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QUANTIFYING FISH HABITAT ASSOCIATED WITH STREAM SIMULATION DESIGN CULVERTS IN NORTHERN WISCONSIN

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ABSTRACT

This study investigated the effects of culvert replacement design on fish habitat and fish weight by comparing substrate diversity and weight at three stream simulation (SS)-design and three bankfull and backwater (BB)-design sites on the Chequamegon-Nicolet National Forest, Wisconsin. Stream channel cross-sections, Wolman substrate particle counts, and single-pass backpack electro-fishing survey data were used to quantify fish habitat and fish weight in 50-m upstream and downstream sample reaches at each site. We applied generalized linear mixed models to test the hypothesis that substrate size and fish weight did not differ according to stream-crossing design type (SS or BB) and location (upstream or downstream). Substrate particle sizes were significantly greater upstream of the stream crossing when compared to downstream of the stream crossing at both SS and BB sites for riffles and pools. Substrate particle sizes were also significantly greater upstream of BB sites when compared to upstream of SS sites. Results of this study indicated statistically greater individual fish weights upstream of SS-design sites in comparison to upstream of BB-design sites in first- to third-order low gradient streams. These results suggested that the SS-design approach appears to be more effective at transporting sediment downstream, and illustrated the value of using fish weight as an indicator of biological success for stream-crossing designs. Published 2017. This article is a U.S. Government work and is in the public domain in the USA.

KEY WORDS: stream crossing; stream simulation design; sediment transport; spawning substrate; fish habitat

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INTRODUCTION

The presence of barriers to fish movement at road-stream crossings is a significant source of aquatic habitat fragmentation (Gibson *et al*., 2005). Barriers occur because of design and maintenance issues resulting in inadequate depth, debris accumulation, high velocity, turbulent flow, excessive slope, and excessive drop (Adams *et al*., 2000; Gibson *et al*., 2005; Gillespie *et al*., 2014; Reiser *et al*., 2006). Removing these barriers has potential to restore extensive amounts of instream habitat that will become accessible for fish to feed, reproduce, avoid predators, and establish populations (Albanese *et al*., 2004; Warren and Pardew, 1998).

Various stream-crossing design approaches for fish passage have been developed and applied historically (Barnard *et al*., 2013; Price *et al*., 2010). The no-slope and hydraulic design methods were applied in the 1990s and earlier (Bates *et al*., 2003). The no-slope design was applied in low-gradient channels (<3% slopes) with bankfull channel widths < 10 feet and installed at zero gradient (Barnard *et al*., 2013; Price *et al*., 2010). The hydraulic design was designed to pass 10-year, 25-year, or 100-year flood flows in relation to swimming and leaping abilities of target fish species (Gillespie *et al*., 2014; Price *et al*., 2010).

The bankfull and backwater (BB) design was first used on the Chequamegon-Nicolet National Forest, Wisconsin in 2007 (D. Higgins, personal communication, 2015). This design passes flow, sediment, and debris up to at least a 100-year flood event with a headwater over depth ratio < 1. The BB design uses a representative bankfull width and stream profile from the stream channel to size the culvert and determine an appropriate bottom of culvert elevation. The BB design is only applicable on low-gradient streams where: (i) a natural backwater will provide depths and velocities that provide aquatic organism passage and (ii) sand or smaller sized materials are the only sediments in transport (D. Higgins, personal communication, 2014) (Figure 1a).

The stream simulation (SS) design method was formalized in 1999 and has a bankfull width, cross-sectional area, slope, bedforms, and substrates similar to a reference reach outside of the influence of the stream crossing (Barnard

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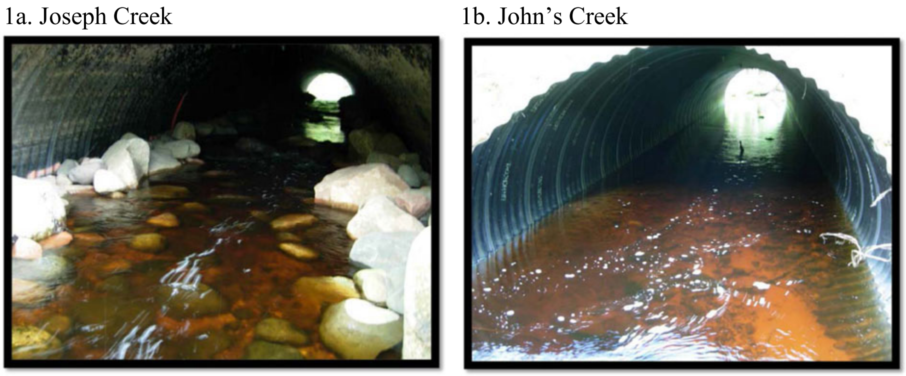

Figure 1. Example of the inside of a stream simulation (SS)-design culvert (1a) and a bankfull and backwater (BB)-design culvert (1b). The SS-design example on the left (1a) shows how substrate is used to construct banks within the culvert so that the fish does not know the difference from the adjacent stream channel. The BB-design example on the right (1b) does not have constructed substrate within the culvert [Colour figure can be viewed at wileyonlinelibrary.com]

et al., 2013). The SS design passes flow, sediment, and debris up to at least a 100-year flood event with the headwater over depth ratio < 0.8 (Barnard *et al*., 2014; Cenderelli *et al*., 2011). The SS structures are designed so that swimming through the structure is the same as swimming through the adjacent stream channel for all life stages of fish (Cenderelli *et al*., 2011; Gillespie *et al*., 2014) (Figure 1b).

