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The Effect of Large Wood Restoration on Algal Biomass and Spatial Distribution in the Narraguagus River

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THE EFFECT OF LARGE WOOD RESTORATION ON ALGAL BIOMASS AND

SPATIAL DISTRIBUTION IN THE NARRAGUAGUS RIVER

by

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ABSTRACT

      The Atlantic Salmon (*Salmo salar)* is an anadromous fish native to the eastern US and Canada. Though they used to inhabit much of the eastern coasts of New England and Canada, the last of the United States' wild Atlantic Salmon are now mostly limited to Maine. Due to habitat destruction from dams and historic logging activity, the quality of food sources, spawning grounds, and essential juvenile salmon habitat have been severely impacted. This habitat is the rearing area for many young salmon, and its quality influences their growth and recruitment into the overall Atlantic salmon population. Restoration of Atlantic salmon in Maine typically focuses on these freshwater rearing habitats, reconnecting headwater streams to the ocean using process-based habitat restoration like the addition of large wood structures to the stream to improve habitat quality. Large wood structures utilize natural processes to trap organic detritus, redirect and alter water flow, and restore ecological processes that foster ideal spawning conditions in the riverbed. Ideally these log structures would encourage winding, meandering stream flow, provide habitat for aquatic insects, and encourage a transition from muddy and sandy substrates to the cobble beds that are ideal for salmon spawning. Ongoing research at UMaine is examining the effects of restoration techniques on insect population structures, substrate, detritus breakdown, velocity, and algal biomass. My thesis as a subset of this project tracks the progress of large wood restoration through its effect on the spatial distribution of algae across 10 test and reference sites in the upper Narraguagus river. We analyzed characteristics of the system pertaining to large wood to determine which had the greatest effect on algal biomass and distribution. We found that the null hypothesis (factors not affected directly by large wood) was the best model, and

that velocity and substrate alone were statistically equivalent. This suggests that restoration status had a lesser effect on algal communities than velocity and substrate. Though we cannot conclude from our analyses that restoration impacts algal communities directly, further analyses into the impact of large wood restoration on velocity and substrate may clarify whether it is indeed helpful to algal communities or not.

ACKNOWLEDGMENTS

education they have all given me has prepared me for my thesis, graduation from the University of Maine, and my career in the natural sciences. I would like to thank my bandmates in Sizzle for giving me a creative outlet for my final two years at UMaine and supporting my academic path. Finally, I would like to thank my family and loved ones for their undying support. Despite being many states away, I never felt alone throughout my four years of college because of them.

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Introduction

For the duration of human history, we have had a complicated relationship with rivers. Our impact on rivers and other sources of water are so pervasive that even "pristine" habitats are altered by anthropogenic activity (Allan & Castillo, 2007). In Maine, the logging industry is one of the largest and oldest commercial endeavors. In the early days of logging, large logs were transported from highlands via rivers. This method of transportation remained widely practiced until the 20th century, causing consistent degradation of many of Maine's waterways for over 200 years (Steve Koenig, pers. comm.). The mechanical stress these logs put on the geomorphology of the river, its banks, benthos, sediment, and hydrologic profile can still be seen today. Effectively, log drives have straightened out natural meandering rivers, embedded stream and river beds, and weakened rivers and streams by simplifying their community structures (Maser et al., 1988). This type of habitat degradation directly impacts the abiotic and biotic processes and components necessary for healthy ecosystem function.

Though humans have attempted to reverse or improve the effects of anthropogenic habitat degradation for decades, classical restoration techniques are often found to be ineffective. Restoration often focuses on returning the habitat to an "original" condition which can be misguided given that our perception of a healthy "baseline" state has constantly shifted throughout hundreds of years of human impact (Allan & Castillo, 2007). Some modern restoration attempts have used habitat engineering and man-made solutions to attempt to return a habitat to the way it "should look." This is a faulty

approach to habitat restoration, as it seeks to restore specific traits rather than to restore the healthy function of the ecological processes which uphold those traits. Anthropogenic habitat engineering often fails, as the human-made habitat augmentation may not suit the ecological potential of the habitat, and engineered solutions like man-made banks, pools, or islands cannot always sustain themselves in the long term (Beechie et al., 2010).

Where classical restoration approaches attempt to control and manipulate target ecological traits of a habitat, process based restoration techniques are tailored to support diversity and function of ecological processes that already exist in the habitat (Beechie et al., 2010). By standard, process based approaches to restoration must address the root cause of degradation. By understanding the natural processes that are responsible for an unwanted outcome in the ecosystem, land managers can manipulate said process to encourage a desired outcome. This has the dual advantages of being self-sustaining in the long term and of supporting the health of the entire ecosystem and all of its species, not just the targets, strengthening the justification for such projects with managers and funding agencies. The restoration approach must also be consistent with the biological potential of the system and the scale of the problem in order to see sustained and long-lasting effects (Beechie et al., 2010).

In streams that have been altered geomorphologically and biologically by anthropogenic removal of logjams or riparian forest, restoration might include adding large wood to the edges of the stream to reinforce banks or improve streambed and instream processes (Neuhaus & Mende, 2021). In streams that naturally contain wood, replicating the natural process of wood falling into the streambed is a restoration practice that has been utilized since at least the 1960's in the United Kingdom (Cashman et al.,

2018) and its effects on hydrology are well documented in Switzerland, the United

Kingdom, and the north west United States (Neuhaus & Mende, 2021). Given that large

wood structures can support varied hydrologic patterns, we can connect them to broad

effects on ecological characteristics including geomorphology, microhabitat formation,

and algae distribution within the habitat (Biggs, 1995).

Restoration projects can span decades, and with a fluid and constantly changing

environment, it is essential that monitoring and upkeep are attentive and comprehensive

to the goals of the project. One such project is ongoing in eastern Maine, an area where

the outcomes of process-based river restoration has not yet been studied. In the upper

reaches of the Narraguagus River, an organization called Project SHARE has been

working to restore ecosystem processes for over two decades. Most recently, this has

involved installing large wood structures called log jams. Multiple aspects of the system

are currently being studied by stakeholder groups to determine the effects of these large

wood structures in the river.

