Influence of a small instream wood addition on fishes and hydrology in channelized agricultural headwater streams in central Ohio

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Abstract

Instream wood is important for fish in headwater streams because it promotes the development of pool habitat and provides cover from predators during periods of low flow in the summer. The benefits of large instream wood for fishes have been extensively documented. However, little is known about small instream wood (diameter < 10 cm, length < 1 m), and its influence on fish communities and hydrology in channelized agricultural headwater streams in the Midwestern United States. Understanding this influence on fishes and hydrology can lead to multiple-use management strategies within agricultural headwater streams that consider the needs of fishes and other aquatic wildlife in addition to the needs of agriculture. In July 2011, one site containing one treatment pool and one control pool was established within each of four channelized agricultural headwater streams within the Upper Big Walnut Creek watershed in central Ohio. I sampled fishes and collected hydrology measurements in each site weekly for two weeks. After this first sampling period (pre-small instream wood addition), four to six pieces of small instream wood were added to each treatment pool and left undisturbed for approximately one month. In August 2011, fish and hydrology sampling resumed weekly for two weeks (post-small instream wood addition). No differences in fish community structure or hydrology occurred between control and treatment pool before or after the addition of small instream wood. Although the instream wood addition did not influence fish communities or hydrology, my results and the results of similar studies suggest that there may be a “threshold” density at which instream wood may be added that would benefit fish communities without influencing hydrology.

Introduction

Instream wood is an important resource for fishes and other aquatic wildlife because it contributes substantially to the physical dynamics and ecological relationships within streams and rivers (Harmon et al. 1986), particularly in historically forested landscapes such as Ohio. Large instream wood in particular influences stream hydrology and geomorphology by redirecting current flow, which creates heterogeneous and complex patches of pool and riffle habitat suitable to different fish species. Instream wood also provides important overhead cover for fishes from predators (Angermeier and Karr 1984) and controls erosion and sediment loading by stabilizing stream banks (Zika and Peter 2002). Nutrient dynamics and cycling are influenced by instream wood through its ability to trap and accumulate detritus and provides an important source of energy, particularly in headwater streams that rely on allochthonous inputs of energy from the riparian zone (Vannote et al. 1980). Many macroinvertebrate species that are an important food resource for fishes rely on instream wood for reproduction, refuge, and foraging (O'Connor 1991; Hrodey et al. 2008).

The benefits provided by instream wood to native fishes are the result of those fishes evolving and adapting to large amounts of instream wood that was once ubiquitous in Ohio streams prior to European settlement (Shields et al. 2006). Following settlement and westward expansion, the natural landscape of Ohio was permanently changed, as forests were removed to make way for agriculture and wood was removed from rivers and streams because it impeded navigation and was seen as unaesthetic (Harmon et al. 1986; Brooks et. al 2004). Further, drainage ditches were constructed and existing streams were channelized in order to remove wetlands and drain hydric soils to increase agricultural productivity (Blann et al. 2009; Smiley and Gillespie 2010). Headwater streams were often targeted because their smaller size made them easier to manipulate. As a result of the widespread use of agricultural drainage and channelization practices, channelized agricultural headwater streams (i.e. drainage ditches) have become common across the Midwest.

Subsequent management of channelized streams typically involves occasional dredging, maintaining herbaceous buffers and preventing natural woody plant succession, and periodic removal of instream wood and anything seen as affecting the drainage capacity of the stream. The homogenization of instream habitat including the removal of instream wood likely has a negative impact on fishes that are naturally adapted to instream wood. In addition, habitat destruction is a leading cause of extirpation and extinction of fish species worldwide (Lester and Boulton 2008). The problem is exacerbated because farmers and stream managers remain unaware or ambivalent to the harmful impacts of channelization and instream wood removal on fish communities. Although the primary function of channelized streams is to drain water from agricultural cropland, they are not isolated from the surrounding environment and are capable of serving as fish habitat (Smiley and Gillespie 2010). Therefore these streams should be managed in ways that consider the needs of fishes in addition to the needs of agriculture (Stammler et al. 2008).