Stream-crossing design success would occur when there is no significant difference between the design channel and natural channel reference reach. Barnard *et al*. (2014) evaluated width, depth, sediment, and flow success parameters for 50 SS-design sites in Washington. Results indicated success of dominant substrate for 50th and 84th percentile, which refer to percentages of the sampled particles out of 100 that were less than or equal to that size (Barnard *et al*., 2014). Results also indicated two successful discharge parameters, 100-year flood flow and 2-year flood channel width, which were calculated using measured flows and regional regression equations for velocity (Barnard *et al*., 2014).

Research to evaluate success of stream-crossing design using fish community characteristics is somewhat limited, and there are no published studies that compare effects of the SS design to the BB design on the fish community. Previous research has shown that trout biomass and density can increase as a result of stream channel reconstruction (Baldigo and Warren, 2008), installation of instream habitat structures (DeJong *et al*., 1997), and substrate diversity that includes gravel and cobble substrates (Scarnecchia and Bergersen, 1987; Stoneman and Jones, 2000). However, to our knowledge, there are no published studies that quantify differences in individual fish weights for all species as indicators of stream-crossing replacement success.

The purpose of this project was to compare effectiveness of SS and BB designs for improving substrate habitat for fish and maintaining individual fish weight in northern Wisconsin. We were testing the hypothesis that the substrate diversity associated with SS-design sites was greater as a result of a continuous design channel and more effective substrate transport through the stream crossing when compared to BB-design sites. Maintaining the design criteria channel hydraulics and sheer stress through the SS structure with continuous substrate should allow the stream to transport larger substrate particles through the structure. This more effective transport of substrate would result in more gravel and cobble substrate diversity that is considered higher-quality fish habitat (Barnard *et al*., 2014; Buffington and Montgomery, 1999; Buffington *et al*., 2004). To investigate effects of stream-crossing design on the local fish community, we tested the hypothesis that fish weight did not differ according to stream-crossing design type and location in relation to habitat. Specifically, we tested the hypothesis that there would be no significant difference in individual fish weight upstream and downstream of SS-design sites as a result of more gravel and cobble substrates upstream and downstream of the stream crossing. We also tested the hypothesis that there would be a significant difference in individual fish weight upstream and downstream of BB sites as a result of less gravel and cobble substrates downstream. To investigate effects of stream-crossing design on the fish community at a given stream-crossing site, we tested the hypothesis that the fish weights would be greater at SS sites when compared to BB sites as a result of more diverse and continuous substrate habitat.

METHODS

Study sites and sampling plan

Three SS-design sites and three BB-design sites were selected from stream-crossing replacement sites on first- to third-order coolwater and coldwater streams with ≤3% slopes in subwatersheds of the Chequamegon-Nicolet

National Forest in northern Wisconsin (Table I; Figure 2). All streams in this study have similar morphologies in the Southern Superior Uplands, Ecological Subregion, characterized by glacial-moraine terrain and well-drained sandy loam soils (McNab *et al*., 2007). Site drainage areas ranged from 2.8 km^2 at the Whiskey Creek BB site to 38.8 km^2 at the Little Popple River1 SS site. Site channel slopes ranged from 0.4% at the Little Popple River2 BB site to 2.6% at the Joseph Creek SS site (Table I). After construction at all six study sites, culvert area (m^2), culvert width (m), and culvert length (m) all increased. Culvert slopes increased for all SS sites and decreased for all BB sites after construction (Table II).

For each of the three SS-design sites and three BB-design sites, 50-m sample reaches were established upstream and downstream of the stream crossing by measuring 50 m from the structure to the start of the sample reach. Within each sample reach, fish, channel morphology, and substrate size data were collected. We did not sample the fish community within each stream-crossing structure because providing fish habitat in the structure was not an objective of the replacement, although it may be an outcome. Additionally, culvert lengths were variable, so upstream and dowstream fish samples would not be comparable at each site or across sample sites.

Stream habitat

Survey information collected to design each stream-crossing replacement was used to characterize differences between sites in drainage area for the stream-crossing location (km^2), stream channel slope (%), and flood flows ($Q_{1.5}$ and Q_{100} m^3/s). Flood flows were based on regression-based analysis of the likelihood of flood occurrence every 1.5 years and 100 years. Local USGS gage flow data was used to determine that bankfull flood events had occurred at all sites that would move substrate and flow through the stream-crossing structure. Major bankfull flood events were quantified as annual peak flow events that were above the mean annual peak flow value for 2005 to 2012 that was the time period between construction and the time of the study for all sites. One upstream 50-m sample reach was established 50 m upstream of the stream crossing and one downstream 50-m sample reach was established 50 m downstream of the stream crossing at each site. One riffle and one pool cross-section location were selected randomly from available riffles and pools within each 50-m sample reach.

At each randomly selected riffle and pool cross-section location, standard rod and level methods were used to quantify mean bankfull width (m) and bankfull maximum depth (m) to characterize physical habitat (Harrelson *et al*., 1994). The mean bankfull width was the average of the riffle and pool cross-section bankfull width for each 50-m reach. We also conducted Wolman particle size counts of 100 particles, using the random zig-zag method across the cross section transect, reaching down at the toe to collect one substrate particle each time. We measured each particle along the intermediate access and assigned it to one of 18 Wolman particle size classes, ranging from <2 mm (sand) to >2048 mm (very large boulder). Particle size counts were used to quantify mean substrate size overall and the median D_{50} particle size, the particle size at which 50% of collected particles were less than that size (Olsen *et al*., 2005; Wolman, 1954).