In the upper Narraguagus, the wood for large wood restoration is sourced directly

from the catchment area surrounding the stream, making it a very close replication of

what would occur if a large piece of wood or a tree naturally fell into the stream and

became anchored or stuck. Along with partnered local, state, and federal organizations,

Project SHARE is tracking the progress of large wood restoration through assays of

abiotic indicators such as flow, velocity, temperature, and sediment profiles, as well as

biotic indicators such as stream invertebrate abundance and diversity, algae distribution,

and fish abundance and diversity. Through years of refinement and research, large wood

restoration has become a possible solution that balances cost effectiveness, abiotic and biotic ecosystem drivers, and ease of implementation.

The upper Narraguagus watershed lies within Hancock and Washington counties, Maine, and in this region the river is relatively small (25 m across, 0.5-1.0 m deep). A variety of stakeholders are particularly interested in restoring the Narraguagus because it is considered essential habitat for the Gulf of Maine DPS (distinct population segment) of Atlantic salmon (*Salmo salar*) and serves as breeding and juvenile rearing grounds for this endangered species. Atlantic salmon spawn in gravelly nests, called redds, in freshwater woodland streams, where they remain during their alevin, fry, and parr life stages, feeding on aquatic invertebrates and insects (NMFS, 2016). In their smolt life stage, they transition from freshwater to brackish and saltwater habitats downriver. As adults, they mature in the Atlantic ocean, returning to the upper reaches of the Narraguagus and other North American rivers (April-November) to spawn in their natal rearing grounds (NMFS, 2016). Because of their need to access all parts of the watershed, it is imperative that even highland first order headwater streams are accessible to Atlantic salmon. Due to ongoing work by project SHARE more than 90% of the watershed is now connected to the ocean, which is essential for salmon as an anadromous fish (Trial et al., 2020).

Due to habitat degradation, the US range of Atlantic salmon is now limited to Maine, with some populations in Canada as well. Ina addition, to access to the headwaters, salmon require a stable food web supported by primary producers and stream invertebrates. In order to support a system that promotes population growth and stability for *Salmo salar*, we have to support healthy function in ecosystem drivers that support

this food web. One aspect of a healthy food web is algal primary production, which supports herbivorous invertebrates, or grazers, that are in turn consumed by salmon. Benthic algae and periphyton are some of the first parts of the riverine food webs to respond to changes in water chemistry, hydrology, and other abiotic characteristics (Stevenson et al., 1996). Thus, algal communities are a great indicator of changes in stream health. By quantitatively assessing the algal biomass within different sites in the stream, I aim to monitor the changing distribution of algae as it relates to the large wood structures.

We expect that by altering scour and deposition of sediment, large wood structures will increase the spatial diversity of habitat patches within reaches of the river that are under restoration. Large wood structures will divert the flow of water, encouraging scour of the streambed in some areas and the subsequent deposition of material in others, forming geomorphological features such as gravel bars, pools, riffles, or side channels that will provide a range of available habitat profiles for different kinds of algae (Biggs et al., 1998; Abbe & Brooks, 2011). Compared to a reference area with no large wood, we expect restored areas to have greater variability in algal biomass across space, due to patchiness and diversity of microhabitats.

A large piece of wood placed along a cross section of the stream will redirect and alter hydrology; most importantly velocity and direction of flow. Some areas will experience increased velocity and lower bed stability, while others will become deeper, slower, or more stable (Gurnell et al., 2002). Over time, restoration will create a matrix of patches, which are heterogeneous across space and time. These patches play a key role in fostering coexistence and diversity of species in the stream as a whole (Winemiller et al.,

2010). In addition to encouraging the formation of microhabitats, the placed wood itself can serve as a refuge for a very specific group of macroinvertebrates and substrate for periphyton (Coe et al, 2009). While a relatively high velocity within the stream might provide continuous flow of nutrients for compact, low profile cyanobacteria and diatoms, it may be too much physical disturbance for a longer, filamentous alga that thrive in lower velocities (Biggs et al. 1998). The delicate balance of velocity-dependent nutrient availability and shear stress creates a range of niches fulfilled by different algal functional groups with varying nutrient requirements and tolerances to shear stress. Thus, by increasing patchiness of stream flow and serving as surface for periphyton to colonize, large wood sustains habitat needs for a range of different types of periphyton.

Additionally, studies show that the breakdown of large wood can also provide an allochthonous energy source to microorganisms and detritivores (Allan et al. 2007). Allochthonous energy sources are any source of nutrients or carbon which originate outside of the stream itself, such as fall leaves, sticks and branches, or naturally falling large wood. With the expansion of the primary producer community, the food web is strengthened through bottom up effects. This means that the base of the food web (periphyton) provides more sources of energy for the primary consumers (grazers), who are consumed by their predators (juvenile salmon). Thus, the health of juvenile salmon in the Narraguagus stream food web can be controlled by the health of the basal community (periphyton).

