Fish Community Response to the Addition of Wood in Smith Creek, Virginia

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Abstract

Large woody debris (LWD) is an important component of healthy stream ecosystems. LWD shapes stream physical habitat features, captures and stores organic matter, and serves as shelter, feeding sites, and reproductive substrate for fish and other aquatic organisms. Loss of in-stream LWD and sources of LWD as a result of human activities has negatively impacted many streams. Recently, restoration of in-stream LWD and riparian sources of LWD have become important facets of stream restoration, though many projects involving LWD restoration lack monitoring and evaluation. I evaluated the effects of adding LWD on the fish community in Smith Creek, a small coolwater stream located in Northwest Virginia with a history of habitat degradation due to intense agricultural activity throughout the watershed. I added wooden pallets to previously established fish monitoring stream sections and employed a repeated measures design to examine changes in fish community metrics two years after wood addition. Analyses revealed a significant decrease in density of a dominant benthic species and increase in densitiy of mid-column fish species and a decrease in density of benthic fish species in complex wood treated sections. These results suggest possible interactions between increases in habitat complexity and fish communities in degraded streams. This research can provide valuable information about expected fish community responses to the restoration or addition of LWD in streams and could have implications for future management decisions involving riparian forest management and stream habitat restoration.

Introduction

The growing recognition of the importance of large woody debris (LWD) in stream ecosystems worldwide has prompted researchers and managers to examine the potential for stream restoration or rehabilitation by adding wood to streams (Reich et al. 2003; Roni et al. 2008). A growing body of research has highlighted the important roles wood plays in many physical and biological processes in streams.

Wood helps create pool habitat which is important to many aquatic organisms (Bilby and Likens 1980; Wallace et al. 1995; Hilderbrand et al. 1997; Dolloff and Warren 2003). Woody debris also contributes to the stability and complexity of stream channels by preventing channel incision and erosion and directing the transport and deposition of sediment (Montgomery et al. 2003). These processes increase channel roughness and increase the heterogeneity of physical habitat and create habitats that vary in depth, velocity, and substrate size (Beechie and Silbey 1997; Hilderbrand et al. 1997; Shields et al. 2003).

Wood also facilitates primary production in streams by capturing and storing inputs of allochthonous organic matter, a major energy source in small streams, and provides attachment sites for the algae and microorganisms that readily colonize wood and form the base of aquatic food chains (Angermeier and Karr 1984; Cuffney and Wallace 1989; Smock et al. 1989; Jones and Smock 1991; Ehrman and Lamberti 1992).

Macroinvertebrate production is also enhanced by wood. The stability, structural complexity, habitat partitioning, and food source wood provides allow for greater abundance and diversity of aquatic macroinvertebrates and the structure of macroinvertbrate communities are greatly influenced by the presence and abundance of

in-stream wood (Hax and Golladay 1993; Wallace et al. 1995; Drury and Kelso 2000; Benke and Wallace 2003).

Many fish species require or are associated with wood at some or all of their life history phases. Wood provides cover, food and feeding sites, and spawning substrate for a variety of fish species (Probst et al. 1984; Monzyk et al. 1997; Johnston 1999; Dolloff and Warren 2003). There is also strong evidence supporting the importance of wood in structuring fish communities. Fish community structure can be influenced by wood itself as well as by the heterogeneous habitats comprised of complex mixes of cover, depth, and velocity characteristics that in-stream wood creates (Gorman and Karr 1978; Angermeier and Karr 1984; Meffe and Sheldon 1988; Lobb and Orth 1991).

The vital functions of wood have been severely reduced or eliminated in many streams. Numerous streams have become degraded due to loss or removal of woody debris along with other factors. Logging and agricultural practices which lead to riparian forest removal can reduce or eliminate sources of wood (Beechie and Silbey 1997). Human impacts such as stream channelization and stream cleaning also reduce the amount of LWD in streams, destroy habitat, and negatively affect fish populations (Dolloff 1986; Roni et al. 2005). In recent decades, stream restoration goals have begun to incorporate techniques to mitigate the loss of in-stream wood. These techniques include the addition of natural wood or manmade wood structures.

Stream restoration projects involving wood addition have had different goals and have employed a variety of techniques in their implementation. These goals and techniques vary by region. Some projects have shown positive results, particularly projects in the Pacific Northwest involving salmonid populations (Crispin et al. 1993;

Cederholm et al. 1997; Solazzi et al. 2000; Roni and Quinn 2001). For many other projects however, results have been unclear. The effectiveness of many projects has been difficult to determine due to unclear or unquantifiable objectives or inadequate monitoring. There are also regions where there is simply not enough published data available to draw conclusions on the effectiveness of projects.

Goals of stream restoration projects using wood fit into four general categories: restoring fish habitat, channel structural complexity, channel stability, and channel dynamics. Most projects in North America have focused on restoring fish habitat in combination with channel complexity. In other areas such as Germany the primary goals of most restoration projects were to restore structural complexity in the stream channel (Reich et al. 2003). In most projects that had goals of improving fish populations the focus was most often on one family or species of fish, usually salmonids.

A number of methods of stream restoration using wood have emerged. Active restoration techniques that involve artificial placement of in-stream wood have become common practice in many areas; however these practices tend to be unsuccessful at improving habitat or fish populations, especially when implemented before anthropogenic impacts causing degradation have ceased (Kauffman et al. 1997). More recently, greater preference has been given to passive restoration techniques that use a more holistic approach and focus on riparian forest restoration to restore recruitment of in-stream wood.

The majority of restoration projects with the goal of increasing in-stream have employed active techniques of placing wood in the stream channel. Different types of wood have been used in stream restoration as well as different methods of placing or

securing wood in the stream channel. Types of wood placed in streams ranges from entire trees with attached root wads, whole or partial boles excluding root wads, root wads, and manmade wood structures. Wood can be placed in a stream in one of three ways: as fixed structures that are attached to the stream bed or bank by cables or other means, loosely attached structures that have the ability to float and partially move during high flows, or mobile structures that are not attached to the bed or bank and can move freely during high flows (Abbe et al. 2003). In North America, the majority of wood addition projects have employed fixed or partially mobile structures, with greater numbers of mobile wood placement projects occurring after 1990 (Reich et al. 2003). Mobile placements of wood have become preferred over fixed structures because they more closely mimic wood recruited in streams by natural processes. In streams where conditions are favorable for the placement of mobile wood, and wood is placed in the most effective way, projects using mobile wood have often shown positive results in improvements to channel morphology and stability. Abbe et al. (2003) and Brooks et al. (2006) both demonstrated the success of projects using mobile wood. Their studies showed improvements in channel morphology and the maintained stability of engineered mobile wood structures during multiple periods of high flows.

Many potential restoration actions lack precedents to follow in terms of expected responses of systems after treatment. Predicting outcomes of restoration actions should be a necessary step toward reducing uncertainty in planning restoration and what types of information are needed to ensure greater reliability in future restoration actions (Wissmar and Bisson 2003). Over the last three decades, thousands of stream restoration projects have taken place. In 2006, total costs of stream restoration projects exceeded US$7

billion with only 15% of projects monitored following their completion (National River Restoration Science Synthesis 2006).The large amount of projects and money spent does not reflect the current pool of knowledge on the effectiveness of using wood in stream restoration. The vast majority of projects undertaken have had no clearly defined objectives or little or no monitoring. Even fewer projects have been monitored long term (Reich et al. 2003; Roni et al. 2005; Kail et al. 2007). Much of the data on wood addition projects exists in the form of relatively inaccessible file reports of state fish and wildlife agencies. While the greatest amount of information exists for restoration projects involving salmonids in the Pacific Northwest, information on projects involving coolwater and warmwater streams in other regions is lacking. Warmwater and coolwater stream ecosystems contain the majority of aquatic species diversity in North America, making them an important area of research. More research needs to be done to evaluate the responses of warmwater stream ecosystems to the restoration of LWD. While it seems that LWD restoration may be an important aspect of stream restoration, there is still much research that needs to be done to determine its utility and effect on a variety of stream types and fish communities.