Fish community methods

Single-pass backpack electro-fishing surveys were conducted within the same 50-m reaches where physical habitat data was collected. Block nets and depletion sampling were not used because no significant differences were detected in Wisconsin streams when block nets and single-pass electro-fishing techniques were used for estimates of fish abundance samples in previous study (Simonson and Lyons, 1995). Total count and weights (g) of fish individuals were recorded according to species. Total number of fish per sample, regardless of species, and total weight (g) per sample were calculated for all upstream and downstream sample reaches.

Table I. Sample sites on the Chequamegon-Nicolet National Forest, including three stream simulation (SS)- and three bankfull and backwater (BB)-design culverts. Site characteristics include year site was constructed, drainage area for the stream crossing location (km^2), channel slope (%), $Q_{1.5}$ flows (m^3/s), and Q_{100} flows (m^3/s)

Site	Site label	Year constructed	Drainage area (km^2)	Slope (%)	$Q_{1.5}$ flow (m^3/s)	Q_{100} flow (m^3/s)
Joseph Creek	SS1	2008	3.0	2.6	1.1	5.4
Little Popple River1	SS2	2010	39	1.0	3.0	8.6
Preemption Creek	SS3	2007	6.9	2.3	1.6	8.9
John's Creek	BB1	2008	3.7	1.5	1.6	7.5
Little Popple River2	BB2	2006	36	0.4	2.6	7.1
Whiskey Creek	BB3	2005	2.8	1.8	0.9	4.3

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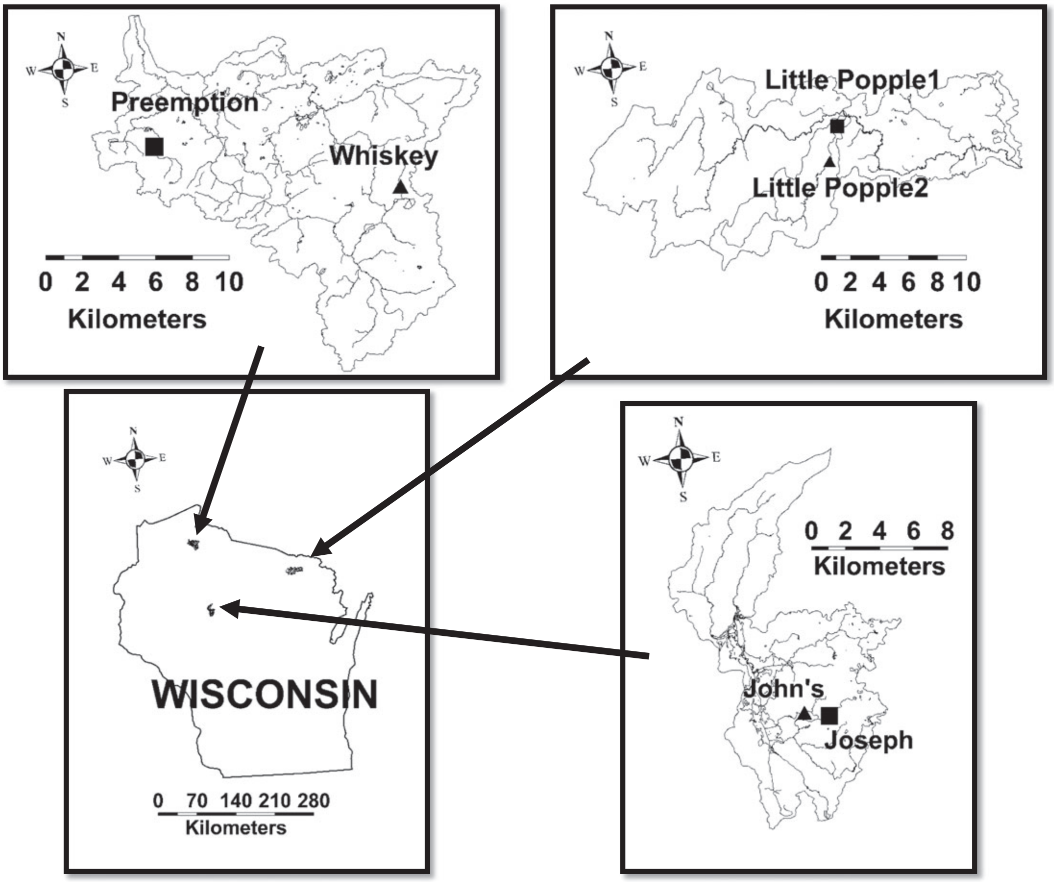

Figure 2. Six stream crossing sites on the Chequamegon-Nicolet National Forest, Wisconsin. Sites include three stream simulation (SS)-design sites (square symbol) and three bankfull and backwater (BB)-design sites (triangle symbol)

Table II. Site culvert characteristics before and after construction, including culvert area (m^2), culvert width (m), culvert length (m), and culvert slope (%) for stream simulation (SS)- and bankfull and backwater (BB)-design culverts