The addition of instream wood to streams is a common restoration practice and many studies have demonstrated that fishes often react positively to instream wood additions. However, most of these studies focus on salmonid species in forested coldwater streams and almost exclusively involve the addition of large instream wood (length > 1-m, diameter > 10-cm) (Talmage et al. 2002). This is troublesome because fish community structure in agricultural drainage ditches is more strongly influenced by instream habitat characteristics than water chemistry or riparian habitat characteristics (Smiley et al. 2009). Only a few papers have been published that document the influence of adding large instream wood on fishes (Angermeier and Karr 1984; Gatz 2008; Hrodey and Sutton 2008) and hydrology (Angermeier and Karr 1984; Ehrman and Lamberti 1992; Lester and Wright 2009) in channelized agricultural headwater streams. I could not locate any studies that documented the specific influence of adding small instream wood on fishes and hydrology in channelized agricultural headwater streams.

I conducted a field experiment in which I added small instream wood to four channelized agricultural headwater streams in order to determine the influence of adding small instream wood on fishes and hydrology in those streams. I hypothesized that *adding small instream wood to channelized agricultural headwater streams would benefit fishes without influencing hydrology*. I then compared the results of my field experiment to those other studies that have documented the influence of adding instream wood on fishes in channelized agricultural headwater streams in order to provide management suggestions for channelized streams that consider the needs of fishes and other aquatic wildlife as well as the needs of agriculture.

Study Area

My field experiment was conducted in four channelized agricultural headwater streams (henceforth referred to as channelized streams) in the Upper Big Walnut Creek watershed in central Ohio (Figure 1). These channelized streams were selected because they possessed similar physical and hydrological characteristics. Specifically, these channelized streams were low-gradient warmwater streams that possessed similar watershed sizes, narrow herbaceous riparian buffers, sparse canopy cover, and contained very low densities and varieties of naturally occurring instream wood (Table 1). In preparation for this experiment I conducted a field survey of instream wood in six unchannelized streams within the Upper Big Walnut Creek watershed and determined that the mean density across the six streams was approximately 0.3 pieces/m^2

and the most abundant type of instream wood were small simple pieces without branches (length < 1-m, diameter < 10-cm).

Methods

Experimental Design

In July 2011, I established one site in each of the four channelized streams. The location of the site within each channelized stream was dependent on the location of pool habitat because pools are important habitat for fishes during the summer in central Ohio when precipitation and stream depths are relatively low. Each site was composed of a pair of adjacent 3-m long pools that initially contained no naturally occurring instream wood. The downstream pool was assigned as the treatment pool and the upstream pool was assigned as the control pool at each site. Treatment and control pools within each site were no further than 50-m apart. Transects were established at the downstream (T0), middle (T1.5), and upstream (T3) ends of each pool for hydrology sampling.

My experiment used a before-after-control-treatment (BACI) design in which all four sites were sampled weekly for two weeks during the first sampling period (pre-small wood addition) when all pools lacked instream wood. Several pieces of small instream wood were then experimentally added to the treatment pools in each site and were maintained for a 27 day treatment period during which time no sampling occurred. Following the treatment period, the second sampling period (post-small wood addition) began during which time treatment pools contained instream wood and control pools lacked instream wood.

Pre-small wood addition fish and hydrology sampling

The first sampling period (pre-small wood addition) began on 14 July 2011 and was completed on 21 July 2011 when all pools within each site lacked instream wood. Upon arrival to a site, block nets were set first within the downstream treatment pool followed by the upstream control pool. After block nets were set a visual inspection was conducted to confirm that no instream wood had migrated into either pool. Fish sampling began at the downstream treatment pool using a backpack electrofisher (100-V, 60-Hz) using a two-pass technique. One person operated the backpack electrofisher while another captured all stunned fishes with a dip net. After completing the first pass, I waited at least five minutes before completing the second pass. All captured fishes were identified to species and measured before being released. Block nets were removed from the downstream treatment pool before repeating the process at the upstream control pool. Fish community data was used to calculate total abundance, species richness, percent sunfishes, percent minnows, mean fish length, and a Shannon Diversity Index for each pool during each sampling week.