Though previous literature suggests that the optimal conditions for increasing algal biomass occur at low velocities, it is now known that a number of factors are important for the rate of periphyton growth (Biggs et al. 1998). Some of the most

important factors contributing to productivity are nutrients, light, and temperature (Biggs, 1995). These factors vary from site to site within the Narraguagus which suggests the influence of large wood additions on algal communities may also be variable. For example, with some reaches being heavily shaded and others clear from tree cover, light and solar radiation (temperature) vary. Depth of the streambed can also affect the temperature, or rate of warming of the water as it is exposed to solar radiation or as scour permeates cooler sources of groundwater. Seasonality plays a large role in temperature fluctuations, which is one implication of sampling in both May and July (Stevenson et al., 1996). Sampling in these two seasons also comes with the consideration of flood frequency and scour, and thus nutrient deposition into the stream. Higher flood frequencies, which come with rainfall and snow melt, bring nutrients like nitrogen and phosphorus into the stream and increase benthic algae and periphyton growth rates (Biggs et al., 2002). Multiple micro and macrohabitats with unique combinations of depth, velocity, light, and temperature can be created within the stream, via the scour, altered flow, and sediment transport catalyzed by large wood addition (Allan et al. 2007). In addition, sediment type is important for algal sampling, as many periphyton are found on the surface of medium to large sized cobbles. Smaller sediments are less likely to be colonized as they are more easily carried by higher flow and pose a greater risk of shear stress on epiphytes. Mid and large sized rocks are not as prone to scour and typically remain in one place long enough to develop a biofilm of bacteria and diatoms necessary for fostering successful periphyton growth (Stevenson et al., 1996). Large wood restoration will not simply increase algal biomass, but rather support a delicate balance of

the aforementioned growth factors and disturbances which are necessary to foster a biodiverse and resilient algal community in riverine ecosystems.

There are a number of ways to monitor the progress of large wood restoration, through assessment of species abundance and diversity, changes in sediment deposition, and changes in water chemistry and hydrology. By monitoring the changes in algal biomass and distribution across space and time in the upper Narraguagus, we can see how large wood restoration changes the availability of food sources for herbivores within the stream. We expect that the addition of large wood structures to the upper Narraguagus will increase algal diversity within the stream by increasing habitat heterogeneity and improving the function of many physical, chemical, and biological processes inherent to stream health.

Field methods

We selected ten constructed log jams in the main stem of the upper Narraguagus River and designated a paired log-free (unrestored) reference area just upstream of each. Log jams either consisted of post assisted log structures (PALS) or griphoist log jams of varying ages, all installed by project SHARE within the past decade. A PALS is a large piece of wood held stable by smaller logs driven into the streambed. A griphoist is a large tree along the edge of the stream that has been pulled down and more closely mimics a tree along the bank falling in naturally. At each site, we made 3 transects across the width of the river, at the downstream-most, middle, and upstream-most points of the log jam of each site. Along these transects, 4 samples were taken at approximately equal intervals. At each sampling location, we measured water velocity, water depth, substrate percent cover, took a surber sample for macroinvertebrates and detritus, and a rock to quantify attached algal biomass. We replicated this sample collection at the paired reference site, where transects were spaced to match the spacing of the log jam.

While other data collected is important to analyzing restoration efforts in the Narraguagus as a whole, I focused on the algae rocks for my project. Rocks were randomly selected from each sampling location during surber sampling. If the rock was too large to fit in a 3 by 5 inch Whirl-pak, or covered in aquatic moss, it was discarded and a replacement was randomly selected. We discarded mossy rocks to avoid confounding the source of chlorophyll in analyses, as moss contains chlorophyll but is

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not edible to herbivorous invertebrates. The rocks were placed in small plastic whirl-pak

bags, transported in dark coolers on ice, and frozen for later use in the lab. Rocks and

subsequent chlorophyll samples were kept out of direct light in order to prevent the

degradation of chlorophyll within the sample.

<u>Lab methods</u>

Rock samples remained in their whirl-paks in a black plastic bag and were stored

in the freezer prior to chlorophyll analysis. We poured 50 ml buffered ethanol into each

whirl-pak and placed the bags into a hot water bath (78º C) for five minutes to lyse algal

cells and release chlorophyll. We then placed them into the refrigerator to extract over a

period of 12-18 hours. After the extraction period, we filled 1 cm cuvettes with the

samples or plain buffered ethanol to act as a procedural control. We then analyzed the

absorbance of wavelengths 665 nm (absorbance for Chl-a) and 750 nm (as a control) in

these ethanol samples using a spectrophotometer. We read the absorbance of samples and

blanks at these two wavelengths in order to correct for turbidity within the ethanol. After

taking these raw readings, we added 0.1 N HCl to convert all chlorophyll to phaeophytin

and measured absorbance again (Hauer and Lamberti, 2017). The difference between

these two readings was the amount of living chlorophyll present on the rock at the time of

collection.

Having a quantitative reading for chlorophyll only gets us halfway to determining

biomass, because we need to standardize for rock surface area. Because rocks are

irregular shapes with crevices, pores, and texture, it can be difficult to estimate their

surface area using conventional measurements such as length, width and height. Instead,

a more accurate estimate of surface area can be calculated by covering the surface area in a material of known density, such as aluminum foil, sand, or plastic wrap (Cooper & Testa 2001, Dudley et al., 2001). In order to find surface area, we used the particle layer method, which is often conducted with particles such as salt, glass beads, or plastic beads. These particles are stuck to the surface of an object in a monolayer using an adhesive such as petroleum jelly or glue, and then weighed (Bergey & Getty, 2006). We sifted sand between 0.5 mm and 0.25 mm mesh sieves, then wet the rocks and rolled them in the sand. Once uniformly applied (according to visual assessment), we rinsed the sand off of the rock into an aluminum tin then used a drying oven to dry the sand at 60° C for >1week. Once dry, we weighed the sand (to nearest 0.01 g) using an electronic balance to find the total mass of sand. We standardized this procedure by repeating it on tiles of a known area and dividing the mass of sand by the area of the tile in centimeters squared to find the average mass per unit area of the graded sand. Once we determined the mass per unit area of the sand, we were able to divide the dry mass of sand on each rock to find its estimated surface area in centimeters squared.

R statistical analysis

We used R (R Core team, 2021) to conduct all analyses. We used the spatial data analysis package "raster" (Hijmans, 2022) to create a series of heat maps depicting algal biomass across sampling locations in the test and reference areas of each site separately for May and July. All heat maps are oriented such that water flow is from top to bottom. The three horizontal rows represent transects and each box in the grid represents one chlorophyll sample taken along the transect. The color of the box shows chlorophyll

biomass per unit surface area from the stone taken from that sample location. The biomass per unit area can be sorted into one of 10 color bins with the darkest red being closest to the upper limit of the sampling range (6 µg/cm2) and white being the lower limit of the sampling range (0 µg/cm2). We tested for significant differences among test and reference areas using t tests ("stats" package, R Core Team 2021) and linear mixed-effects models (package "lme4", Bates et al., 2015).