	Culvert area (m^2)		Culvert width (m)		Culvert length (m)		Culvert slope (%)	
Site label	Before	After	Before	After	Before	After	Before	After
SS1	2.6	4.9	1.8	3.3	26	26	1.8	2.6
SS2	4.7	6.8	1.2	7.3	15	18	0.8	1.0
SS3	1.2	5.1	1.5	3.7	10	16	1.3	2.3
BB1	2.6	4.7	1.8	2.8	13	18	1.2	0.0
BB2	3.5	8.3	1.2	6.3	7.0	10	1.3	0.0
BB3	0.7	3.0	0.9	2.3	8.0	18	1.9	1.3

Data analysis

To investigate effects of stream-crossing design on fish habitat, we applied generalized linear mixed models using the PROC GLIMMIX procedure in SAS version 9.4 (SAS Institute Inc., 2011) to test the hypothesis that substrate size did not differ according to stream-crossing design type (SS or BB) and location (upstream or downstream). We applied a double-nested study design approach with location and channel unit (pool or riffle) nested within the stream-crossing design type. The fixed factors for all models applied in this study were design type and location and a random effect was stream site for 12 samples (six SS samples, three upstream and three downstream; and six BB samples, three upstream and three downstream). We applied the PROC GLIMMIX procedure with contrast statements to

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pool and riffle particle size count data separately using a multinomial distribution for categorical data and cumulative logit link function at the $\alpha < 0.05$ significance level. The categorical counts were particle sizes within the 18 Wolman particle size classes, ranging from <2 mm (sand) to >2048 mm (very large boulder) (Wolman, 1954). Contrast statements were designed to test differences between upstream and downstream samples for all streams, upstream and downstream samples at SS streams, and upstream and downstream samples at BB streams.

To investigate effects of stream-crossing design on the local fish community, we also applied generalized linear mixed models to test the hypothesis that fish weight did not differ according to stream-crossing design type and location. For this analysis, we used a lognormal distribution for continuous data and identify link function at the $\alpha < 0.05$ significance level. Individual fish weight was used as the dependent variable in the model because there was sufficient power from the large number of fish per sample to characterize the variability of weights from each 50-m sample, regardless of species. We applied the Tukey adjusted LS-Means procedure to analyze the means of fish weight. Pearson's residual analysis associated with the linear mixed model of design type and location as fixed effects identified the BB3 site with only four large fish for the upstream sample as having a potential effect on the lognormal distribution best fit for the model. Although this upstream sample only included four fish, fish number was then included as a factor in the model to address the inequality of the number of fish per sample.

RESULTS

The mean bankfull width for 50-m reaches was greater for the upstream sample reaches compared to the downstream sample reaches for all SS and BB sample sites except for the SS3 site (Table III). The greater mean bankfull width upstream is equivalent to greater potential habitat upstream. The majority of mean particle sizes were in the coarse gravel (>16–64 mm) and cobble (>64–180 mm) size classes (Wolman, 1954). The riffle below the stream crossing at BB3 was the only site with a mean particle size in the fine gravel size class (4–6 mm) (Wolman, 1954). Substrate particle sizes were significantly greater upstream of the stream crossing when compared to downstream of the stream crossing at both SS and BB sites for riffles ($F = 55.7$, $p < 0.0001$) and pools ($F = 27.7$, $p < 0.0001$). For the substrate particle sample contrast analysis comparing three SS sites to three BB sites, upstream BB-site substrate particle sizes were significantly greater than upstream SS-site substrate particle sizes for both riffle samples ($F = 53.1$, $p < 0.0001$) and pool samples ($F = 13.7$, $p = 0.0002$) (Figure 3). Major bankfull flood events greater than the mean annual peak flow for 2005 to 2012 occurred at all sites since construction according to documented events at adjacent USGS gages. Specifically, at SS sites, two events occurred at the SS1 site, one event occurred at the SS2 site; and two events occurred at the SS3 site since construction. At BB sites, two events occurred at the BB1 site, two events occurred at the BB2 site; and two events occurred at the BB3 site since construction (Figure 4).

The most common fish species sampled across all sites were blacknose dace (*Rhinicthys atratulus*), brook stickleback (*Culaea inconstans*), brook trout (*Salvelinus fontinalis*), central mudminnow (*Umbra limi*), common shiner (*Luxilus cornutus*), creek chub (*Semotilus atromaculatus*), and hornyhead chub (*Nocomis biguttatus*). Other fish species that were sampled as a part of this study included: golden shiner (*Notemigonus crysoleucas*), finescale dace (*Phoxinus neogaeus*), spottail shiner (*Notropis hudsonius*), pumpkinseed (*Lepomis gibbosus*), johnny darter (*Etheostoma nigrum*), northern redbelly dace (*Phoxinus eos*), rainbow darter (*Etheostoma caeruleum*), mottled sculpin (*Cottus bairdi*), and white sucker (*Catostomus commersoni*). The mean number of fish species was equivalent upstream and downstream at all sites, and the mean number of fish per sample was the same upstream and downstream of BB sites. The mean number of fish per sample and total weight per sample was greater upstream in comparison to downstream at all SS sites, and the total weight per sample was less upstream in comparison to downstream at all BB sites (Table IV).