Upon completion of fish sampling, block nets were removed from upstream control pool and I waited five minutes before beginning hydrology measurements. Beginning at the downstream transect (T0) of the downstream treatment pool, wetted width was determined and used to identify four equidistant points along the transect at which I measured water depth and water velocity using an electromagnetic flow meter and top setting wading rod. This process was repeated at the middle (T1.5) and upstream (T3) transects of the pool. After completing hydrology sampling in the downstream treatment pool, the process was repeated at the upstream control pool. The collected data was used to calculate mean water velocity, mean water depth, mean wetted width, pool area, and mean discharge for each pool during each sampling week.

Mean water depth and mean water velocity were determined for each pool by averaging the twelve water depth and water velocity data points measured in each pool. Mean wetted width was calculated for each pool by averaging the measured wet width at each of the three pool transects. Mean discharge was calculated at each pool by first calculating discharge at each transect and averaging across the three transects. Pool area was calculated by multiplying pool length by the average wetted width across the three transects.

Small instream wood addition and treatment period

After the completion of the first sampling period on 22 July 2011, small instream wood pieces (length = 1-m; diameter = 3-6 cm) without branches were collected and submerged in a tub filled water to maintain water saturation and limit buoyancy. Four to six of these small instream wood pieces were added to the treatment pool in each site on 25 July 2011 to give an approximate instream wood density of one piece/m^2 of treatment pool area (Figure 2). Colored zip ties were added to each added piece of small instream wood to aid in visual inspection and distinguish it from natural instream wood that may migrate into the treatment pool later on. The instream wood type and density was selected based on my preliminary instream wood survey.

After the small instream wood addition a 28 day treatment period from 25 July 2011 through 21 August 2011 was established during which time no sampling occurred. Weekly checks were conducted at each site to ensure added instream wood had not migrated out of the treatment pool. Any added pieces of small instream wood that migrated out of the treatment pool were returned. If the piece could not be found, it was replaced to maintain instream wood density in the treatment pools.

Post-small wood addition fish and hydrology sampling

Following the treatment period, I began the second period of sampling (post-small wood addition) on 22 August 2011 and was completed on 30 August 2011 during which time treatment pools contained small instream wood and control pools lacked instream wood. Fishes and hydrology were sampled once a week for two weeks at each site using the same sampling procedure as previously described.

Statistical Analysis

I used the Kolmogorov-Smirnov test and the Levene Median Test to determine if my response variables met the assumptions of normality and equal variance using SigmaStat. Response variables that did not meet the assumptions were either logarithmically transformed (fish abundance, species richness, wood density, wood volume, mean discharge) or arcsine square root transformed (percent sunfishes) before analysis. I performed a blocked two-factor ANOVA with “site” serving as the block and “pool type” and “week” serving as the independent factors. The ANOVA was performed using SAS (proc GLM) and used to determine the effect of adding small instream wood on fishes and hydrology. I was specifically interested in the interaction effect between “pool type” and “week” to determine if wood density, wood volume, fish abundance, species richness, percent sunfishes, percent minnows, mean fish length, Shannon Diversity Index, mean water velocity, mean depth, meant wetted width, mean discharge, or mean pool area were influenced by the small instream wood addition. I focused on the interaction effect because I had a replicated BACI design. This design predicts differences (i.e. relationships) between control and impact sites will change following the impact (i.e. manipulation). Therefore, only the interaction effect provides me with information to determine whether the trend between control and treatment pools changed following the small instream wood addition. If a significant difference was detected at the 0.05 level, Tukey's honestly significant difference test was performed to determine which means differed.