We used linear mixed effects models to investigate which factors or combinations of factors best predicted algal biomass distribution. In our models, water velocity, depth, substrate type, and restoration status were all included as fixed effects, and day of year and site were included as random effects. We ranked competing linear mixed effects models using Akaike Information Criterion (AIC; "stats" package, R Core Team, 2021). AIC is a method for ranking effects within a model based on their predictive power. So, if a system component has a stronger effect on algal biomass, it will have a lower AIC ranking value. AIC values that are within 2 points of each other can be considered statistically equivalent.

<center>Results</center>

Heat maps (figures 2-7) showed clear differences between samples taken in May and July, but there were no consistent patterns between test and reference, or type of log jam (griphoist or PALS). Moreover, the paired t test of mean chlorophyll a biomass (t = 0.56, p = 0.58) shows that the mean chlorophyll-a biomass for the test and reference were not statistically different. Similarly, t-test for mean coefficient of variation between test and reference sites (t = 1.16, p = 0.26) also indicated that the variation in chlorophyll biomass between both test and reference groups is not significantly different from one another. While average coefficient of variation was similar among test and reference sites, variation of the coefficient of variation is greater across the reference dataset than the test (Figure 1). We can interpret this to mean that test sites are more similar to each other in terms of how heterogeneous they are and reference sites are more varied in heterogeneity from site to site.

AIC ranking of linear mixed effects models ranked the null (containing only random effects) as the best model. This remained true when we included site as a fixed effect instead of a random effect to test for differences in site-specific responses. The next best models, included substrate or velocity alone, substrate and velocity together, and year built (age of logjam) (table 1). They were >2 points away from the AIC value for the null hypothesis (table 1), so they cannot be considered statistically equivalent to the null.
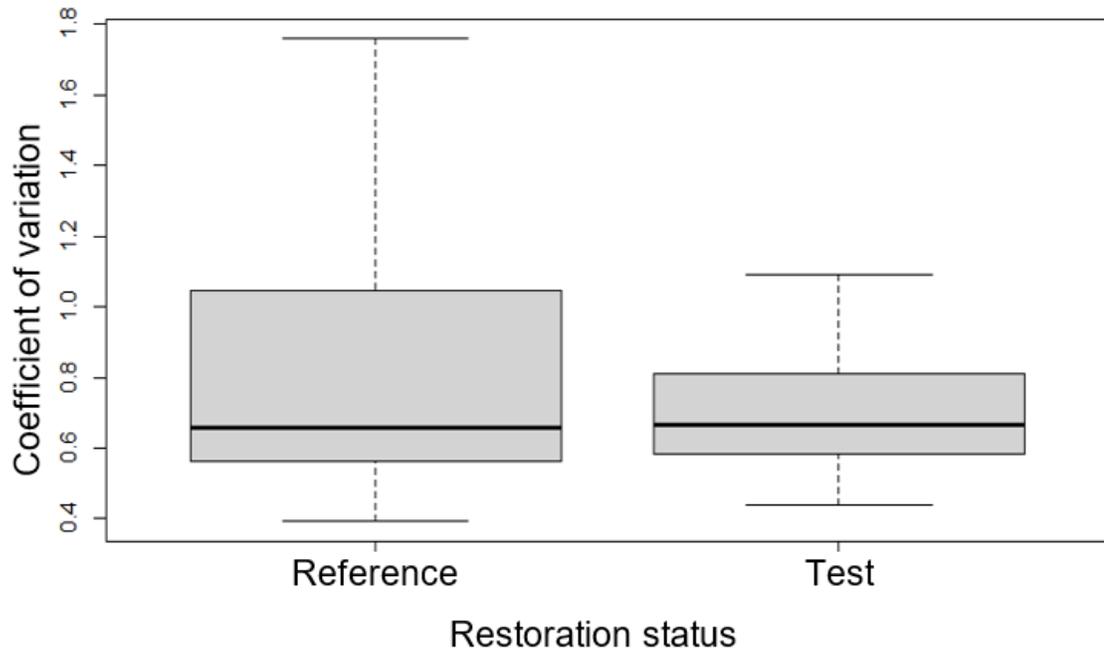
<center>13</center>

Figure 1. This box and whisker plot shows the comparison of the mean coefficient of variation and measures of central tendency of algal biomass the reference and test datasets as sampled in May and July 2021.

Model	AIC value	D.F.
Null	1182.91	4
Substrate index	1184.3	5
Velocity	1185.649	5
Velocity+Substrate	1186.985	6
Year built	1188.104	5
Depth	1188.215	5
Site	1189.359	5
Restoration Status	1189.417	6
Substrate+Year built	1189.442	6
Depth+Substrate	1190.254	6
Substrate+Site	1190.682	6

Table 1. AIC rankings of the first ten most significant models. The most predictive model was the null hypothesis, that all random effects were more powerful than fixed effects. Substrate index was within ±2 of the null AIC value, so it can be considered statistically equivalent and just as important.

The absence of statistically significant differences among reference and control warrants a closer inspection of responses at the site scale. When comparing the test and reference areas at site 1 (figure 2), the reference was more heterogeneous in algal biomass distribution, showing 4 different color bins in the reference, and 3 color bins in the test. The test also had a greater area of the grid in one color bin (chl-a < 1 $\mu g/cm^2$). The log structure is located in the leftmost column in this site, and the figure shows that immediately around the griphoist, chlorophyll biomass is lower than in the reference with no logjam and on the right side of the test, across from the logjam (figure 2).

For many sites, algal biomass was higher in July than in May. In site 1, where ¾ of the test site had chlorophyll concentrations below 0.5 µg/cm^2 in May 2021, only ⅓ of the test site had chlorophyll concentrations below 0.5 µg/cm^2 in July 2021 (figure 3).