This study was specifically designed to examine the direct effects of increasing complex wood habitat on a coolwater fish community and monitor changes in fish community metrics in the initial two years following wood addition. I hypothesize that adding wood will cause noticeable changes in the fish community and that these changes will be caused by increases in cover, food, and habitat partitioning as well as changes in habitat characteristics such as depth, velocity, and substrate that result from wood's influence on the stream channel.

While the ultimate goal of stream restoration is to restore streams and their riparian corridors to conditions for sufficient amounts of natural large wood recruitment, this goal will take decades to achieve. Findings of this study will reveal how the fish community will respond immediately after wood addition and also give insights into what the fish community will be like after restoration of riparian forest is completed and recruitment of natural wood is closer to pre-disturbance levels. Knowledge gained from this project could be used to help evaluate the role of LWD restoration in achieving long term goals of stream restoration projects.

Study Area

The study was conducted along a 1.5 km segment of Smith Creek, Rockingham County, Virginia. Smith Creek is a third order stream within the 55.39 km^2 Smith Creek subwatershed (Hydrologic Unit Code 510172) in Rockingham County, Virginia, approximately 16 kilometers northeast of Harrisonburg, Virginia. (Figure 1). Smith Creek is a pool-riffle stream in a broad valley floodplain. Average stream gradient is 1.74%, and average stream wetted width is 7.1 m. This reach of Smith Creek was grazed by cattle and mostly devoid of riparian trees for the last 100 to 150 years until riparian forest restoration began in 2005. Restoration has been implemented through the removal of livestock and the planting of young trees in the floodplain. Few adult riparian trees exist along the stream and few pieces of in-stream LWD are present. Since 2005, annual fish sampling has occurred at eighteen 30 m long stream sections (Figure 2). Seventeen different fish species have been collected during sampling from 2005 to 2009 (Table 1).

Materials and Methods

Experimental Design

The study employed a repeated measures design to examine the effects of adding complex wood on the fish community. Eighteen 30 m long stream sections were used in the study. The sections were established in a previous study (Hudy and Shiflet 2009). Fish populations were monitored each July at each of the 18 sections since 2005. Of the total 18 sections, nine were chosen randomly as treatment sites, the remaining nine sections were used as controls. Some sections were adjacent, but neither treatment nor control sections were adjacent to more than one section of the same group. Sections consisted of riffle and run habitat characterized by moderate to high velocities at base flow and cobble, gravel, or boulder substrate. While some sections consisted of pool habitat with greater depth and lower velocity, none of the sections had greater than 40% of their total area consisting of pool habitat.

Wooden pallets were added to the stream to simulate increases in complex wood habitat. I chose to use pallets to ensure uniform treatments across the nine treatment sections because they can be constructed to exact specification, and they provide complex wood habitat (albeit with an unnatural architecture). Pallets used in the study were made of white oak and measured 48”X 48” with 1 inch thick cross boards and were manufactured by Neff Lumber Mills, Broadway, VA. Pallets were added in pairs of two pallets stacked and nailed together (Figure 3). I chose a loading density of pallets to mimic natural wood loading density of Fridley Run, an upstream forested tributary of Smith Creek. Estimated wood loading density of Fridley Run was approximately 1.2 m^3 of wood volume per 100 m^2 of stream which is equivalent in volume to 12 pallets.

I placed pallet structures in treatment sections based on a stratified random scheme. Each treatment section was divided into quadrants; each pallet structure was assigned to one of four quadrants at random (Figure 4). Placement of pallet structures within assigned quadrants was based on the ability to effectively anchor them to the streambed and to provide the greatest amount of surface area usable to fish at base flow. Pallet structures were anchored to the streambed with rebar and steel cable to prevent movement during high flows. No pallet structures were placed within 2 m of the upstream and downstream border of each treatment section. This was to allow room for setting block nets during sampling and to maintain separation between adjacent sections. During the length of the experiment any pieces of natural large wood greater than 1 m in length and 10 cm in diameter that fell into treatment or control sections were removed as soon as possible. Small twigs, leaves, and debris that collected on pallet structures were not removed as this mimics the function of natural wood in capturing debris. Over the duration of the study, two pieces of natural LWD that fell into one control and one treatment section were removed. Pallets that were dislodged or washed away during high flows were replaced as soon as possible. A total of four pallets were dislodged during high flows in May 2009, all of which were replaced within one week.

I measured average thalweg (deepest continuous line in the channel) depth from each section prior to pallet additions and two years after pallet placement to examine changes in depth characteristics associated with pallet additions. A meter tape was stretched along the length of each section and water depths were measured to 5 cm precision every 2 m along the thalweg. Though not the main focus of this study, I also recorded visual observation of zones of scour and deposition for each treatment section

two years after pallet placement. I used these observations as a qualitative measure of the effect of pallet placement on stream channel morphology at the microhabitat scale. Scour areas are defined as areas in the stream channel that were characterized by concave depressions with exposed coarse sediment. Deposition areas are defined as areas in the stream channel that were characterized by mounds of fine sediment or infilling of pallet structures with fine sediment. I categorized each treatment section into one of two classes for scour and deposition; greater scour, or greater deposition based on the occurrence and area of scour and deposition characteristics at or adjacent to pallet structures. Stream stage height was recorded over the course of the study by an automated monitoring station located in the middle of the 1.5 km study reach.

Fish Sampling

Sampling took place each July from 2005 through 2010. The resolution of sampling was at a 30 m section level and was not adequate to demonstrate direct use of pallet structures. Fish were sampled with 3-pass depletion electrofishing using a Smith Root LR-24 DC backpack electrofishing unit. Sections were blocked at the upstream and downstream end with block nets. Multiple passes were made through the section starting at the downstream end. Two netters collected fish and placed them in buckets. When fish numbers were not depleted after three passes, additional passes were made. After each pass, fish were identified to species, counted, and measured to the nearest millimeter. After completion of the final pass all fish were released into the middle of the section.

Statistical Analyses

This study employed the use of a repeated measures design to examine fish community metrics before and after wood addition and to look for differences in fish community metric changes between control and treatment sections. I chose seven fish community metrics to examine a-priori. These metrics were: total fish density, individual fish species density, proportions of total catch of individual fish species, density and proportion of benthic and mid-column fish. Shannon's species diversity (H'), mean length of individual fish species, and biomass of Potomac sculpin, *Cottus giardii*. Biomass of Potomac sculpin was estimated using a length-weight relationship for transformed data (Murphy and Willis 1996). The length weight relationship was developed in October 2009 from 1,100 Potomac sculpin collected from a 700 m reach of Smith Creek that encompassed 15 of the 18 study sections (linear regression; $y = 3.19x-5.22$; $r^2 = 0.92$)

The nine treatment and nine control sections served as replications for before-after comparisons between control and treatment groups. I calculated differences in each metric before and after wood addition for each of the 18 stream sections. Before-after comparisons of fish community metrics were made using the mean of 2005 to 2008 values as before values and the mean of 2009 and 2010 values as after values. When calculating changes in each fish metric after wood addition, I subtracted mean before values from mean after values for each of the 18 sections. This resulted in a total of nine before-after differences for each metric in control and treatment sections from which mean treatment and control changes were calculated.

Differences in fish size was calculated in the same way, however complete past length data were not available for all years and all species. Before-after comparisons were only made using the mean of 2007 and 2008 as before data for Potomac sculpin and only 2008 data as before data for all other species analyzed.

Mean before-after differences of each metric for treatment and control section groups were compared using t-test. A significance level of $\alpha = 0.05$ was used in all analyses. All analyses were carried out using Minitab 15.

Results

Density

The total fish density and the density of Potomac sculpin, fantail darter, *Etheostoma flabellare,* . Longnose dace, *Rhinichthys cataractae,* white sucker, *Catostomus* commersonii, bluntnose minnow, *Pimephales notatus*, and green sunfish, *Lepomis cyanellus*, decreased in density in both control and treatment sections (Table 2, Figure 5). Five species, bluehead chub,*Nocomis leptocephalus,* blacknose dace, *Rhinichthys atratulus,* pearl dace, *Margariscus margarita,* rock bass, *Ambloplites rupestris,* and common shiner, *Luxilus cornutus,* increased in density in both treatment and control sections (Table 2, Figure 5). Mid-column fish density increased in both treatment and control sections while benthic fish density decreased in both treatment and control sections (Table 2, Figure 6). While most species exhibited similar trends in both treatment and control sections, the magnitude of these changes did differ between groups.