Results

Of the twenty one pieces of small wood added during the experiment, only one piece was lost and replaced. In several instances, a piece of wood migrated downstream and was returned to the treatment pool. As a result of increasingly low water velocity and discharge within the treatment pools, the added pieces became covered with a thick layer of silt. Wood density ($F = 85.48$; $df = 3$; $P < 0.0001$) and wood volume ($F = 62.05$; $df = 3$; $P < 0.0001$) significantly increased in the treatment pools relative to the control pools following the small instream wood addition (Figure 3).

A total of 660 fishes were captured from the four channelized streams, of which 209 fishes were captured during the first sampling period when no pools contained instream wood and 451 fishes were captured during the second sampling period when treatment pools contained small instream wood. The most common fish species captured were fathead minnow (*Pimephales promelas*), creek chub (*Semotilus atromaculatus*), bluegill (*Lepomis macrochirus*), johnny darter (*Etheostoma nigrum*), and orangethroat darter (*Etheostoma spectabile*) (Table 2). Trends in fish abundance, species richness, percent sunfishes, percent minnows, mean fish length, and Shannon diversity index between the control and treatment pools did not change ($P > 0.05$) following the instream wood addition (Table 3).

Not including the storm event one day prior to the instream wood addition on 25 July 2011 (personal observation), there were no major precipitation events during the experiment and pools gradually became smaller. Between the first and second sampling periods, mean water depth decreased slightly in all pools (0.18 m to 0.17 m) as well as mean wetted width (1.82 m to 1.76 m), mean discharge (0.0007 m^3/s to 0.0001 m^3/s), and mean pool area (5.46 m^2 to 5.28 m^2). Mean water velocity was negative for both sampling periods and was considered zero. Despite the drying conditions, all pools retained water during the experiment. Trends in mean water velocity, mean water depth, mean wetted width, mean discharge, and mean pool area did not change ($P > 0.05$) between the control and treatment pools following the small instream wood addition (Table 4).

Discussion

Fish Communities

My results do not support my original hypothesis in that adding small instream wood at a density of one piece/m^2 does not influence fishes in pools in channelized streams. However, a few studies have observed fish communities responding positively to instream wood additions in channelized streams. Angermeier and Karr (1984) found that species richness, abundance, and large fish were higher on the debris side compared to the no-debris side in a channelized headwater stream in Illinois. In addition, they conducted a multiple-reach experiment in the same stream in which wood structures were added at different densities to debris reaches and found that abundance was generally higher in debris and control reaches compared to cleared reaches but the effect of instream wood was often dependent on species and age class. Gatz (2008) increased overhead cover in a headwater stream in central Ohio by placing floating wood structures in treatment reaches that resulted in greater abundances of bluntnose minnow (*Pimephales notatus)*, creek chub (*Semotilus atromaculatus)*, and longear sunfish (*Lepomis megalotis)*. Hrodey and Sutton (2008) added half-log structures to three channelized headwater streams in Indiana and observed higher abundance and species richness in reaches with half-logs but the frequency of positive fish responses to half-log structures was dependent on the amount of pre-existing cover.

My calculated wood density of pieces/m^2 made comparisons with other studies difficult, so I calculated percent of pool or reach area covered by instream wood in my experiment and those of Angermeier and Karr (1984), Gatz (2008), and Hrodey and Sutton (2008) using the available data in each paper. In my experiment I had approximately 3.9% instream wood coverage in treatment pools. This was greater than the approximate instream wood coverage of 1% - 3% in the multiple-reach experiment conducted by Angermeier and Karr (1984), similar to the 3-4% instream wood coverage by the floating structures used by Gatz (2008), and greater than the 1.7% instream wood coverage by half-logs in the study conducted by Hrodey and Sutton (2008). Wood volume was not compared between studies because I could not confidently calculate it using the available information in the other studies.

