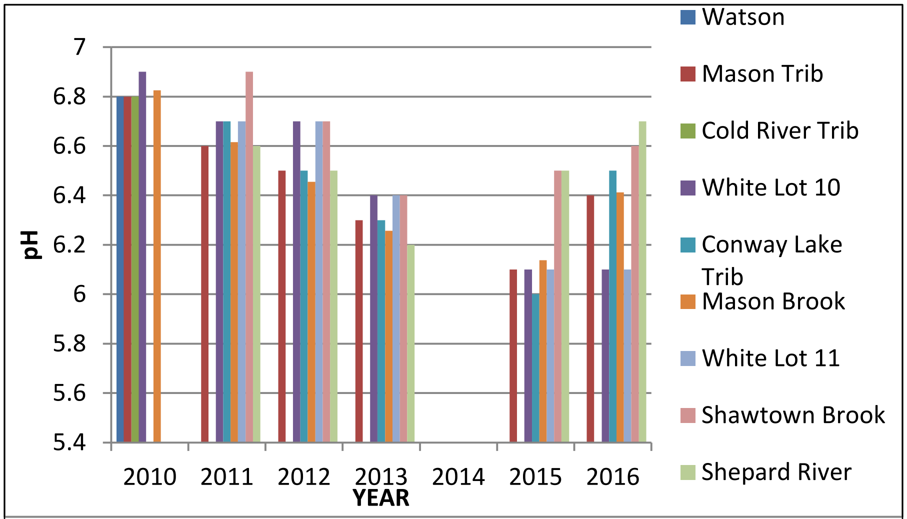

Figure 5. Average pH in each stream for each year of the study. 2014 measurements are excluded.

There was subtle variation in pH both between years and between streams. The pH seemed to be higher in 2010, 2011, and 2012 than in 2013, 2015, and 2016, but Shawtown Brook and Shepard River had consistently high pH levels throughout the years (Figure 5). Data collected in 2014 is excluded due to an equipment malfunction.

Focal headwater streams were primarily surrounded by northern hardwoods (NH) and eastern hemlock (EH) natural communities with some spruce-fir (SF) and white pine (WP) present. Their pH ranged between 6.6 and 6.8 during the first year of sampling, and their gradients ranged from 1% to 7% (Table 1).

Table 1. Summary of habitat characteristics of each stream. Dominant riparian vegetation types are abbreviated as follows: NH = northern hardwoods; EH = eastern hemlock; SF = spruce- fir; WP = white pine

Site	survey year	mean wetted width (m)	mean bankfull width (m)	est. pool area (m^2)	sample length (m)	canopy cover (%)	gradient (%)	dominant riparian veg left	dominant riparian veg right	pH
Watson	2010	6.4	17.2	723.3	1000	84.2	4.18	NH	NH	6.8
Mason Trib	2010	7	16.025	886.7	1000	86.25	1.63	EH	EH	6.8
Cold River Trib	2010	4.2	8.7	695.7	950	80.3	2.01	NH	SF	6.8
White Lot 2010	2010	9.6	14.535	1201.9	1000	96.25	5.89	NH	NH	6.9
Conway Lake Trib	2011	3.4	4.5	141.9	1000	78.25	7	EH	EH	6.7
Mason Brook	2011	7	10	585.6	1000	94	5	NH	EH	6.6
White Lot 2011	2011	8	12.2	1167.4	1000	96	6	EH	NH	6.7
Shawtown Brook	2011	10.8	19.7	1184.8	1000	88	4.9	WP	NH	6.9
Shepard River	2011	9.7	16.7	2088.3	1000	88.3	1	EH	NH	6.6

Wood was added to the focal set of streams in 2010 and 2011, substantially increasing the square footage of wood at all sites (Figure 6). The goal for these streams was to reach 6%-8% cover. Initially, wood cover ranged from 0.7 to 6.2%, and after addition streams were covered by between 4.3% and 18.9% wood. (Table 2).