Mean decrease in Potomac sculpin density was significantly different between treatment and control sections (T test; t = 2.01; df =16; P = 0.048) with decreases of 57.39 and 34.81 respectively (Figure 7). Despite the large increase in common shiner density, the difference in mean change between control and treatment sections was not statistically significant (T test; t = 1.23; df =16; P = 0.24). There were no significant differences in mean change in total fish density or mean change in density of any other individual species between treatment and control sections (Table 2). The mean change in mid-column fish density differed significantly between control and treatment sections (T test; t = 2.47; df =16; P = 0.025) (Table 2). Change in mean benthic fish density also differed significantly between control and treatment sections. Benthic fish density

decreased significantly more in treatment sections than control sections (T test; t = 2.52; df =16; *P* = 0.022) (Table 2).

Proportions

Mean change in proportion of total catch of Potomac sculpin was significantly different between treatment and control sections (T test; t = 2.19; df =16; *P* = 0.043). Proportion of Potomac sculpin decreased by 3% in control sections compared to an 8% decrease in treatment sections (Table 2). Common shiner had the greatest mean change in proportion of any species sampled. The proportion of total catch comprised of common shiner increased by 12% in treatment sections; nearly twice the mean increase in proportion of 7% in control sections, however this difference was not statistically significant (T test; t = 1.23; df = 16; *P* = 0.236). The proportion of mid-column fish increased by 14% in treatment sections compared to an increase of 9% in control sections. This difference in mean change in proportions of mid-column fish species differed significantly between treatment and control sections (T test; t = 2.47; df = 16; *P* = 0.025). Mean increases in proportions of blacknose dace, a species that typically makes up a large proportion of the total catch in all stream sections, were observed in both treatment and control sections. Fantail darter, another species that also typically comprises a large proportion of the total catch, experienced decreases in both control and treatment sections. Mean change in proportions of these two species did not differ significantly between control and treatment sections. No other fish species had mean changes in proportions of total catch greater than 5% in either control or treatment sections and none differed significantly between groups (Table 2).

Species Diversity

Shannon's species diversity (H') increased in both control and treatment sections following wood addition. Treatment sections had a slightly greater increase in diversity of 0.09 compared to control sections that had an increase of 0.06 (Table 2). The difference in mean change in species diversity between control and treatment groups was not statistically significant (T test; t = 0.818; df = 16; $P = 0.236$).

Mean Length and Biomass

Potomac sculpin, blacknose dace, fantail darter, and longnose dace experienced increases in mean lengths in both treatment and control sections. There were no significant differences in mean change in length between treatment and control sections for any of the four species (Figure 8). Potomac sculpin biomass decreased by 21.6 kg/ha in treatment sections, a decrease three times that observed in control sections, which had a mean decrease of 7.2 kg/ha; however, this difference was not statistically significant (T test; t = 2.0; df = 16; $P = 0.062$) (Figure 9).

Stream Channel Morphology

Comparisons of mean change in average thalweg depth and standard deviation were made using depth data from fall 2008 (before wood addition) and spring 2010 (two years after wood addition). There were no significant differences in mean change in thalweg depth (T test; t = 0.054; df = 16; $P = 0.096$) or mean change in thalweg depth standard deviation (T test; t = 0.615; df = 16; $P = 0.547$) between treatment and control sections (Figure 10 and Figure 11).

Scour or deposition characteristics associated with pallet structures were observed in all treatment sections. Depositional features were more prevalent in treatment sections than scour features. On average, depositional features were observed at or adjacent to 64 percent of all pallet structures in treatment sections, compared to an average of 30 percent of pallet structures with scour features.

Discussion

Following the addition of complex wood habitat, similar decreases in density were observed for most fish species in both treatment and control sections. However, decreases in density of the most abundant fish species in Smith Creek and the density and proportion of benthic fish species were significantly greater in sections that received wood addition. The results also revealed that while the density of mid-column fish species remained stable in control sections, their density increased significantly more in wood treated sections. These findings suggest that in-stream wood plays a role in structuring the fish community of Smith Creek. Previous studies have shown strong relationships between the diversity and structure of fish communities and the complexity and heterogeneity of habitat (Pearsons et al. 1992; Downes et al. 1998; Talmage et al. 2002; Rowe 2007). Increasing or enhancing the structural complexity of in-stream habitat can result in increases in fish abundance, biomass, and diversity (Gorman and Karr 1978; Angermeier and Karr 1984). In this study, increases in habitat complexity also resulted in decreases in densities of some species.

The differences observed in the responses of individual species and fish community metrics to the addition of complex wood are likely due to species specific habitat preferences. For example, reduction of high current velocity cobble substrate habitat in treatment sections reduced the dominance of Potomac sculpin. Prior to wood addition, each of the 18 study sections consisted of shallow, moderate to high velocity habitat with predominantly cobble substrate. This type of habitat is ideal for Potomac sculpin, benthic fishes that are adapted to swift water riffle habitats with cobble substrate (Jenkins and Burkehead 1994). Gray and Stauffer (1999) observed habitat use of mottled

sculpin, *Cottus bairdi* and slimy sculpin, *Cottus cognatus* two *Cottus* species very similar to Potomac sculpin and found that they occupied shallow high velocity habitats and most often occurred beneath substrate. Adding pallet structures significantly reduced preferred Potomac sculpin habitat. Pallet structures placed in areas of high velocity diverted stream flow and created pockets of low velocity microhabitat. In addition, I observed that pallet structures collected debris and sediment that filled in interstitial spaces in cobble substrate. Based on the loading density used in treatment sections, pallet structures themselves covered 10% of the total stream bottom area in each treatment section, most often over cobble substrate. I observed that depositional features were the most common stream morphology characteristics associated with pallet structures in Smith Creek. Diversion of stream flow by pallet structures resulted in areas of fine sediment and organic debris deposition adjacent to pallets that may have further reduced interstitial spaces in cobble substrate. The combination of these factors would result in a net decrease in suitable Potomac sculpin habitat in treatment sections and is a likely explanation for the greater decrease in density observed in treatment sections compared to control sections.

Habitat changes responsible for changes in Potomac sculpin density may not have had the same effect on densities of similar species due to subtle differences in habitat preference. Fantail darter, a similar benthic non-gravel spawning species as Potomac sculpin, did not exhibit a significant decline in density in treatment sections. Fantail darters are found in a wide range of habitat types ranging from moderate to high velocity and varying depths and areas of coarse or fine substrate. It is also likely that fantail darters use the top of substrate rather than the spaces beneath. Tessellated darter,

Etheostoma olmstedi, a species morphologically and ecologically similar to fantail darter, was found to use the top of substrate most often (Gray and Stauffer 1999). Fantail darters are habitat generalists that are found in a variety of habitats, which explains their ubiquitous distribution throughout North America. While pallet structures may have caused changes to stream habitat that reduced Potomac sculpin density, these changes would likely have little effect on the highly adaptable habitat generalist fantail darter and could explain why no significant difference in change in density was observed between treatment and control sections.

The habitat changes that occurred in treatment sections affected other species differently. Adding pallet structures caused habitat conditions to shift towards those more suitable for mid-column fish species such as common shiner. Velocity breaks created by pallet structures resulted in lower velocity microhabitats interspersed in moderate to high velocity riffle and run habitat. This type of habitat is ideal for common shiner, a species that prefers deeper, low to moderate velocity habitat and makes forays into higher velocity areas to forage (Jenkins and Burkehead 1994). Pallet structures that caused scour in the streambed may have also increased depth and improved common shiner habitat, however I was not able to detect differences in depth at the 30 m sections scale, and at the individual pallet structure scale, deposition was more prevalent than scour. It is more likely that the overhead cover and the debris pallet structures collected was more influential than depth in regards to common shiner habitat quality. Depth preferences are a result of interactions with predation risk; overhead cover can moderate the effects of depth and allow fish to utilize shallower habitats while still minimizing risk of predation (Harvey and Stewart 1991). Although not statistically significant, the

combination of increases in ideal foraging habitat and increases in overhead cover in these shallow habitats could be a driver of the increasing trend in common shiner density observed in treatment sections.