The approximate percent instream wood coverage for my experiment is similar to the approximate percent instream wood coverage found in previous studies (Angermeier and Karr 1984; Gatz 2008; Hrodey and Sutton 2008) yet I found no influence of the small instream wood addition on fish communities. This suggests that the quality of instream wood (e.g. size, complexity) may be more important than the quantity of instream wood (e.g. density, abundance) in relation to fish habitat. Increasingly large and complex types of instream wood produce localized changes in flow that fish may use as refuge from stream current (Zika and Peter 2002). Further, large and more complex instream wood structures may support more individuals due to the presence of high quality overhead cover for predator protection (Angermeier and Karr 1984; Gatz 2008) and increased macroinvertebrate foraging area (O'Connor 1991).

In addition to providing high quality habitat large and complex instream wood types remain effective longer because they are more resistant to environmental degradation. Of the 108 half log structures installed by Hrodey and Sutton (2008) 106 were still functional after two years. In addition fishes were observed using half-log structures that had become inundated with sand and silt. By the end of our field experiment, the added pieces of small instream wood had become covered with a thick layer of silt, which may have reduced their effectiveness as fish habitat. Although we did not observe significant loss of added small instream wood pieces, their small size and resulting high probability of downstream migration further limits the ability of fishes to utilize them as habitat (Hilderbrand et al. 1998).

My ability to detect a change in fish communities during my experiment may have also been limited by the spatial size of my sampling unit. The pools I sampled were 3-m long, whereas Angermeier and Karr (1984) sampled 30.5-m and 35-m reaches, Gatz (2008) sampled 20-m and 15-m reaches, and Hrodey and Sutton (2008) sampled 25-m reaches.

Hydrology

My results support my original hypothesis that adding small instream wood at a density of one piece/m^2 does not influence hydrology in pools in channelized streams and is reinforced by three other studies that looked at the influence of large instream wood on hydrology in channelized streams. During the split-stream experiment of Angermeier and Karr (1984), water velocity slightly increased on the cleared side relative to the debris side. Water depth and water velocity did vary between altered and controlled reaches during the multiple-reach experiment, but differences were not consistent and may be more related to the stream flow regime than the addition of instream wood. Although water velocity decreased in reaches that contained a channel-spanning logjam compared to reaches that had large instream wood only at the edge or no wood at all, Ehrman and Lamberti (1992) found that stream discharge and depth did not differ between reach types in an Indiana headwater stream. Lester and Wright (2009) did not observe any significant differences in water velocity and stream discharge between treatment and control reaches following an instream wood addition. Because my added instream wood pieces were simple (i.e. low structural complexity) and were relatively small compared to other studies, it is very unlikely that my instream wood addition influences hydrology except at very small spatial scales.

The degree to which instream wood influences hydrology is dependent on several factors including size, structure (Lester and Wright 2008), orientation relative to stream flow (Hildebrand et al. 1998), and location within the water column (Mutz 2003). However, the spatial scale at which these factors influence hydrology are not well understood due to inconsistent results among studies, though it appears that most instream wood types other than log jams or debris jams may not significantly influence hydrology at the reach scale and beyond.

Conclusions

The results of my experiment coupled with the results of other studies suggest that adding instream wood can have a positive influence on fish communities without significantly influencing hydrology at large spatial scales (Angermeier and Karr 1984; Ehrman and Lamberti 1992; Gatz 2008; Hrodey and Sutton 2008; Lester and Wright 2009). As such, instream wood has the potential to be incorporated into a multiple-use management strategy for channelized streams that consider the needs of fishes as well as the needs of agriculture. Adding a variety of instream wood sizes and types (e.g. large simple pieces, logjams, overhanging woody vegetation, etc.) that do not span the entire channel can provide high quality fish habitat without impeding the drainage capacity of the channelized stream. A passive alternative strategy to actively adding instream wood to channelized streams could be to allow natural woody debris recruitment and woody riparian buffer succession. This strategy does not require maintenance, is cost-effective, and can at least partially restore stream dynamics to which the native aquatic community is adapted.