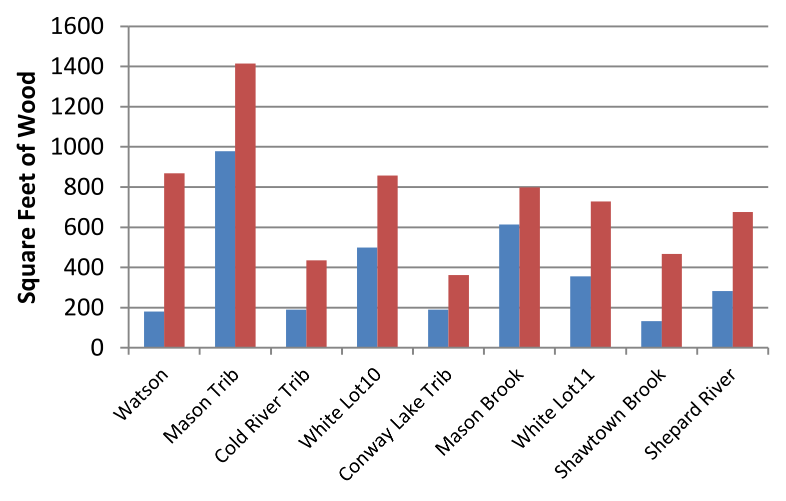

Figure 6. Wood addition in each stream; blue bars represent the square footage of wood present before treatment, red bars after treatment

Table 2. Summary of wood characteristics before and after wood addition for each stream

Site	year treated	# existing logs	area existing logs (ft2)	logs added	area logs added (ft2)	% existing wood	area wood after addition	% increase in wood	% wood after addition
Watson	2010	11	181	60	688	1.1	869	0.79	13.6
Mason Trib	2010	58	978	36	348	6.1	1326	0.26	18.9
Cold River Trib	2010	12	191	33	246	2.2	436	0.56	10.9
White Lot10**	2010	40	500	34	357	3.4	857	0.42	8.9
Conway Lake Trib	2011	57	190	43	172	4.2	362	0.48	10.6
Mason Brook	2011	122	614	16	185	6.2	799	0.23	11.4
White Lot11	2011	92	356	31	373	2.9	729	0.51	9.1
Shawtown Brook	2011	44	133	34	334	0.7	467	0.71	4.3
Shepard River	2011	74	282	37	394	1.7	676	0.58	7.0

***More wood was added to White Lot 10 in Aug 2014, bringing cover to 10% wood*

Fish Community

A significant least-squares regression was found between biomass and the percent wood increase in the stream (Figure 7; 1-way ANOVA, F=0.0356). Overall biomass was greater in streams that had experienced the largest increase in wood after treatment. Biomass was also significantly higher during the most recent two years than the year of treatment and first year after treatment (Figure 8; p=0.0048).

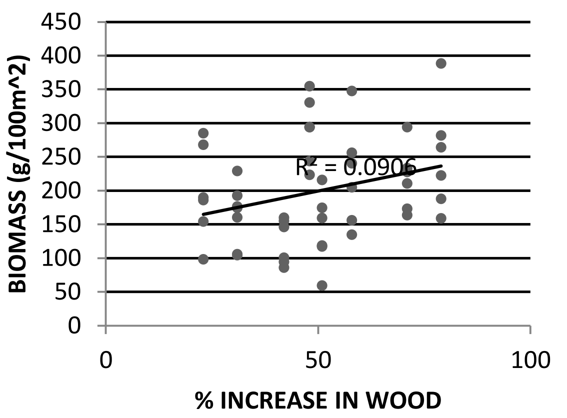

Figure 7. Least-squares regression between brook trout biomass and percent increase in wood

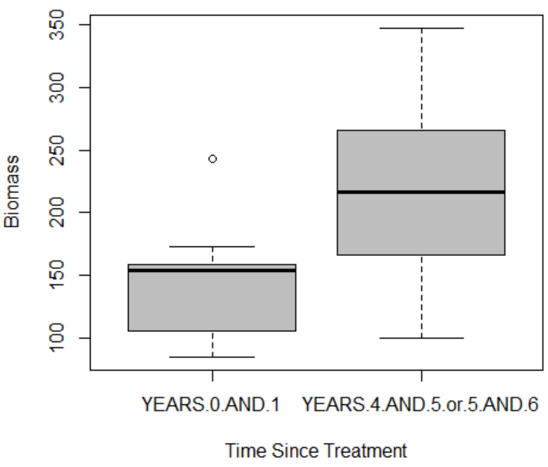

Figure 8. average biomass compared between the year before treatment to first year after treatment and the 4th and 5th or 5th and 6th years after treatment.