Proportions of benthic and mid-column fish in Smith Creek is a metric that may be useful for measuring the effects of stream restoration. The rationale for the use of this metric is that as habitat conditions improve, the fish community will shift towards that of unimpaired streams in the area which exhibit higher densities and proportions of mid-column fishes. Treatment sections exhibited significantly greater increases in mid-column species and significantly greater decreases in benthic species compared to control sections.

Examining suites of species may allow for more generalized conclusions about the effects of wood addition on the fish community. As discussed previously, individual species may react differently to changes in habitat based on subtle differences in habitat preference. The magnitude of natural variability in density and the response of individual species to the timing and severity of natural disturbances can vary greatly among species. The disparity in changes in densities of individual species, even those ecologically or morphologically similar, may diminish the conclusions of analyses with the goal of determining changes in the fish community brought about by habitat manipulation. While much can be learned from observing changes in individual species, when the focus is on restoration of the entire fish community, it may be more prudent to examine changes in groups of species that share similar life history traits and/or general habitat requirements.

Many studies involving wood addition have also identified significant changes in stream channel characteristics such as depth, channel heterogeneity, and pool and riffle area (Wallace et al. 1995; Zika and Peter 2002; Shields et al. 2003). Studies involving LWD addition often attribute observed changes in fish and macroinvertebrate abundance and community structures to changes in the stream physical habitat. Wood causes the greatest changes in the stream channel during periods of high flows. Two bankfull events occurred at Smith Creek over the course of the study. These high flow conditions would have been sufficient for causing changes to the stream channel. The potential for changes to steam habitat existed, but unlike in other studies, I was unable to detect significant differences in mean change in thalweg depth and thalweg depth variability at the 30 m section scale; however I visually observed changes in the stream channel at the scale of individual pallet structures.

There were several limitations to this study that may have made it difficult to detect significant differences in changes in the stream habitat and fish community. This study was designed to examine changes in the fish community at the scale of 30 m stream sections. Intuitively, changes in stream habitat were measured at the same scale. The methods used to examine changes in section thalweg depth and variability were ineffective at detecting smaller scale changes adjacent to pallets, especially those outside the thalweg. These small changes, collectively, could be drivers of the changes observed in the fish community.

Incorporating a more thorough sampling method to measure changes in habitat at both the section and microhabitat scale could strengthen the hypothesis that changes at both scales scale are responsible for changes in the fish community. Strategic placement

of wood structures to create the greatest change in habitat could also make the effect of wood addition greater and more detectable. The random method of placing pallet structures may have limited their effects and the ability to detect effects on stream channel characteristics. Other studies have shown that strategic placement of LWD in areas of the channel conducive to flow deflection is most effective at causing changes to the stream channel (Hilderbrand et al. 1997; Hilderbrand et al. 1998; Abbe et al. 2003). In addition, the relatively small size and open design of pallet structures compared to larger pieces of natural LWD may not have deflected sufficient stream flow to cause large scale changes in channel characteristics. Natural wood consisting of larger, solid boles could be more effective at deflecting the volume and velocity of stream flow needed to shape the stream channel (Bilby and Ward 1991; Beechie and Silbey 1997).

Natural variability inherent to this system, and others, must also be considered. High temporal variability in species abundance is a common limitation of studies attempting to quantify the effects of habitat improvement on fish communities. There was high variability (coefficients of variation) in both individual species density and total fish density in all sections over the six years of sampling (Table 1 and Figure 12). This high variability reduced the ability to detect small differences in the fish community. During the design phase of this study, a statistical power analysis using variances prior to complex wood addition showed that for total fish density and the three most abundant species, a 30% difference in density would be needed to achieve power of 0.80 or greater. Given the greater variance of other less abundant species, an even greater change would be required to detect differences between treatment and control sections. Species with very large natural temporal variation in abundance will only reveal environmental

impacts if they are massive and long-term (Underwood 1992). Differences in densities of species at Smith Creek were generally less than 30% and may not have been great enough to detect significant effects of complex wood addition or more time may be need for significant effects to be observed. Continued annual sampling is needed to distinguish the effects of complex wood addition on both individual fish species and the fish community.

This study demonstrates the opportunity to use artificially placed complex wood to help predict long term restoration effects without waiting for natural wood recruitment. Complex wood addition caused changes to the fish community at Smith Creek. These changes were attributed to increases in habitat complexity and changes in stream habitat characteristics; however more data is needed to strengthen the link between habitat changes and changes in the fish community. Continued sampling will also strengthen the findings of this study and help determine how the fish community will respond to wood addition over time. This type of information could be valuable for predicting the long term effects of stream restoration techniques that involve the restoration of riparian forests and enhancement of LWD recruitment. The ability to predict the effects of restoration activities can allow managers to adapt restoration techniques and objectives to ensure that they effectively meet the specific goals of stream restoration projects. The ability to predict the end result of restoration techniques also provides a useful reference point that can be used to gauge the status and success of stream restoration projects.

Table 1. Fish species collected annually at 30 m fish monitoring stream sections of Smith Creek. Trophic and spawning guilds of each species as described by (Jenkins and Burkehead 1994). Average density and coefficient of variation (CV) calculated for each species from 2005 to 2008 sample periods from all fish monitoring sections. **b** denotes benthic species.

Common Name	Scientific Name	Trophic Guild	Habitat Guild	Density (#/100 m^2)	CV
Potomac sculpin**b**	*Cottus girardi*	Insectivore	Non-gravel	146	0.52
Fantail darter**b**	*Etheostoma flabellare*	Insectivore	Non-gravel	37	0.64
Blacknose dace	*Rhinichthys atratulus*	Omnivore	Gravel	36	0.85
Longnose dace	*Rhinichthys cataractae*	Omnivore	Gravel	17	1.20
Pearl dace	*Margariscus margarita*	Insectivore	Gravel	12	2.56
White Sucker	*Catostomus commersonii*	Omnivore	Gravel	7	1.60
American Eel	*Anguilla rostrata*	Insectivore/Piscivore	Catadromous	< 5	--
Bluehead chub	*Nocomis leptocephalus*	Omnivore	Gravel	< 5	1.31
Brook trout	*Salvelinus fontinalis*	Insectivore/Piscivore	Gravel	< 5	--
Bluntnose minnow	*Pimephales notatus*	Omnivore	Non-gravel	< 5	1.60
Common shiner	*Luxilus cornutus*	Omnivore	Gravel	< 5	2.42
Creek chub	*Semotilus atromaculatus*	Omnivore	Gravel	< 5	--
Cutlips Minnow	*Exoglossum maxillingua*	Omnivore	Gravel	< 5	--
Green sunfish	*Lepomis cyanellus*	Insectivore/Piscivore	Gravel	< 5	1.80
Rock bass	*Ambloplites rupestris*	Insectivore/Piscivore	Gravel	< 5	2.22
Yellow bullhead	*Ameiurus natalis*	Omnivore	Gravel	< 5	--

Table 2. Change in mean density and proportion of total catch of individual fish species between the 2005 to 2008 mean (before wood addition) and the mean of 2009 and 2010 values (after wood addition) in control and treatment sections with significance level for both density and proportion. Results in **bold** are statistically significant ($P < 0.05$).