Table III. Mean bankfull (BF) widths (m) and number of mean BF widths for the upstream (US) and downstream (DS) 50-m reaches of three stream simulation (SS)-design and three bankfull and backwater (BB)-design sites. Values are reported as mean ± standard error

Site label	Mean US BF width (m)	Mean DS BF width (m)	# mean BF widths/50 m US	# mean BF widths/50 m DS
SS1	3.6 ± 0.4	3.5 ± 0.1	13.9 ± 1.7	14.5 ± 0.6
SS2	6.6 ± 1.6	3.3 ± 1.4	8.10 ± 1.9	9.00 ± 1.8
SS3	2.7 ± 0.4	3.1 ± 0.0	18.6 ± 2.7	16.0 ± 0.1
BB1	5.9 ± 0.1	3.8 ± 0.4	8.50 ± 0.1	13.3 ± 1.5
BB2	8.1 ± 0.6	4.9 ± 0.5	6.20 ± 0.4	10.3 ± 1.1
BB3	3.6 ± 0.8	1.7 ± 0.0	14.8 ± 3.3	28.7 ± 0.5

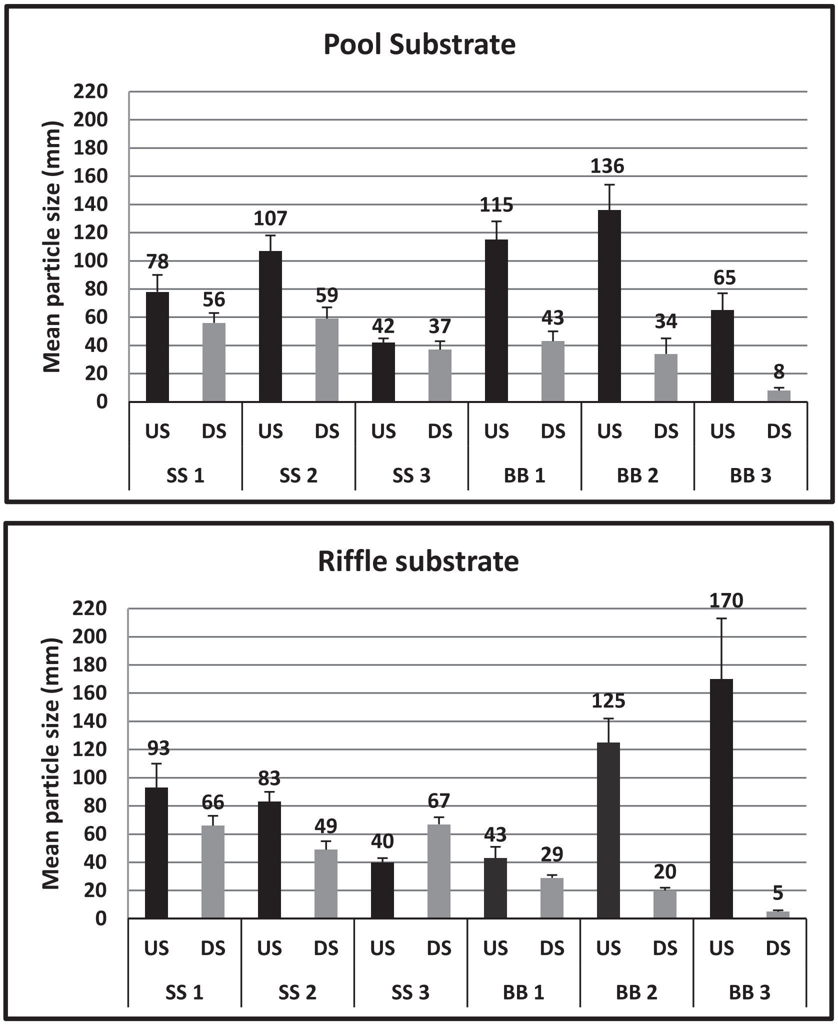

Figure 3. Riffle and pool mean particle sizes (mm) for upstream (US) and downstream (DS) locations at the three stream simulation (SS)- and three bankfull and backwater (BB)-design sites. Wolman size classes include sand (<2 mm), gravel (>2 to 64 mm), cobble (>64 mm to 256 mm), and boulder (>256 mm to 4096 mm)

There was sufficient species diversity at all sites to not have a biased effect of species dominance. There was also not a biased effect of individual weight according to species upstream and downstream at each stream site because of similarity of species present and sizes consistent with natural variability within the local fish population (Figure 5). However, chub species (creek chub and hornyhead chub) and brook trout composed large percentages of total weight at specific sites. For example, chub species represented 95% of the total weight (upstream and downstream sample combined) at the SS1 site; 72% of the total weight at the SS2 site; 92% of the total weight at the BB1 site; and 83% of the total weight at the BB2 site. Brook trout represented 76% of the total weight at the SS3 site and 96% of the total weight at the BB3 site. In addition, although not statistically significant, the chub species total weight was greater upstream of the stream crossing for all of the SS sites.