Biomass was not significantly correlated with pH (F=0.2573, Figure 9) or initial percentage of logs forming pools (F=0.2581, Figure 10).

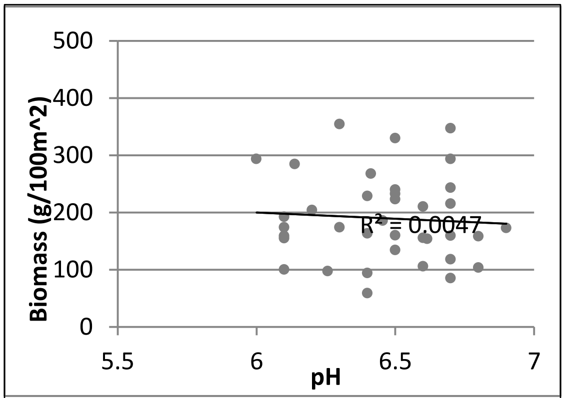

Figure 9. Least-squares regression between brook trout biomass and pH

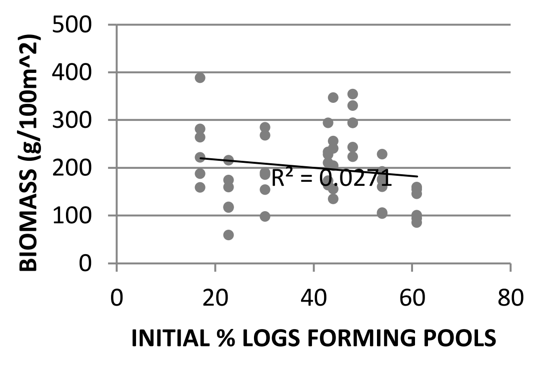

Figure 10. Least-squares regression between brook trout biomass and initial percent logs forming pools

In most streams, trout length increases over time after treatment (Figure 11). Most of these are only subtle trends, but Cold River Trib showed a statistically significant increase in fish length (linear regression, R^2=0.95; 1-way ANOVA F=0.0098). Average length of fish in several streams fluctuated through the years. Additional years of sampling may clarify these relationships.

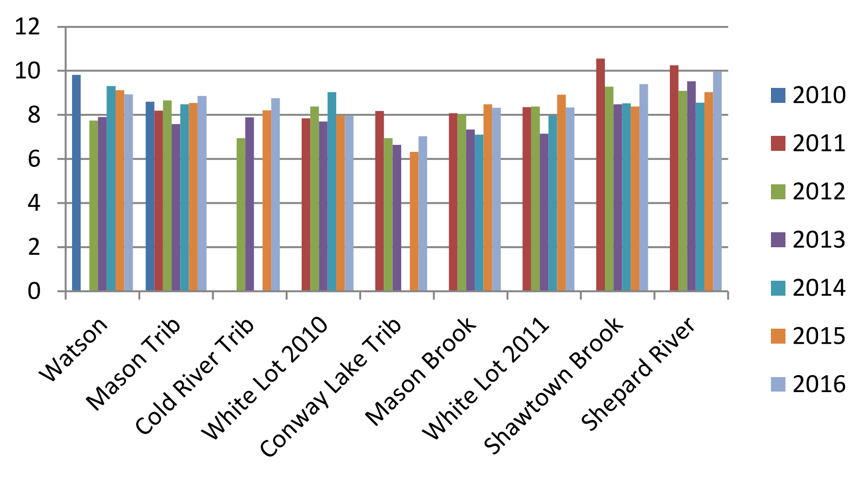

Figure 11. Average trout length in each stream between 2010 and 2016

Age structure was highly variable both within and among study sites. Watson Brook's percentage of YOY remained consistently around 20%. Conway Lake Tributary and Mason Brook had the highest proportion of YOY and showed relatively small fluctuations in age structure. Shawtown Brook, White Lot 2010, White Lot 2011, Mason Tributary, and Shepard River all had a lower proportion of YOY and experienced slightly more fluctuation than other streams. The percentage of YOY began very high, but declined steadily over 5 years in Cold River Tributary (Figure 12). Several streams also had substantial fluctuations in age structure in 2013 and 2014.