	Δ Density (#/100m^2)				**Δ Proportions (% of Total)**			
Species	**Treatment**	**Control**	**Difference**	***P***	**Treatment**	**Control**	**Difference**	***P***
Bluehead chub	0.30	0.02	0.28	0.384	< 0.01	< 0.01	< 0.01	0.255
Blacknose dace	2.75	5.12	2.37	0.697	0.05	0.06	0.01	0.983
Bluntnose minnow	-2.84	-1.56	1.28	0.329	-0.01	-0.01	0.00	0.650
Common shiner	26.81	14.76	12.04	0.236	0.12	0.07	0.05	0.425
Fantail darter	-26.24	-21.22	5.03	0.364	-0.08	-0.06	0.01	0.162
Green sunfish	-0.19	-1.38	1.19	0.397	< -0.01	-0.01	< 0.01	0.063
Longnose dace	-10.72	-9.04	1.68	0.517	-0.02	-0.03	0.00	0.402
Pearl dace	9.39	0.50	8.89	0.175	0.03	< 0.01	0.02	0.138
Rock bass	0.73	0.16	0.56	0.364	< 0.01	< 0.01	0.00	0.447
Potomac sculpin	-57.39	-34.81	22.58	**0.048**	-0.08	-0.03	0.05	**0.043**
White sucker	-4.43	-2.21	2.22	0.681	-0.01	-0.01	0.00	0.885
Total	-62.55	-49.83	12.72	0.735	--	--	--	--
Mid-column	19.42	5.80	13.62	**0.025**	0.14	0.09	0.05	**0.020**
Benthic	-81.97	-55.63	26.34	**0.022**	-0.14	-0.09	0.05	**0.020**
Shannon's diversity	0.09	0.06	0.04	0.631	--	--	--	--

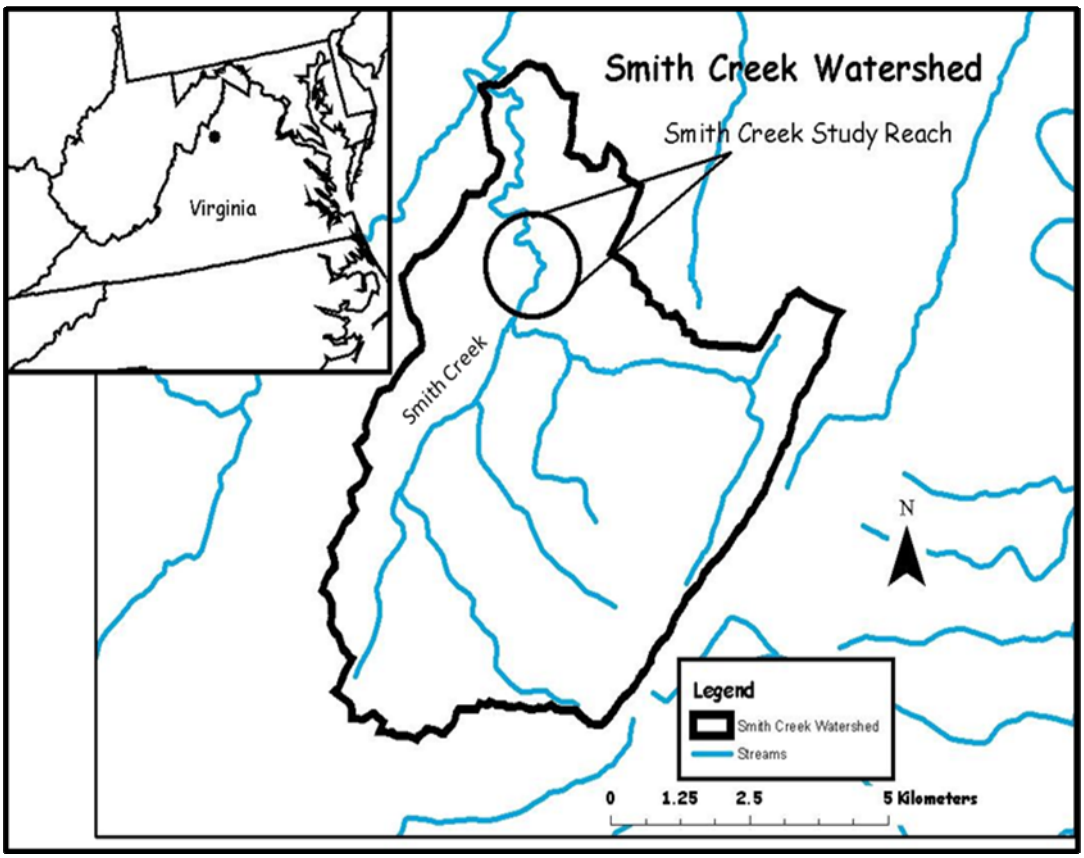

Figure 1. Map of the location of the Smith Creek watershed and the 1.5 km study stream reach.

Figure 2. Aerial photograph and location of the Smith Creek restoration area with nine 30 m control (C) and treatment (T) sections labeled.

Figure 3. Photograph of front (A) and side (B) view of a pallet structure.

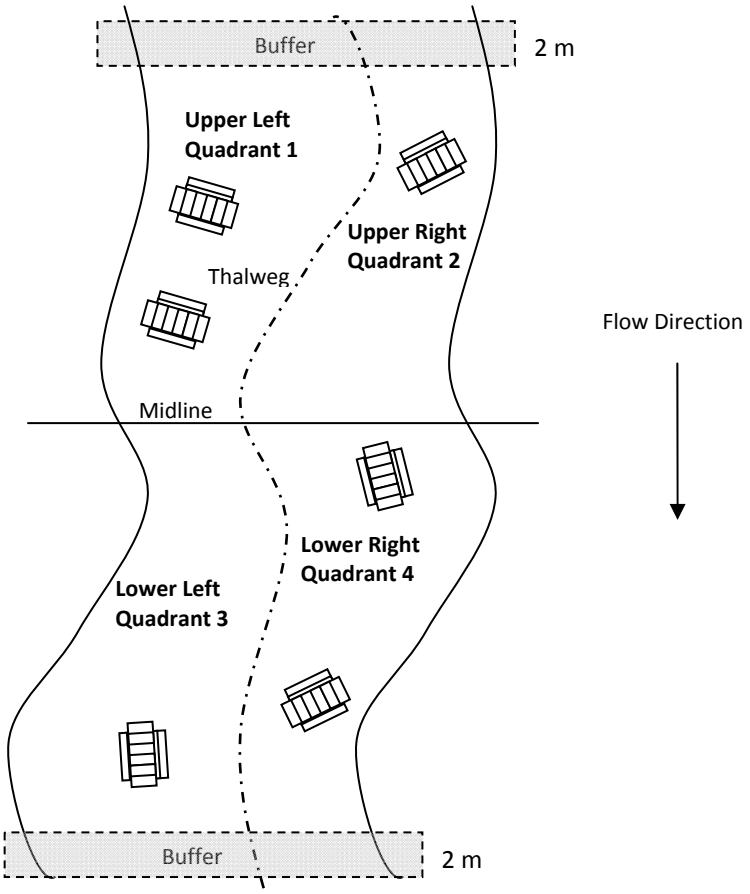

Figure 4. Sketch of randomization method used for placement of pallet structures within 30 m treatment stream sections. Placement into quadrants was determined by random number table.