We found a statistically significant relationship between individual fish weight and location nested within design type ($F = 4.1$, $p < 0.02$). The relationship between fish weight and stream-crossing design type by itself was not significant ($F = 0.10$, $p < 0.75$). However, the LS Means procedure further clarified this relationship between fish weight, culvert design, and location to identify a statistically significant difference between the upstream and downstream individual fish weight samples for SS-design culverts (for three SS sites; $t = 2.8$, $p = 0.01$), with individual fish weights being significantly greater upstream of the culvert when compared to downstream of the culvert for all SS sites. In addition, individual fish weight upstream samples at SS sites were significantly greater than individual fish weight

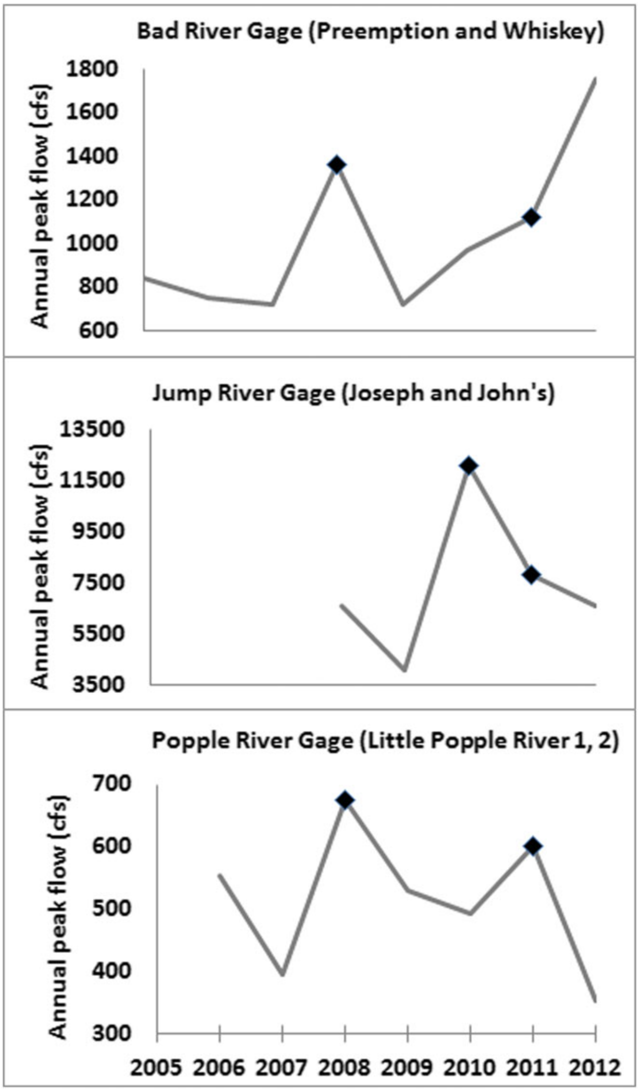

Figure 4. Annual peak flow (cfs) events that occurred at USGS gages adjacent to study sites. The black square symbols indicate events that were greater than the mean annual peak flow calculated for each gage using 2005 to 2012 data. Mean annual peak flow for the Bad River gage (adjacent to Preemption Creek, SS3 and Whiskey Creek, BB3 sites) in the top graph was 1104 cfs; mean annual peak flow for the Jump River gage (adjacent to Joseph Creek, SS1 and John's Creek, BB1 sites) in the center graph was 7332; and mean annual peak flow for the Popple River gage (adjacent to Little Popple River1, SS2 and Little Popple River2, BB2 sites) in the bottom graph was 539 cfs [Colour figure can be viewed at wileyonlinelibrary.com]

upstream samples at BB sites (for three upstream SS samples and three upstream BB samples; $t = 2.0$, $p = 0.04$).

DISCUSSION

This study was the first investigation comparing the effects of the SS and BB stream-crossing replacement design approaches on fish habitat structure (stream width and bed-sediment particle size) and fish weight. The results of this study suggested that the SS-design approach supported statistically greater individual fish weights upstream of SS-design sites in comparison to upstream of BB-design sites in first- to third-order streams that are ≤3% gradient. The results of this study also showed that BB-design sites had significantly larger substrate particle sizes upstream of the stream crossing when compared to upstream of the stream crossing at SS sites. In addition, this study illustrated the value of using individual fish weight as an indicator of biological success for stream-crossing designs.

Stream-crossing design and fish habitat

When stream-crossing structures are replaced, one of the goals is to restore processing of flow and sediment in relation to the natural stream channel. Construction associated with stream-crossing replacement can result in sediment accumulation downstream of the stream crossing, which can have a negative effect on the downstream fish habitat (Lachance and Dube, 2004). Although substrate particle size was not quantified before and after construction associated with this study, previous research has documented significantly more abundant <2mm fine sediment and significantly less abundant >5mm particle sizes downstream of the stream crossing during the first year post-construction. This increase in fine sediment and decrease in gravel and larger particle sizes can return to pre-construction amounts three years post-construction over time as flood flows move accumulated fine sediment downstream (Lachance *et al*., 2008).

The scouring capacity of flood flows within a stream will determine the size of the substrate particle that will move downstream, with the higher the capacity, the larger the substrate particle (Buffington *et al*., 2004). Because of the variability in flood flows in any given year, larger substrate particles may or may not have been transported downstream. Sites associated with this study were constructed from 2007 to 2010 for SS sites and 2005 to 2008 for BB sites and data was collected in 2012. The number of bankfull flood events greater than the mean annual peak flow since construction was two at all sites except the SS2 site that had one event since construction in 2010. These flood events were sufficient to move substrate through the stream crossing, but substrate particle sizes upstream of the stream crossing remained significantly greater at both SS and BB sites. More flood events over time would be necessary to achieve no significant difference between upstream and downstream substrate particle sizes.