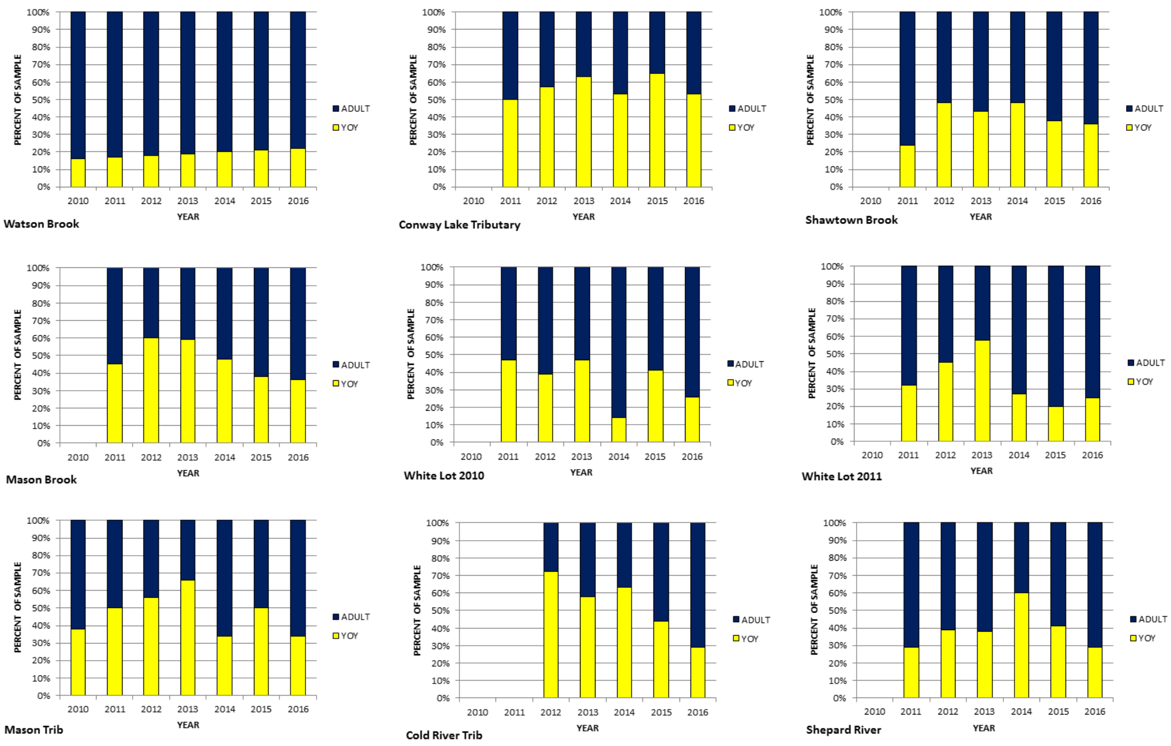

Figure 12. Proportion of adult (blue) and YOY (yellow) eastern brook trout by year; each stream is represented as a separate column chart

Previous TMCC interns saw statistically significant differences in abundance between the first and last years of treatment, but broken down into individual years a consistent increase or decrease is less apparent.

Excluding missed individuals, numbers remained fairly steady over time in Watson and Shawtown Brooks. Mason Trib saw no real increase in abundance through the years. Mason Brook, White Lot 2010, Shepard River and White Lot 2011 had increasing trends over time, and Conway Lake Trib and Cold River Trib saw decreasing trends over time (Figure 13). The actual abundances cannot be directly compared between streams because there was some variation in sample lengths and widths.