When we compare reference site 1 from May to July, ⅙ of the site had chlorophyll concentrations of less than 0.5 µg/cm^2 in May and no samples read less than 0.5 µg/cm^2 in July (figure 3).

When visually comparing a griphoist site (site 4) and a post assisted log structure site (site 5) to their controls in May, there appears to be no striking differences (figure 4). Both the griphoist and post assisted log structure sites showed more widely distributed chlorophyll in their test sites than in their reference sites (figure 4). In our AIC ranking, restoration status alone was the 7th most powerful model, 6.507 points away from the null.
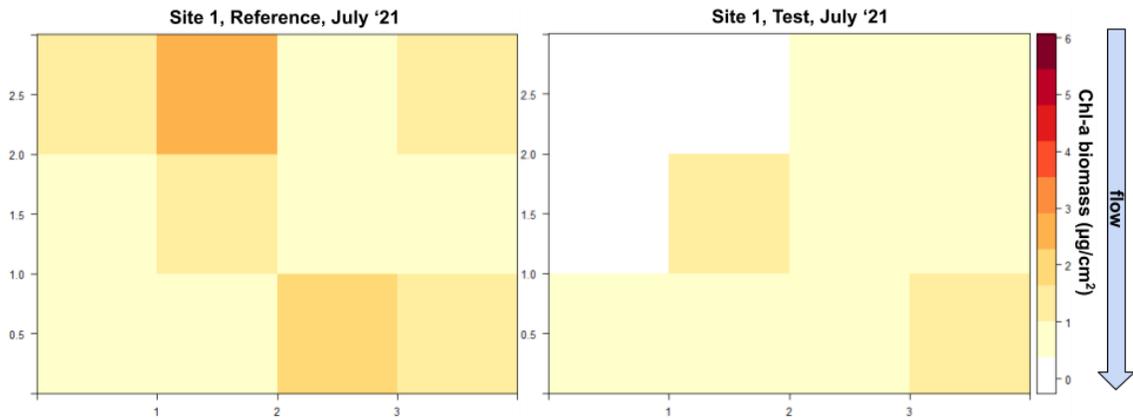
Figure 2. Heat maps depicting the chlorophyll biomass (reference and test segments of site 1, a griphoist site, as sampled in July 2021. Water flow is from top to bottom in this image, where each row is a transect and each box represents one chlorophyll sample taken along each transect. Color of the box represents chlorophyll biomass per unit area (μg/cm^2) on a stone taken in that location. At this site, the log structure mostly exists in the leftmost column of the test segment.