We hypothesized that the substrate for fish associated with the SS design would be more continuous and diverse when compared to the BB design as a result of more effective transport of larger substrate particles downstream

Table IV. Total number of fish species, total number of fish individuals, and total weight per sample (g) upstream and downstream of stream simulation (SS)- and bankfull and backwater (BB)-design sites. Values are reported as mean ± standard error

	# species		# fish		Total weight (g)	
Site label	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
SS1	5	4	70	22	538.3	187.7
SS2	5	6	125	124	931.5	665.3
SS3	6	4	32	17	383.9	283.5
Mean ± SE	5 ± 0	5 ± 1	76 ± 27	54 ± 35	617.9 ± 163.0	378.8 ± 145.9
	# species		# fish		Total weight (g)	
Site label	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
BB1	4	4	27	29	202.1	268.4
BB2	6	8	131	109	669.1	864.1
BB3	1	3	4	25	120.4	181.0
Mean ± SE	4 ± 1	5 ± 2	54 ± 39	54 ± 27	330.5 ± 170.9	437.8 ± 214.6

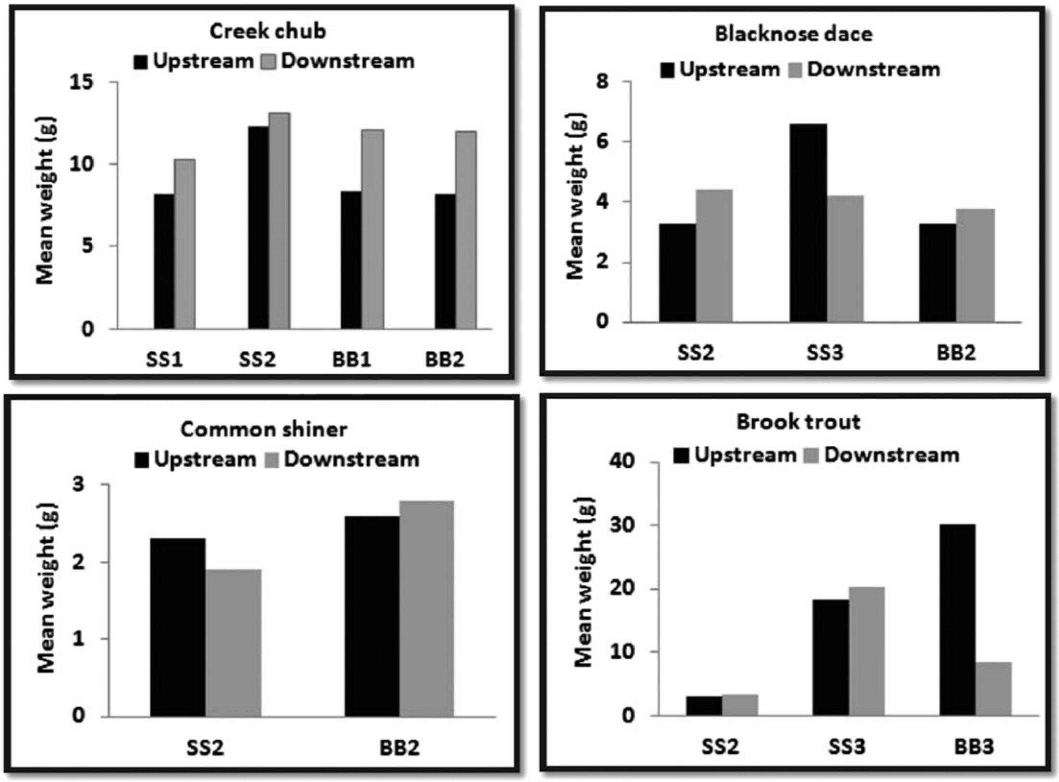

Figure 5. Mean individual weight per sample (g) for four fish species found upstream and downstream of stream simulation (SS)-design and bankfull and backwater (BB)-design sites. Individual weights for creek chub, blacknose dace, common shiner, and brook trout were comparable and consistent with natural variability for individuals within the local fish population

through the structure. Substrate particle sizes were significantly different upstream and downstream of SS sites and substrate was larger and more diverse at BB-design sites, which did not support our hypothesis. This result for BB sites was consistent with the design goal of only transporting sand and small material downstream and retaining larger substrate particles. Further quantification of substrate particle size change and transport over time from upstream, within, and downstream of the stream-crossing location for our study sites would help to compare effectiveness of SS and BB designs for sediment transport.

Substrate and fish community

Our hypotheses that there would be no significant difference in individual fish weight upstream and downstream of SS-design sites and a significant difference in individual fish weight upstream and downstream of BB-design sites were not supported by the results. Structural habitat data did not completely explain the larger fish weights for samples collected upstream of the stream crossing at SS sites when compared to upstream of BB sites. All streams in this study had similar broad valleys, low gradients, and sand or gravel dominant substrates, so there were no inherent differences in stream morphology (Savery *et al*., 2001). Substrate particle sizes for both pools and riffles were larger and included more diverse particle sizes in the medium to large cobble size classes at the BB sites when compared to the SS sites with the majority of substrate particles in the very coarse gravel to small cobble size classes. In addition, mean bankfull widths were generally less upstream of the SS sites when compared to upstream of the BB sites, which constitutes less habitat upstream of SS sites. Culvert slopes of sampled sites did not explain differences in fish weight either, as slopes $<3\%$ are not known to have significant effects on passage through the stream-crossing structure for fish species sampled in this study (Adams *et al*., 2000; Poplar-Jeffers *et al*., 2009).