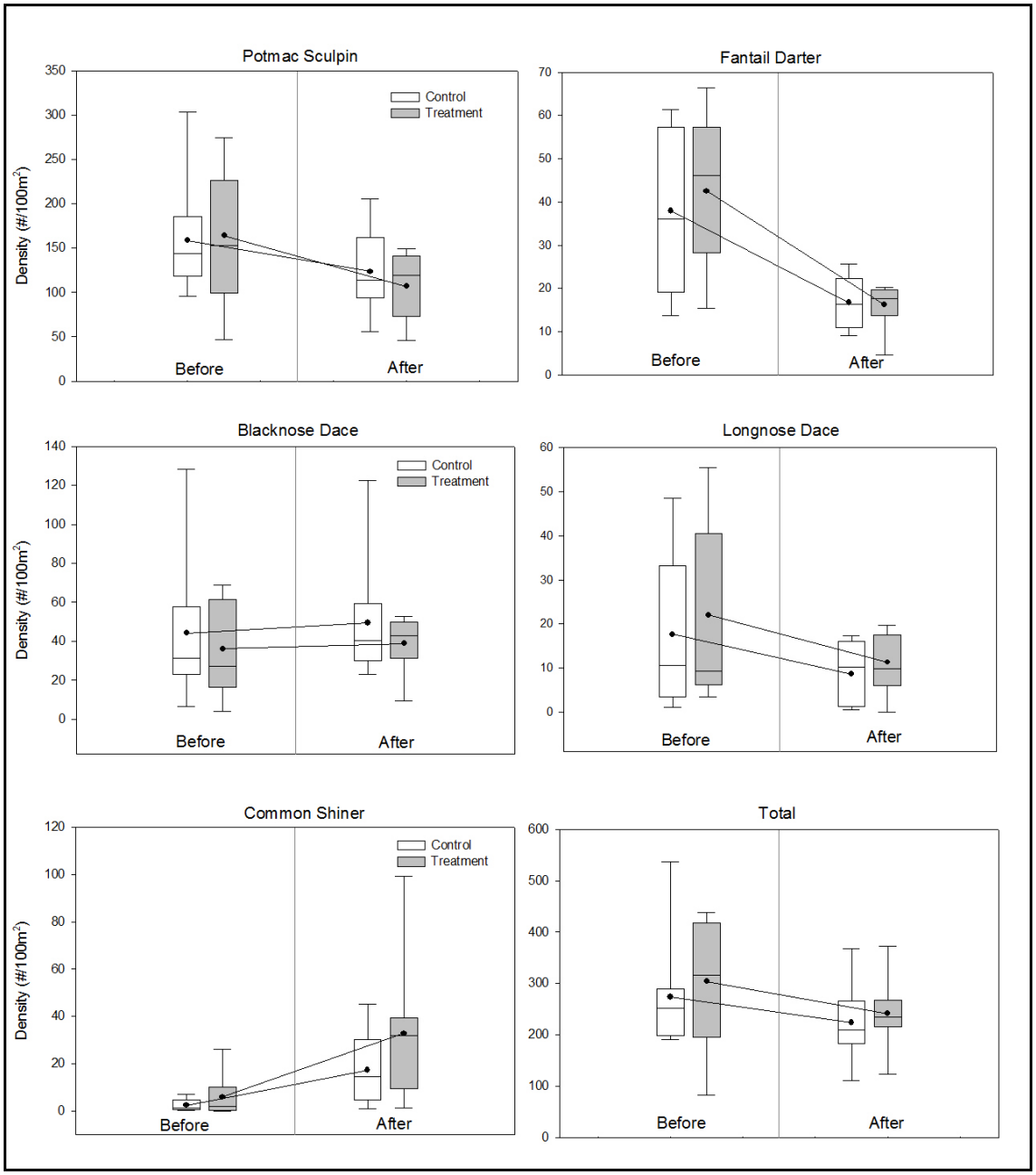

Figure 5. Boxplots of density (#/100m^2) of Potomac sculpin, fantail darter, blacknose dace, longnose dace, common shiner, and total fish in control and treatment 30 m stream sections before and after wood addition. Black dots and connecting lines indicate means and direction of change in density.

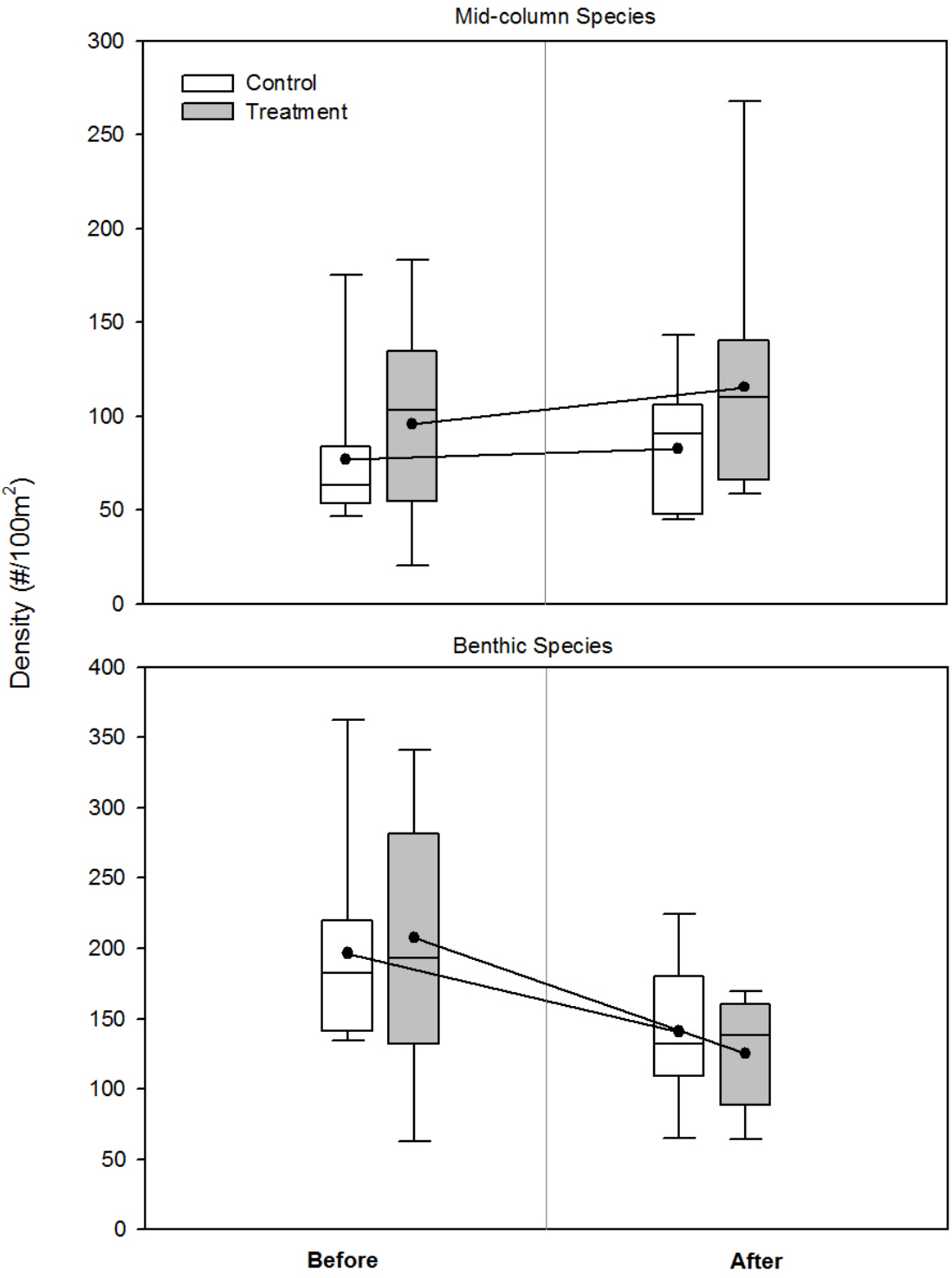

Figure 6. Boxplots of density (#/100m^2) of mid-column and benthic fish species in control and treatment 30 m stream sections before and after wood addition. Black dots and connecting lines indicate means and direction of change in density.