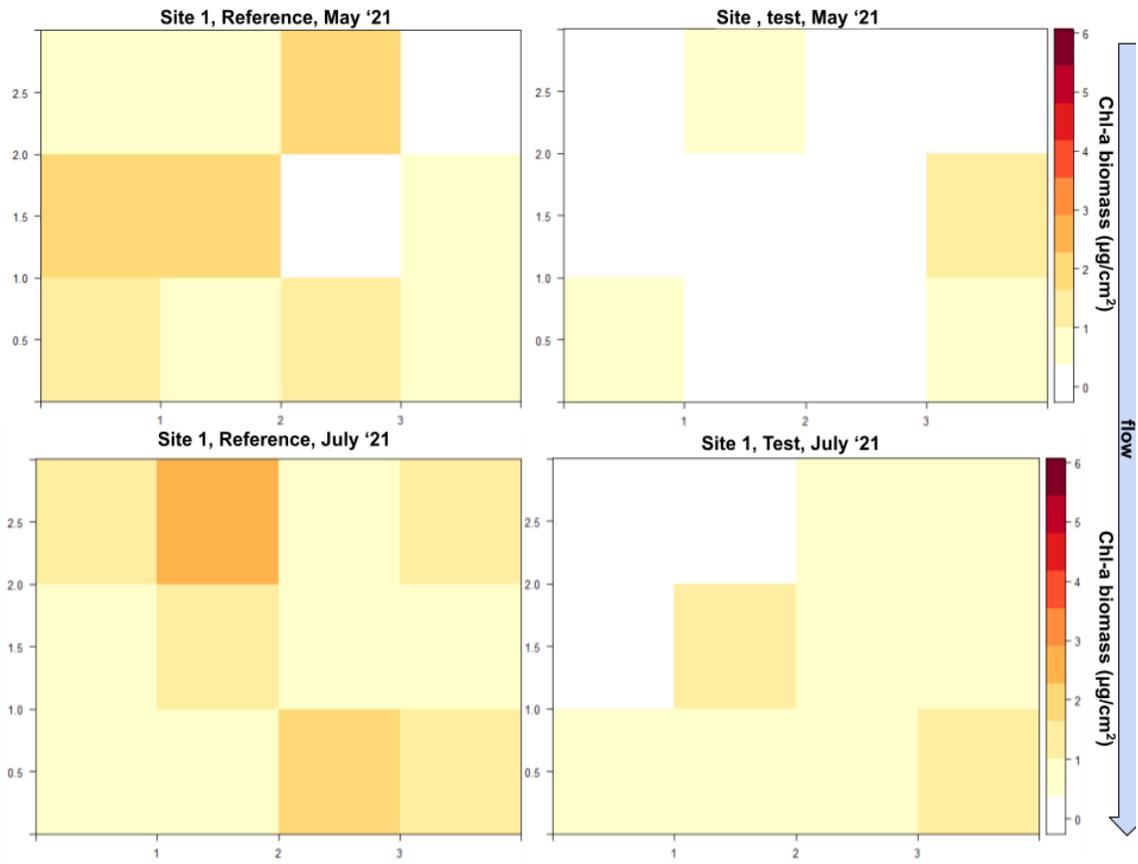Figure 3. Heat maps depicting chlorophyll biomass µg/cm² at reference and test site 1 in May (top) and July (bottom), sampled in 2021. At this site, the griphoist log structure takes up most of the left column in test images.
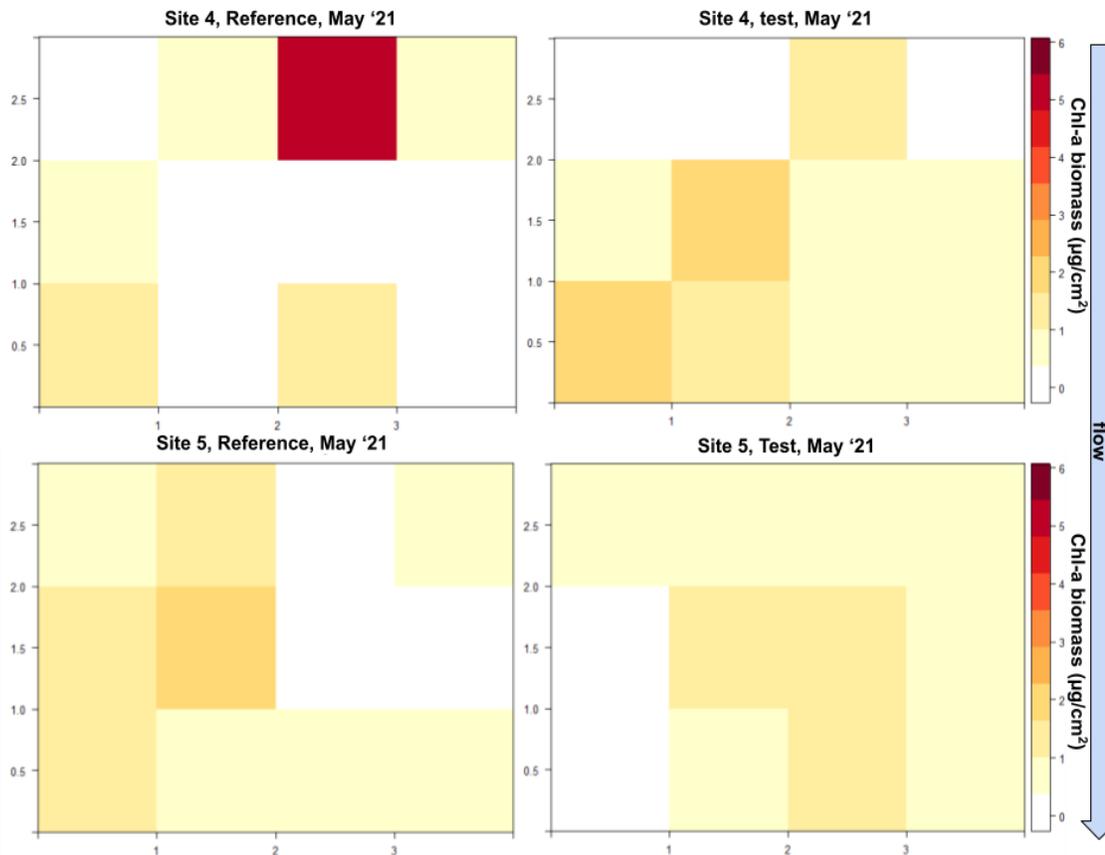
Figure 4. Heat maps depicting chlorophyll biomass µg/cm^2 at reference and test sites 4 (top) and 5 (bottom) in May 2021. Site 4 is a griphoist structure and site 5 is a PALS. At site 4, the logjam is in and around the bottom left corner and at site 5, the structure is in the left column.

Comparing site 6 reference and test in July 2021, we saw a slight increase in chlorophyll biomass in some sample locations, but a decrease in others (figure 5). When we look at the entire grid, site 6 reference July 2021, the reference had 7 color bins and the test had only 5. In this case, the reference was more variable in algal biomass distribution than the test. However, this is not a consistent pattern across all sites.

At site 7 in May 2021, the reference had 4 color bins and the test had 5. In this case, the test was more spatially diverse than the reference, and less homogenous. We can

see a large patch of homogeneity (chl-a <1) across the middle of site 7 in the reference
(figure 6).

At site 8 in July, the reference had only 3 color bins, with one sample with high
algal biomass (chl-a>5) and the rest of the site being relatively low in algal biomass (chl-
a<1). The paired test site had 5 color bins, all between 0 and 3 units abs/cm^2 chl-a. In
this case, the test site was more spatially diverse than the reference (figure 7). We can see
that as in figure 5, the reference site can be more heterogeneous than the test, but it can
also be less heterogeneous than the test site as in figure 7.
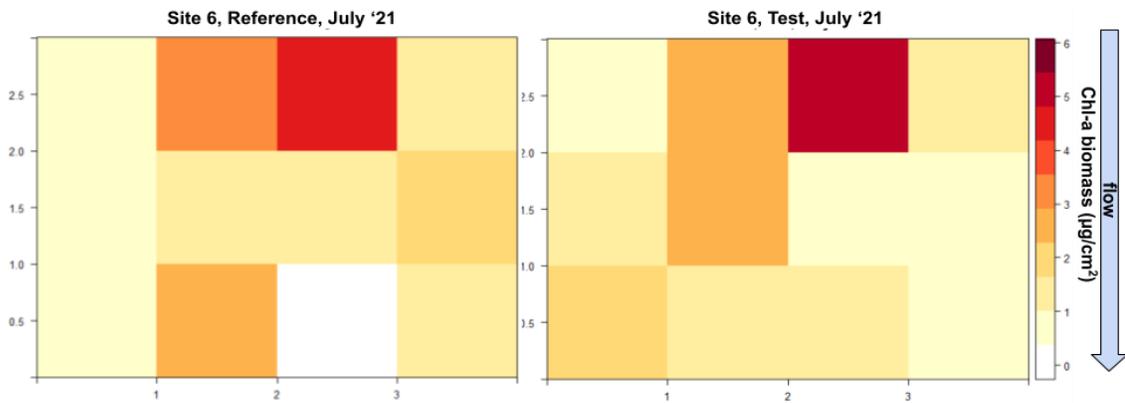

Figure 5. Heat maps depicting chlorophyll biomass µg/cm^2 at reference site 6 in July (left) and test site 6 in July (right), sampled in 2021. At this site, the griphoist log structure takes up most of the left column in both images.