The ability for individual fish in a population to establish and have its weight contribute to biomass at a site may be dependent on the presence of preferred substrate that is necessary for successful spawning and recruitment (Davis and Davis, 2011; Scarnecchia and Bergersen, 1987; Stoneman and Jones, 2000), which was illustrated by this study. Chub species are known to use large gravel (32–64 mm) and small cobble (64–90 mm) for building spawning mounds and to colonize areas where these preferred substrate sizes are present (Lobb and Orth, 1988; McManamay *et al*., 2010; Wolman, 1954), and chub species contributed up to 95% of the total weight per sample at study sites. We visually observed evidence of chub spawning activity during the 6/25/12 to 6/28/12 sampling period in the form of spawning mounds for all sites where chubs and preferred spawning substrates were present. Chub total weight per sample was greater upstream when compared to downstream for all SS-design sites, which contributed to greater fish weights upstream. Although no evidence of brook trout spawning activity was observed during this study, brook trout, which contributed up to 96% of total weight per sample at the BB3 site, are also known to include gravel and cobble substrate particles between 4 and 63 mm in their redd structures where they lay their eggs (Witzel and MacCrimmon, 1983).

Fish weight, presence, and abundance

This study offered an opportunity to investigate the use of fish weight as an indicator of stream-crossing design success. In this case, the analysis of the individual fish weight data from 12 samples at six sites had enough statistical power to identify statistically significant relationships between upstream and downstream reaches at SS sites and between SS and BB sites. Previous research to investigate effects of stream-crossing barriers on fish has documented effects on fish species presence and overall total fish abundance, regardless of species (Diebel *et al*., 2014; Nislow *et al*., 2011; Warren and Pardew, 1998). The use of fish species presence and fish abundance as indicators in this study would show little difference between the two stream-crossing designs because sample size was too low for enough statistical power to compare variability between sites. In addition, sample site reaches designed to effectively quantify number of species present in Wisconsin streams require areas 35 times the mean stream width (Simonson and Lyons, 1995). The 50-m reaches we sampled for this study ranged from 6.2 ± 0.4 mean bankfull widths at the Little Popple2 River, BB2 site to 28.7 ± 0.50 mean bankfull widths at the Whiskey Creek, BB3 site, which are not large enough sample reaches to effectively estimate number of species present. Species information for the sample was used to eliminate potential effects of species dominance by only one species per sample in a given stream site, which was not the case in this study.

Fish weight can be a useful indicator that reflects growth of the present individuals foraging within local habitat patches accessed from typical dispersal distances for sampled fish species (Johnston, 2000; Schlosser, 1982; Stoneman and Jones, 2000). For the sake of this analysis, we assumed that the majority of the fish individuals in our samples were using local habitats. Fish are less likely to move out of an area if they have access to suitable habitat (Albanese *et al*., 2004), and suitable habitat was present at all sites for all present fish species. The majority of fish individuals sampled in this study were small-bodied species that are not known to disperse far, other than the brook trout that is known to disperse up to 6.6 km (Flick and Webster, 1975). There still is a possibility that small percentages of small-bodied individuals may disperse beyond local sample reaches (Albanese *et al*., 2004), which may affect sampled fish weights in each sample. For example, individuals of the bluehead chub (*Nocomis leptocephalus*) are known to disperse up to 225 m (Skalski and Gilliam, 2000), and individuals of the blue shiner (*Cyprinella caerulea*) are known to disperse up to 332 meters (Johnston, 2000). The creek chub, which shows preference for upstream dispersal (Albanese *et al*., 2003; Nislow *et al*., 2011), was the most common species in our study. For the six sites sampled during this study, total chub species weight (creek and hornyhead chub together) was greater upstream of all three SS-design sites compared to downstream.

Further sampling at each of our study sites using sample reaches of 35 times the mean stream width upstream and downstream of each stream-crossing location using block nets could be used to further investigate use of fish species presence as an indicator of design success and the effect of fish dispersal on fish weights at a given site. Additionally, evidence of dispersal could be investigated using long-term pit tag data collected over longer distances upstream and downstream of stream-crossing locations, keeping in mind that the probability of recapture for marked fish can be extremely low (Gowan and Fausch, 1996).

CONCLUSIONS

This study identified statistically significant differences in substrate particle sizes upstream and downstream of both SS- and BB-design sites and larger substrate particles upstream of BB sites when compared to SS sites. These results suggest that design success criteria of no difference in mean substrate size should be applied in relation to timing of typical frequency of flood flows post-construction at a stream crossing. Quantifying substrate size differences upstream and downstream of SS- and BB-design sites over a longer period of years post-construction may offer an opportunity to observe no difference. It also appears that SS sites are transporting sediment particles downstream more effectively than BB sites. However, site location slopes were 1.5% and 1.8% at BB1 and BB3 and may have been too high for the BB-design approach.

At all sites, sampled substrate particle sizes did not include any particles within the <2mm fine sediment range that could negatively affect fish spawning success and were all within the gravel and cobble size ranges that are considered desirable for chub and trout spawning habitat (Lobb and Orth, 1988; Witzel and MacCrimmon, 1983). Therefore, from a substrate structural fish habitat standpoint for species present, both designs were successful. Significantly greater fish weights upstream of SS sites when compared to BB sites suggest that SS sites are having a more positive effect on upstream fish dispersal.

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