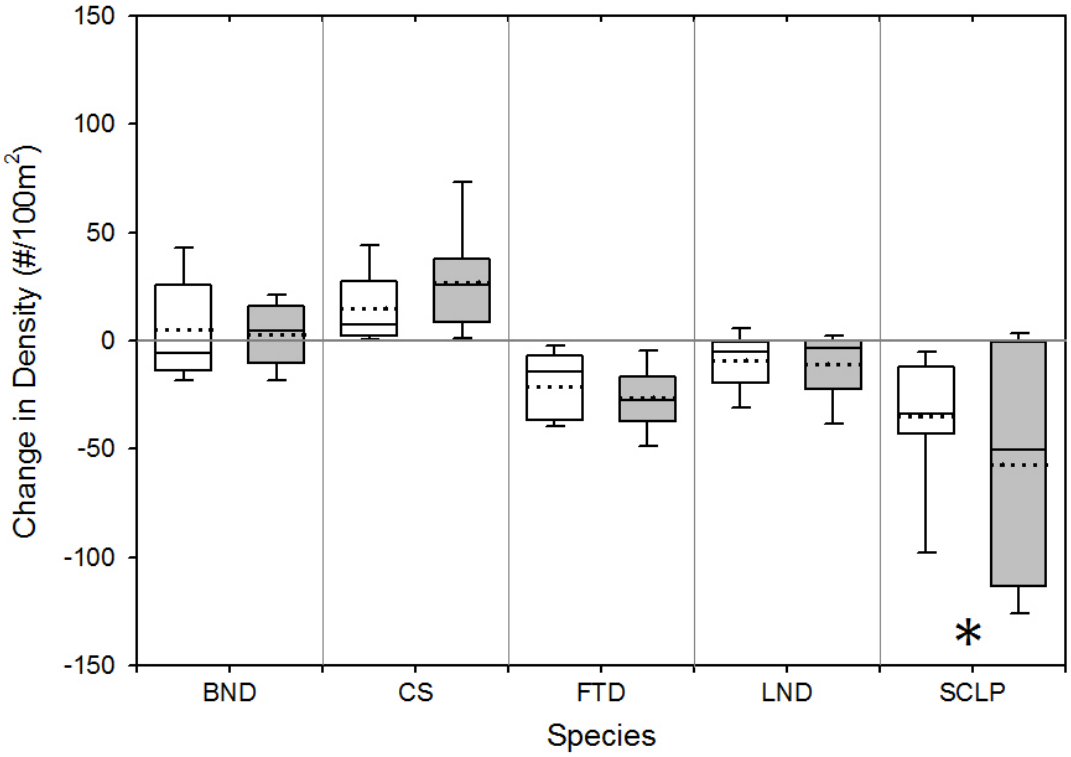

Figure 7. Boxplots of mean change in density between the 2005 to 2008 mean (before wood addition) and the mean of 2009 and 2010 values (after wood addition) of the five most abundant fish species in Smith Creek (BND = blacknose dace; CS = common shiner; FTD = fantail darter; LND = longnose dace; SCLP = Potomac sculpin) in control (unshaded, n = 9) and treatment (shaded, n = 9) 30 m stream sections. Dashed line is mean. * denotes significant difference ($P < 0.05$.)

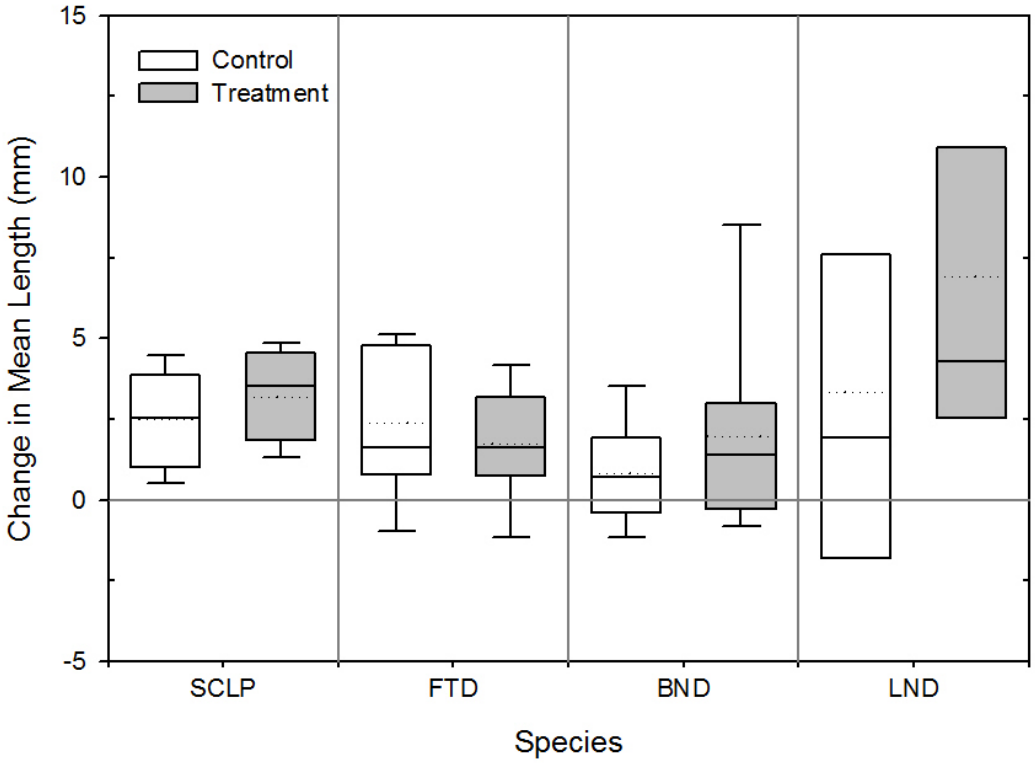

Figure 8. Boxplots of mean change in average length of Potomac sculpin (SCLP), fantail darter (FTD), blacknose dace (BND), and longnose dace (LND) before and after wood addition in control (unshaded) and treatment (shaded) 30 m stream sections. Dashed line is mean.

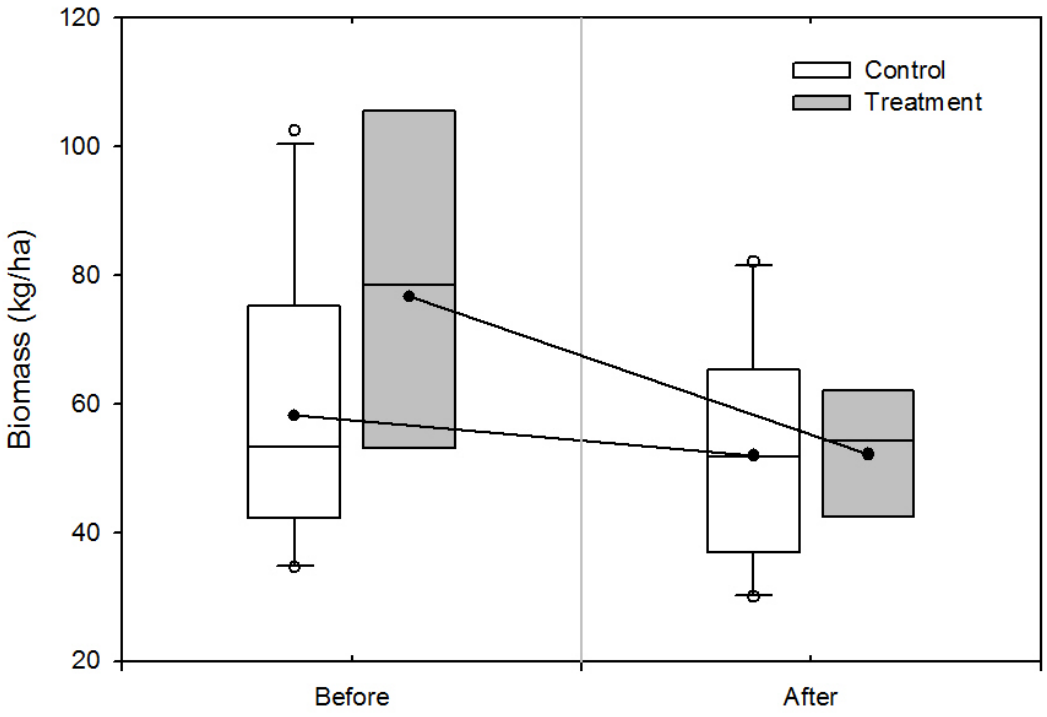

Figure 9. Boxplots of biomass (kg/ha) of Potomac sculpin in control and treatment 30 m stream sections before and after wood addition. Black dots and connecting lines indicate means and direction of change in biomass.