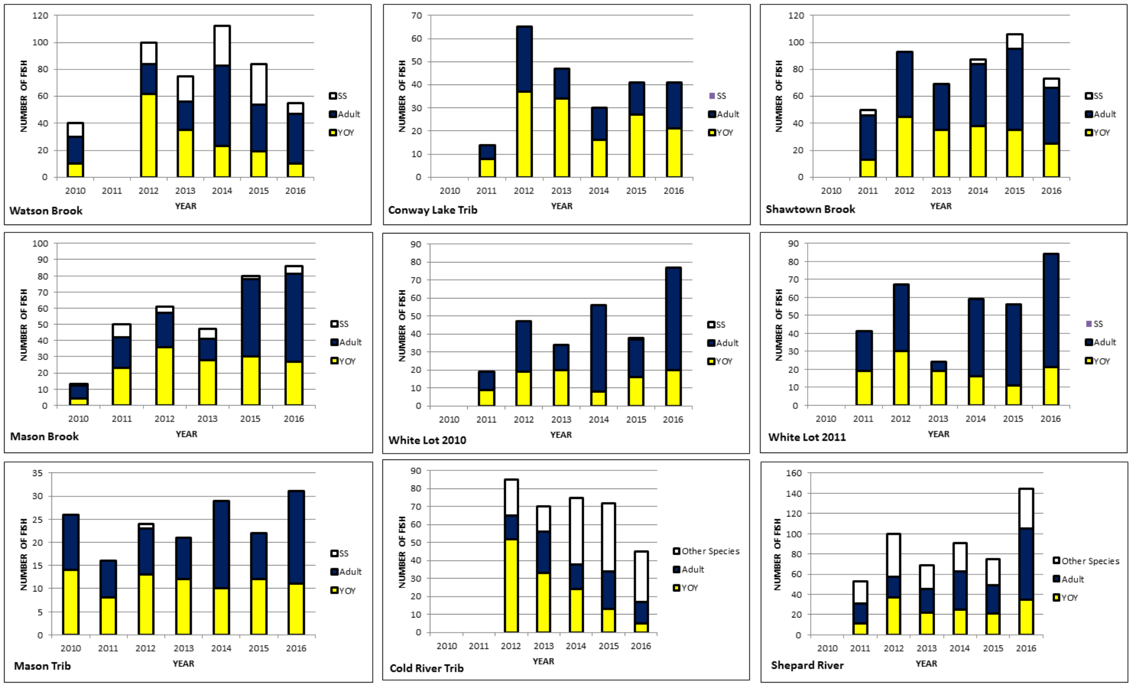

Figure 13. Abundance of trout (yellow=adult, blue=YOY) and other species (white); each stream is represented as a separate column chart

DISCUSSION

Yearly biomass did not seem to be affected by changes in temperature or precipitation. This may be because factors specific to each stream are more significant drivers of fish condition and growth rates than external, weather-related elements. The percentage of YOY did not seem to correlate with average temperature, but it did show a significant correlation with total precipitation. 2012 and 2013 had the most total precipitation between May and July each year, and 6 out of the 9 streams (Conway Lake Trib, Mason Brook, Mason Trib, Cold River Trib, White Lot 2010, and White Lot 2011) had relatively high percentages of YOY in those years. It is possible that higher precipitation influences the reproductive success of trout by bolstering populations of benthic macroinvertebrates. According to Resh et al. (2013), in California's headwater streams, high-flow years resulted in a higher abundance of benthic macroinvetebrates that likely caused the increase in reproductive output observed in some fish species. A similar pattern may be in prevalent in our study sites.

Wood cover was increased substantially at all sites, but an increase in wood does not necessarily mean an improvement in trout habitat. The stability, orientation, and placement of wood may all play a role in the effectiveness of the addition and its ability to form pools. Unfortunately, only pre-treatment habitat data has been collected thus far, so more survey effort will be needed to answer questions about the impact of wood addition on trout habitat and stream geomorphology.