Figure 6. Heat maps depicting chlorophyll biomass µg/cm² at reference site 7 in May (left) and test site 7 in May (right), sampled in 2021. At this site, the log structure takes up most of the right column and is a PALS.

Figure 7. Heat maps depicting chlorophyll biomass µg/cm² at reference site 8 (left) in July and test site 8 in July (right), sampled in 2021. At this site, the griphoist log structure takes up most of the right column in the test image.
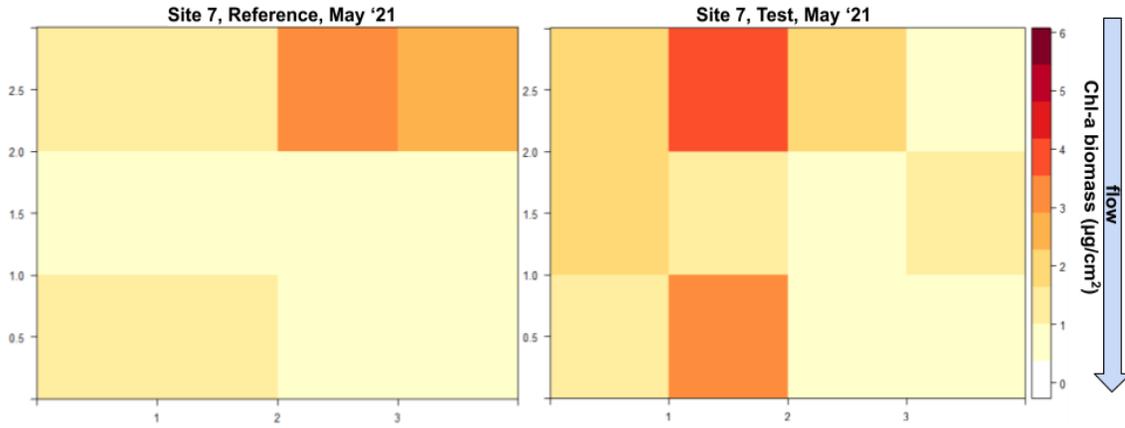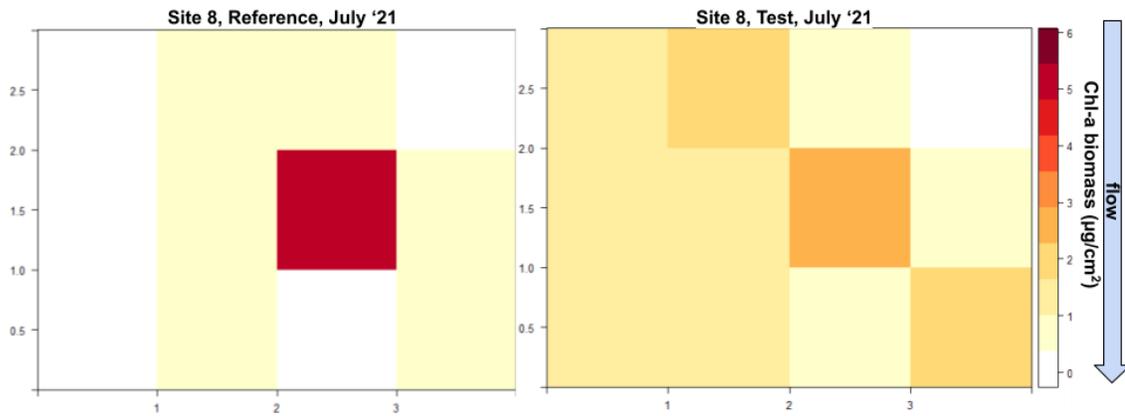
<u>Discussion</u>

Streams such as the upper Narraguagus that have been impacted by anthropogenic activity suffer from drastic alterations to their sediment bed, hydrology, wood and debris retention, and other processes essential to the Atlantic salmon food web. As physical habitat alterations such as log drives have simplified riverine habitats and damaged biodiversity, process based restoration techniques such as large wood structures have become an increasingly popular solution for restoring habitat heterogeneity. Though research to support this is still ongoing, habitat heterogeneity is thought to support overall biodiversity by providing structural complexity, spatio-temporal variability, and habitat patchiness (Palmer et al., 2010). It is now known that by providing structural heterogeneity, wood plays a role in the formation of stream characteristics such as pools, riffles, and glides, as well as stabilization of geographic features within the stream. These effects vary based on other characteristics of the rivers, such as channel width, velocity, and margin form and thus are different from site to site (Gurnell et al., 2002).

Our project sought to quantify responses of benthic algal biomass to large wood additions in the Narraguagus River of eastern Maine. Benthic algae and diatoms, which make up the periphyton in this stream, serve as the main autochthonous food source for grazing invertebrates. As they form patches containing a diverse range of growth forms (crustose, filamentous, stalked, gelatinous), these patches become grazing grounds for scrapers such as mayflies and caddisflies (Abbe & Brooks, 2011). Having a wider range of algae diversifies the presence of specialized grazers within the stream, and patchiness allows them to distribute spatially across the streambed. However, periphyton are not

only important as primary producers in the stream. They are also heavily impacted by minute changes in the stream's hydrology, water chemistry, and sediment profiles, and thus they are one of the clearest references for monitoring the impact of large wood restoration (Stevenson et al., 1996). This is why we chose algae as one of the key monitoring points to determine to what degree large wood restoration is successful in increasing habitat heterogeneity in the upper Narraguagus river.