In addition to potential management implications, my results and the results of others suggest there may be a "threshold" density at which instream wood can be added that will benefit fish communities without influencing hydrology. Specifically, this threshold could be a numerical value or range of values of instream wood density that would take into account the previously discussed factors determining the quality of instream wood as fish habitat (e.g. size and structure) and factors determining the influence of instream wood on hydrology (e.g. orientation, proportion of stream width occupied). This number or range of numbers could be directly applied by stream managers and property owners that would enhance the ecological integrity of degraded channelized stream ecosystems. More research is required to determine what this threshold may be in channelized streams.

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Table 1. Environmental characteristics of the four channelized agricultural headwater streams used in this study.

	Site			
	A1	B1	SR1	WW1
Instream wood density (pieces/m^2)	0.032	0.030	0.034	0.000
Shannon Diversity Index (wood)	0.349	1.253	1.213	0.000
Watershed size (km^2)	4.50	3.78	4.44	1.16
Mean riparian width (m)	39.16	41.45	5.11	9.16
Mean percent canopy cover	5.15	0.12	0.23	0.00
Land use				
Percent Agriculture	75.8	75.1	60.9	95.1
Percent Urban	21.3	18.5	25.7	3.9
Percent Forest/Scrub	2.9	6.4	13.4	1.0

Table 2. Summary of fish captures from control and treatment pools before and after the small instream wood addition from the four channelized streams.

Species	Pre-small wood addition					Post-small wood addition					
	Control pools		Treatment pools		Total	Control pools		Treatment pools		Total	Grand total
Sampling week	**1**	**2**	**1**	**2**		**3**	**4**	**3**	**4**		
Black bullhead (*Ameiurus melas*)	0	0	0	0	0	0	0	1	0	1	1
Bluegill (*Lepomis macrochirus*)	8	3	16	4	31	4	16	8	17	45	76
Bluntnose minnow (*Pimephales notatus*)	1	0	0	0	1	12	15	4	0	31	32
Creek chub (*Semotilus atromaculatus)*	36	32	26	7	101	12	20	20	9	61	162
Fathead minnow (*Pimephales promelas)*	7	1	0	1	9	28	75	28	30	161	170
Green sunfish (*Lepomis cyanellus*)	3	1	1	2	7	0	6	6	2	14	21
Johnny darter (*Etheostoma nigrum)*	2	4	2	1	9	16	8	11	9	44	53
Largemouth bass (*Micropterus salmoides*)	1	0	0	0	1	0	1	1	3	5	6
Orangethroat darter (*Etheostoma spectabile*)	6	5	1	0	12	11	5	3	0	19	31
Pumpkinseed sunfish (*Lepomis gibbosus*)	2	0	0	0	2	0	0	0	0	0	2
Central stoneroller (*Campostoma anomalum)*	5	15	0	0	20	0	1	1	0	2	22
White sucker (*Catostomus commersonii)*	1	1	0	0	2	1	0	4	0	5	7
Unknown fish	0	0	1	0	1	0	0	1	0	1	2
Unknown minnow	0	7	0	6	13	20	11	24	7	62	75
Grand total	72	47	69	21	209	104	112	158	77	451	660

Table 3. Reported untransformed means and (SE) for the fish response variables. Associated p-values were derived from the ANOVA interaction between the independent factors “pool type” and “week”.

Response variable	Pre-small wood addition		Post-small wood addition		F	df	P
	Control pools	Treatment pools	Control pools	Treatment pools			
Total abundance	17.63(3.78)	8.5 (2.18)	32.75 (15.53)	23.63 (11.63)	0.34	3	0.795
Species richness	3.38 (0.63)	2.25 (0.37)	3.63 (1.00)	3.63 (1.12)	0.83	3	0.494
Percent sunfishes	26.73 (16.02)	36.77 (14.68)	16.57 (8.50)	38.45 (14.55)	0.37	3	0.775
Percent minnows	62.43 (14.06)	48.38 (14.63)	56.11 (14.83)	30.41 (11.62)	0.21	3	0.887
Fish length (cm)	5.14 (0.63)	4.71 (0.49)	6.31 (1.14)	6.31 (0.82)	0.08	3	0.971
Shannon Diversity Index	0.73 (0.21)	0.50 (0.15)	0.94 (0.24)	1.13 (0.17)	0.97	3	0.426

Table 4. Reported untransformed means and (SE) for the hydrology response variables. Associated p-values were derived from the ANOVA interaction between the independent factors “pool type” and “week”.