Despite limitations in our habitat data, we were able to examine the effect of wood addition in relation to characteristics of the fish population. Biomass was significantly correlated with the percent increase in wood. Similarly to the observations of Warren et al. (2010) and Antón et al. (2011), wood increases were associated with biomass increases. This may again be related to the effectiveness of wood in creating pool habitat that can be occupied by larger trout in addition to increasing the amount of biomass in the system starting at the bottom of the trophic chain by trapping organic materials and supporting more benthic macroinvertebrates. Additionally, biomass was significantly related to the amount of time after wood addition; it was generally lower before addition and one year after addition than the two most recent years (either 4-5 years after addition or 5-6 years after addition). This also suggests that wood additions are impacting trout biomass substantially. It is possible that wood additions are forming larger or deeper pools over time; Ecret and Mihuc (2013) found that trout tend to prefer pools over riffles, and pool depth was the most significant factor influencing microhabitat use by a variety of size classes. Future habitat analyses with a more complete dataset will allow us to more thoroughly understand the mechanisms driving this relationship.

Contrasting the findings of Warren et al. (2010), there was no significant correlation between biomass and pH in our streams. However, our streams had low interannual variability in pH and similar surrounding vegetation communities. Gradient and initial percent logs forming pools also did not have significant linear regressions with biomass. These factors may not have had as strong an association with biomass because streams are morphologically variable and many factors interact to produce good trout habitat. Each characteristic alone may not be a prerequisite of an increase in trout biomass after wood addition.

Subtle trends in trout length were observed year-to-year, but only one stream was significant. This suggests that trout length did not increase or decrease substantially after wood addition. Because there is fluctuation in trout length and growth rates can vary year-to-year, reproductive cycles or environmental conditions may have more of an effect on the length of trout than wood additions do. Generally, biomass increased even though mean length did not. This could possibly be because the size of trout fluctuated substantially throughout the years while the total mass of trout remained similar. New Hampshire Fish and Game researchers observed that length changes in what seems to be a cycle in their Johnson Brook and Nash Stream Forest sites; every three years there is a high proportion of two year old trout in the population followed by a year with a relatively high abundance of YOY (John Magee, personal communication). We did not notice the same cycle in our streams, but particularly if it is the case that trout length fluctuates, length and biomass could change independently of one another. It is also possible that wood additions particularly favor larger trout. Antón et al. (2011) observed that wood additions seemed to provide refuges allowing adult trout to inhabit areas they did not before wood additions. Additional sampling may elucidate patterns that take more than 5 to 6 years to develop.

As expected, age structure was highly variable within streams over the years. Young and adult trout use habitat differently (Ecret and Mihuc 2013), so a healthy stream will support a variety of age classes. Most streams generally did this. The only stream with little variability in age was Watson Brook. According to TMCC trout project coordinator Richard Fortin, Watson is a high-flow stream and logs added to it form particularly large and deep pools. This may make the area more favorable for large fish and less favorable for small fish, or the high flow may result in less trapped sediment and larger substrates that are less suitable for spawning. All other streams have variable age structure, but some fluctuate differently than others. Many streams saw an increasing trend in the number of adult trout, which is consistent with the findings of Antón et al. (2011) in their examination of the effect of wood addition on brown trout age structure. Because young trout will readily use riffles and shallow pools even when adults prefer deeper pools, more habitat surveys will be needed to determine the degree to which wood additions are influencing age structure.

The variety of abundance trends in these streams could have been the result of a number of factors. It is likely that wood additions impacted different streams in different ways, and it is difficult to determine the specific effects of wood additions without post-treatment habitat data. Surprisingly, the streams with the greatest increases in abundance also seem to have increases in the number of adult trout. It is important to note, however, that these abundance estimates were not corrected for the number of missed fish and cannot be compared to biomass and density estimates. Due to the variation in the area sampled, these corrected metrics may be more informative than the abundance of fish caught.

Starting in the summer of 2017, we will be conducting post-treatment habitat surveys on many streams. This should help us to address more questions relating to the impact of wood additions on trout habitat and the underlying stream characteristics that influence the success of wood addition in the stream. Long-term monitoring of both habitat and trout populations will also help us reach additional goals of this study, such as understanding the role of forest age class in natural recruitment of woody material in streams. After obtaining more data on the changes in habitat brought about by wood addition, wood movement data will be examined along with this additional habitat data to learn more about the effectiveness of wood addition, and both this information and information relating to the trout population in each stream will be used to develop a set of guidelines to help identify streams as good candidates for successful restoration by wood addition.

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