Our analyses showed that despite some visual differences in algal biomass between test and reference areas, large wood did not significantly change algal biomass or the spatial distribution and heterogeneity of algae. However, velocity and substrate index alone and velocity and substrate together had marginally significant effects on algal biomass. Velocity can be altered by large wood implementation as it redirects flow around itself and creates geomorphological features that alter flow. Substrate can be deposited, scoured, sorted, and sheared due to the altered velocity speeds and direction due to large wood implementation. It can also be accumulated, forming islands, bars, pools, and riffles when large wood attributes to sediment retention in some areas of a stream. Despite velocity and substrate being the most important factors for algal growth, they were ranked separately from restoration status in our analyses. Because the combined effect of restoration status and either velocity or substrate was still lower in significance than velocity and substrate alone, we cannot say that large wood restoration has any greater effect on algal growth than the processes already existing in the system.

It is not yet entirely clear why the null hypothesis was ranked more significant than velocity and substrate. Some reasons may be that the most impactful system component for algae was something we did not measure, like light availability, available

nutrients, or something else. Additionally, each site was geomorphologically different, with different tree cover, vascular plants, bank height/structure, and sediment type. It makes sense that our results showed largely stochastic effects of the large wood from site to site. For example, site 3 was downstream from a delta, where tributaries run from an area with a lot of blueberry barrens. At this site, the streambed sediment was noticeably sandier than at other sites. Because of the finer sediment grains at this site, periphyton had less habitable surface area. It is impossible to ignore the effects on algal biomass of characteristics like geology and vegetation in the floodplain, but because they were not directly in the stream we did not measure them. Another unique site was site 7, which had an ATV bridge running across the stream. At this site, many of the trees around the river's edge had been cut or cleared and the streambed was wider and shallower. This allowed for more available light, and thus, we could see more vascular plants and periphyton. Because of these and other varied characteristics between sites, each site had a different biological potential. In addition, none of our references can be called controls, as they are all downstream from something, whether that is an intentional logjam implementation, or a natural logjam. We could clarify some of these results in the future by examining whether the distance to the next logjam or number of logjams in a reach could strengthen the predictive power of our models.

Current literature regarding wood supply in rivers seems to collate evidence that wood has an effect on sediment transport, allochthonous energy sources, hydrology, habitat formation, and more, however, there is little quantitative and definitive evidence that it can affect these things in any one direction. It seems that the effects of wood restoration are largely site specific and depend on a number of other factors towards the

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movement, fixation, consumption, and assimilation of wood and its breakdown products. A 2022 study by Danhoff and Huckins studied channel bed morphology changes as a function of large wood volume in headwater streams in the western Upper Peninsula of Michigan, hypothesizing that large wood would increase habitat complexity. They found that average large wood abundance varied across sites of low, moderate, and high complexity, and that some of the most complex sites had the lowest large wood abundance (Danhoff & Huckins, 2022). This is not to say that large wood restoration does not work, however, results are highly variable. Of 78 similar studies, only two revealed significantly increased biodiversity as a result of the restoration (Palmer et al., 2010).

Overall, it is clear based on the available literature that wood can contribute to the overall dynamic of a system, but that the relationship is often non-linear and poorly understood. Due to the site-specific and greatly diverse nature of large wood's effects on a stream, they foster a myriad of spatially and temporally complex interactions and disturbances (Townsend, 1989). These effects cascade downstream from the large wood and change over time, such that a highly dynamic shifting mosaic of patch microhabitats are created within the system (Gurnell et al., 2002). While wood-addition to streams is a well known method of process based restoration that has been used to address a variety of degradation problems, such as hydromorphological reinforcement and fish habitat creation (Cashman et al., 2018), current studies for its effectiveness towards salmon habitat restoration in the northeastern United States and Canada are still under way. In order to determine whether large wood restoration actually addresses the root causes of degradation in the upper Narraguagus and is indeed a suitable method for reaching our

restoration goals, it is imperative that all parameters of the system that can be affected by the large wood restoration are monitored in this and future studies (Beechie et al., 2010). This includes electrofishing, macroinvertebrate monitoring, sediment profiling, hydrology, water chemistry and quality, and algal biomass monitoring. With these extensive studies, it can be impossible to control for factors outside of the system such as weather, human and animal disturbances, pollution, etc., so it may be worthwhile to study the interactions between algae and wood in a controlled laboratory environment, such as a smaller scale flow-through tank representing a larger ecosystem. Considering the current lack of research regarding the direct effects of large wood restoration on algal distribution and biomass in forested riverine ecosystems and the ambiguity of our results, I hope my research will serve as a valuable resource for project SHARE and all other stakeholders in the Upper Narraguagus region as research continues. Keeping in mind that as the hydrology of the river changes and more microhabitats are formed, ongoing monitoring of the algal communities within the restoration region is necessary, and our results here are not definitive of the total impact of large wood restoration.

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AUTHOR'S BIOGRAPHY

Kiera Luu was born on September 27th, 2000 in Baltimore, Maryland to stunt pilot Duc Luu and world peace crusader Anne Marie Foerster Luu. She spent her younger years collecting pretty rocks and hiding them in people's shoes. In her 21 years of life, she has developed an affinity for all aquatic creatures and has made it her mission to study and care for them. In her free time, she likes building and maintaining aquaria where she holds hostage some of the worlds' most beautiful freshwater fishes. She graduated from Blake High School in Silver Spring, Maryland in 2018, where she learned sousaphone and upright bass from a band of Canadian geese. Later, these musical credentials would land her a job as the bassist for Orono's only jamband, Sizzle. At the University of Maine, she has learned to farm shellfish, finfish, and seaweeds for human consumption, as well as ornamental freshwater fish and garden plants just because they're pretty. Sometimes she wonders if college was just an expensive farming tutorial with cool new friends but knows deep down it was a long path down the journey to inner happiness and higher knowledge. After college, she plans to work in aquaculture farms across the world as a way to fund sightseeing and music-making, but mostly has no idea what she's doing. She hopes to use the doors she has opened at UMaine to continue her journey on this long strange trip.