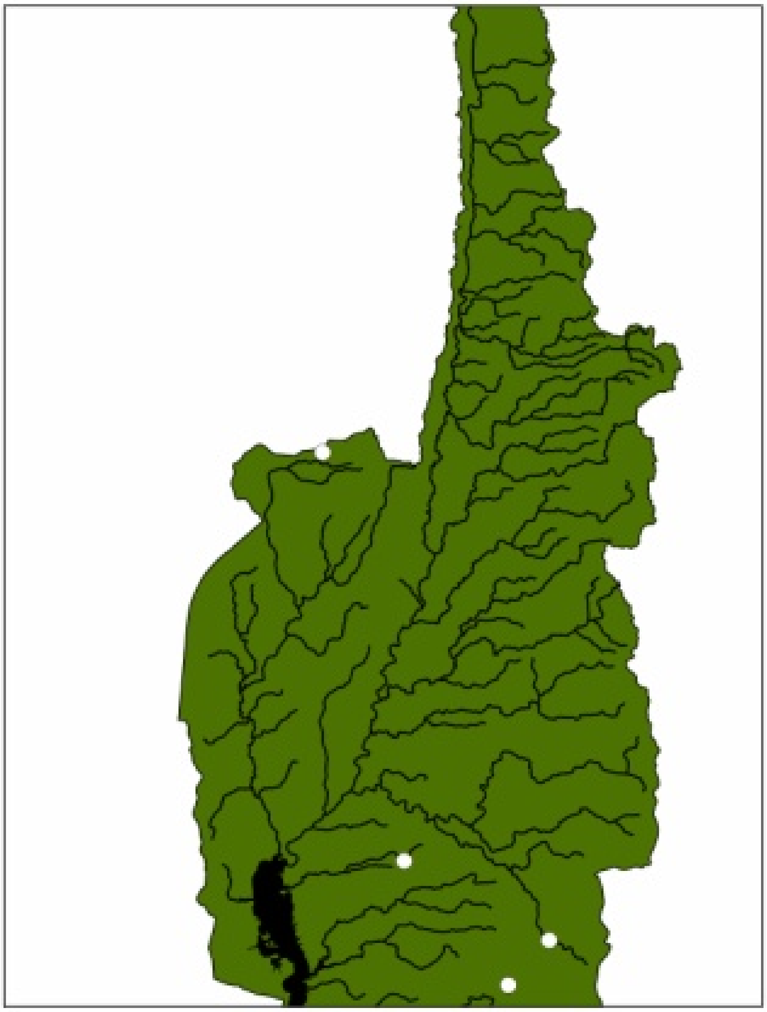
Response variable	Pre-small wood addition		Post-small wood addition		F	df	P
	Control pools	Treatment pools	Control pools	Treatment pools			
Water velocity (m/s)	-0.01 (0.01)	-0.0004 (0.003)	-0.02 (0.003)	-0.02 (0.003)	0.30	3	0.828
Water depth (m)	0.18 (0.01)	0.19 (0.02)	0.17 (0.01)	0.17 (0.02)	0.21	3	0.890
Wetted width (m)	1.86 (0.18)	1.79 (0.14)	1.81 (0.19)	1.71 (0.19)	0.07	3	0.975
Pool discharge (m^3/s)	0.001 (0.0003)	0.001 (0.0002)	0.0001 (0.0001)	0.0001 (0.0001)	0.30	3	0.825
Pool area (m^2)	5.57 (0.54)	5.36 (0.43)	5.44 (0.57)	5.13 (0.56)	0.07	3	0.975