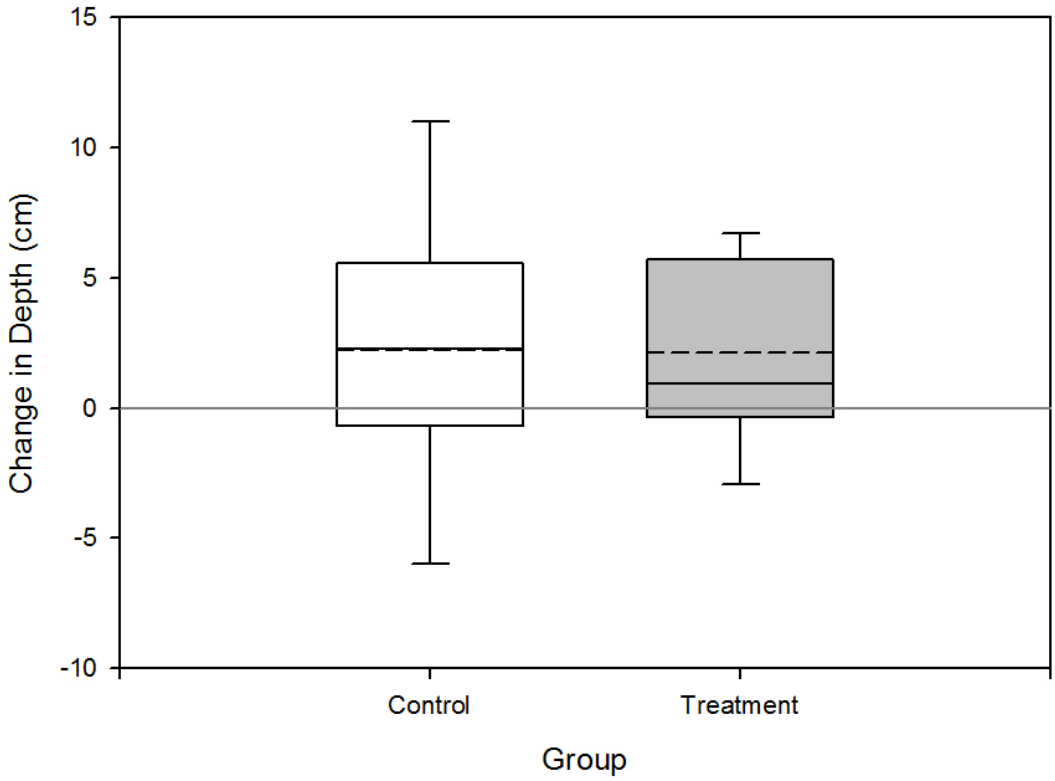

Figure 10. Boxplots of mean change in average thalweg depth in control (unshaded, n = 9) and treatment (shaded, n = 9) 30 m stream sections two years after wood addition. Dashed line is mean. Observed differences are within measurement error.

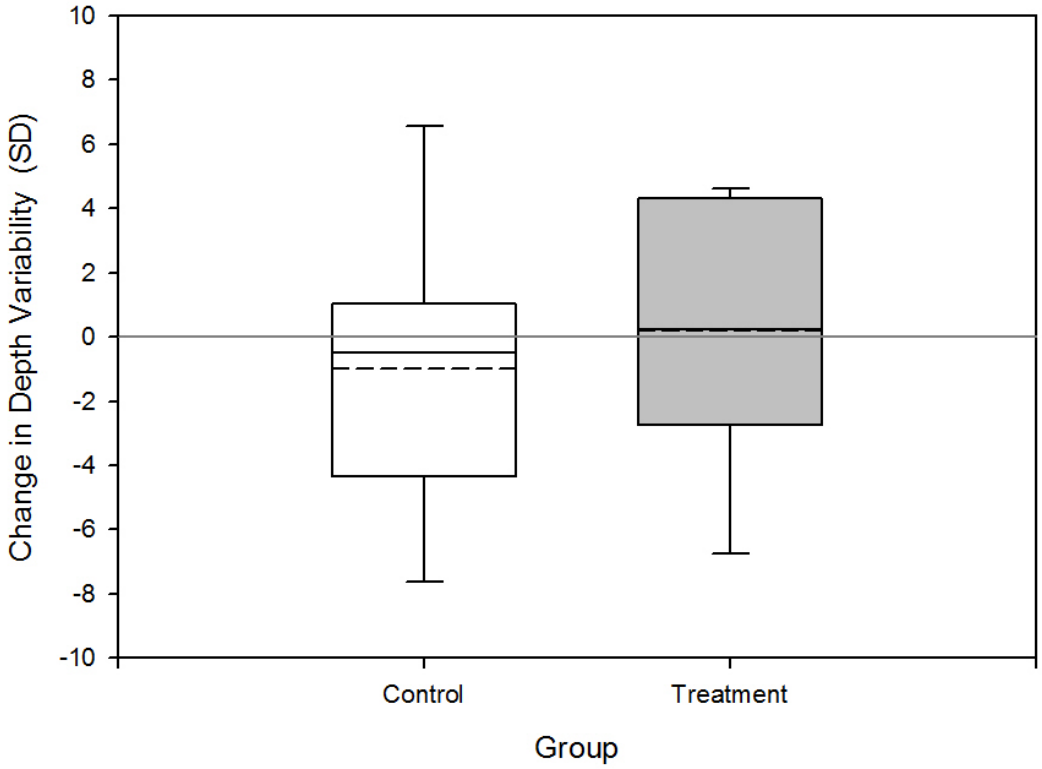

Figure 11. Boxplots of mean change in thalweg depth standard deviation in control (unshaded, n = 9) and treatment (shaded, n = 9) 30 m sections two years after wood addition. Dashed line is mean.

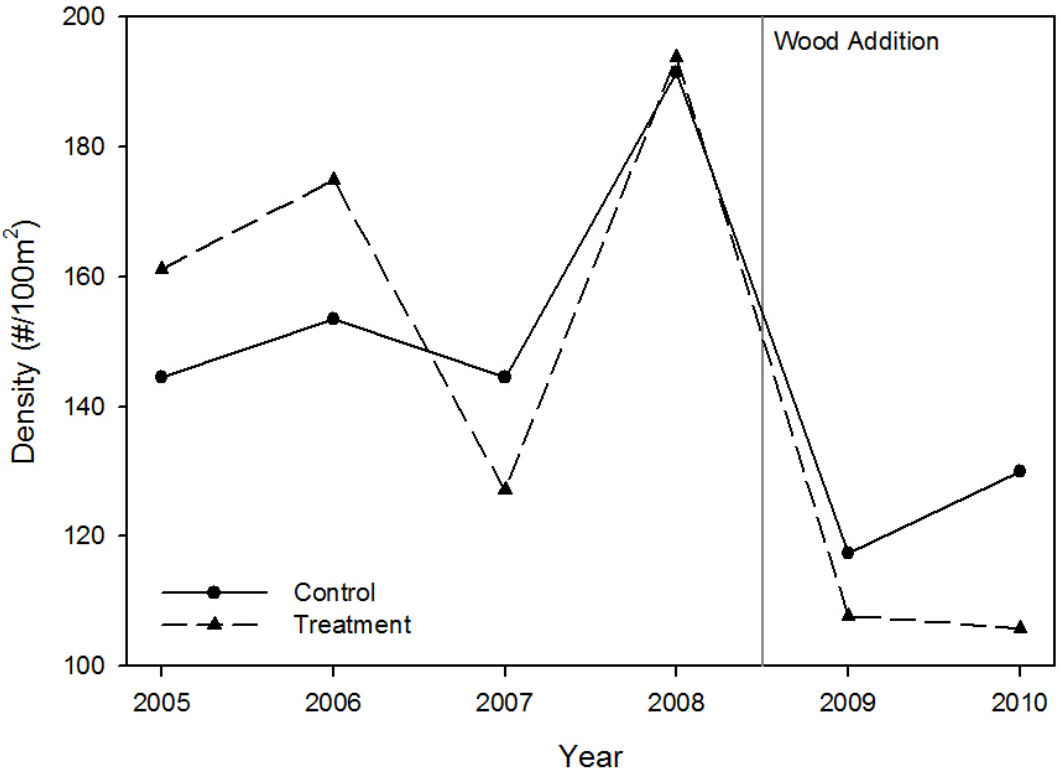

Figure 12. Variability in yearly mean Potomac sculpin density (#/100m^2) (mean of all control and treatment sections) over the six year sampling period with time of wood addition shown.

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