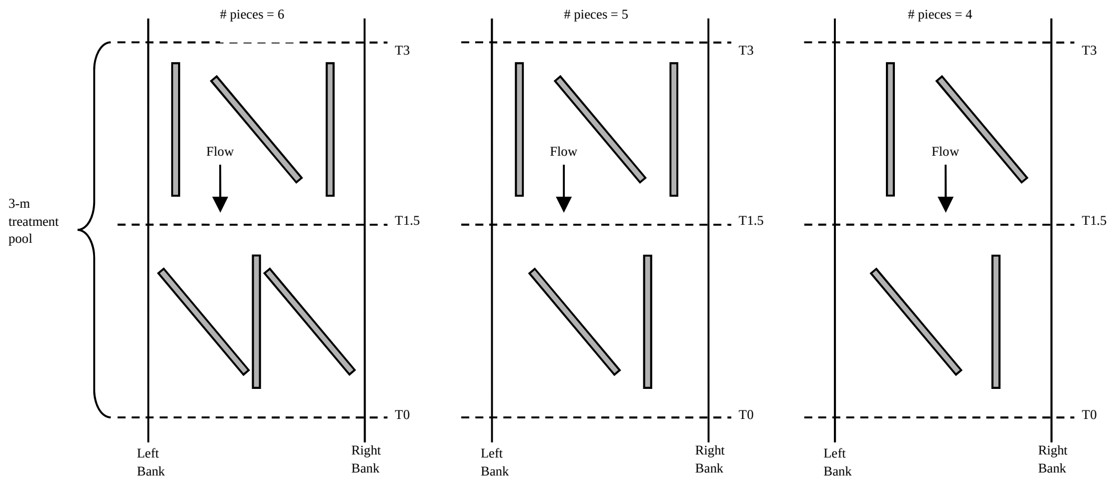
Figure Legends

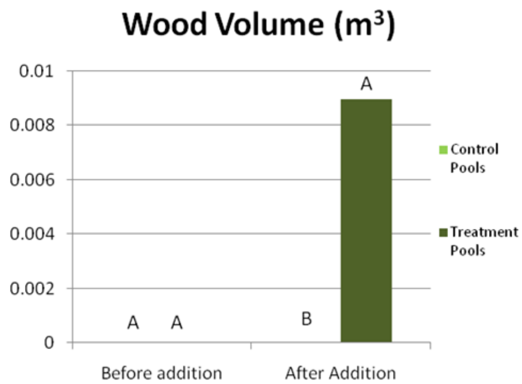
Figure 1. Location of sites within the Upper Big Walnut Creek watershed. Sites are represented by white dots.

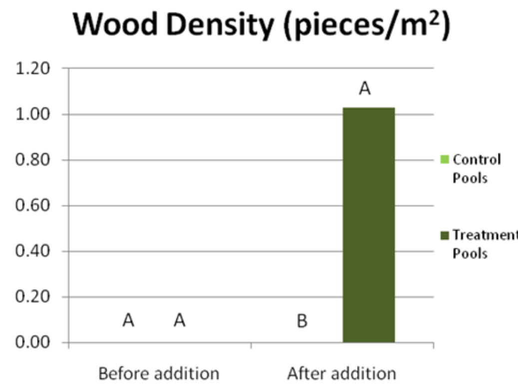
Figure 2. Representations of treatment pools and the arrangement of added small wood pieces (represented by grey rectangles) in the treatment pools. Either six (sites = B1,WW1), five (site = A1), or four (site = SR1) of small wood pieces were added to give an approximate density of one piece/m^2 treatment pool area. Treatment pools are not drawn to scale.

Figure 3. Wood density and wood volume differed in the treatment and control pools before and after the small instream wood addition.




pieces = 6
pieces = 5
pieces = 4
T3
T1.5
T0
Flow
3-m
treatment
pool
Left
Bank
Right
Bank


Wood Volume (m3)
0.01
0.008
0.006
0.004
0.002
0
A
A
A
B
Control Pools
Treatment Pools
Before addition
After Addition


Wood Density (pieces/m2)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
A
A
A
B
Control Pools
Treatment Pools
Before addition
After addition