Minnesota Department of Natural Resources
Investigational Report 502, 2003

EVALUATION OF WALLEYE SPAWNING HABITAT IMPROVEMENT PROJECTS IN STREAMS[1]

Donna L. Dustin and Peter C. Jacobson

Minnesota Department of Natural Resources
Division of Fisheries
500 Layafette Road
St. Paul, MN 55155

Abstract – Improvement of walleye *Stizostedion vitreum* spawning habitat in streams is becoming increasingly common in Minnesota, but most projects have not been rigorously evaluated. A "U"-shaped riffle design was evaluated for stability, and for ability to increase walleye fry production. This design can be fit to the form and profile of many stream types, and should be stable over time. We built "U"-shaped riffles in two streams to improve walleye spawning habitat, and sampled newly hatched walleye fry in both streams for two years before and after riffle installation. Substrate samples were also collected to compare riffle versus non-riffle egg abundance. Cobble and gravel substrates have been maintained in the riffles over the three years since their construction, despite high sediment loads and flood events in both streams. Although fry catch rates did not increase substantially after adding riffles to the Pelican River, walleye were observed spawning on the riffles. Developing walleye eggs were found in the riffles, but not in unmodified reaches of the stream. In Ada Brook, more fry and fewer viable eggs were caught in drift nets downstream from the riffles than upstream. Riffles may trap and hold walleye eggs, preventing them from rolling and drifting downstream. The chance removal of beaver dams upstream from a study reach in the spring of 2001 caused a flood at the end of the walleye spawning season. The high discharge apparently attracted a late run of walleye, suggesting that beaver dam removal could be coordinated with the spawning season to increase stream discharge and attract greater numbers of fish.

---

[1] This project was funded in part by the Federal Aid in Sport Fish Restoration (Dingell-Johnson) Program. Completion Report, Study 631, D-J Project F-26-R Minnesota.

Introduction

Walleye *Stizostedion vitreum* are the most sought after sport fish in Minnesota and there is significant public interest in improving walleye populations and consequently, in spawning habitat improvement projects. A 1998 survey of Minnesota DNR Area Fisheries Managers found that two-thirds of walleye spawning habitat improvement projects were initiated, and at least partially funded, by lake associations or sportsman's groups (MN DNR, unpublished data). Artificial spawning reefs have been built for walleye in Minnesota lakes since the 1960s, and have been evaluated for biological and cost effectiveness (Newburg 1975). Stream projects have become more popular recently with 4 projects completed prior to 1990, and at least 20 completed since 1990. A variety of techniques have been used to improve spawning habitat in streams, but evaluation has been sporadic or absent, and there is little data available to support objective recommendations for future projects.

Walleye need clean rocky substrate with well oxygenated water for optimal spawning (McMahon *et al.* 1984). They are broadcast spawners, releasing gametes in the water column and letting the fertilized eggs settle to the bottom where they fall into cracks between the rocks for protection (Kerr *et al.* 1997). Walleye spawning has also been documented over sand, muck, and vegetation. Egg survival may be good when eggs are protected by living vegetation, particularly *Chara* spp. in lakes, but eggs that come to rest on sand, silt, or muck experience high mortality (Johnson 1961; Priegel 1970). In small streams in Minnesota, there is little plant growth during the late April spawning season, and gravel/cobble substrate is required to protect walleye eggs. Sedimentation caused by development, agriculture, and forestry in the watershed has buried the rocky areas in many streams (Waters 1995). Expanding beaver populations have also been implicated in walleye spawning habitat destruction though damming of spawning streams.

The goal of this study was to design low maintenance stream walleye habitat improvement projects, and to evaluate the effectiveness of these projects for increasing walleye reproductive success.

Methods

Study sites. Potential study streams were identified through discussions with area fisheries staff and field inspections. Promising streams were tributaries to lakes with known walleye spawning runs. In 1999, we used night spotlighting to confirm that adult walleye came to the streams during the spawning season, and egg deposition was verified by kick net sampling of the substrate. Potential streams were examined for substrate type and availability of continuous reaches for habitat work. We selected two streams with confirmed spawning runs, sufficiently long reaches for sampling, and poor spawning habitat quality (Table 1).

The Pelican River (H-26-81-12) in the city of Detroit Lakes is a tributary to Detroit Lake (DOW 03-0381), and contains excellent walleye spawning habitat south of U.S. Highway 10. Immediately north of U.S. 10, the stream is a channelized low gradient ditch with shifting sand and muck substrate. The study reach is in this channelized section. The Rosgen classification for this reach is B5c, which is a moderately entrenched, moderate sinuosity, low slope, sand bed stream with a moderate bankfull width to bankfull depth ratio (Rosgen 1996).

Ada Brook is a tributary to Ada Lake (DOW 11-0250). The study reach is located in T139 R29 S22, approximately 10 miles east of Backus. The stream has a large permanent beaver dam 1 km upstream from the lake that acts as a fish barrier and defines the upstream end of the study reach. Beaver periodically build new dams throughout the reach all the

Table 1. Physical characteristics of the study stream reaches prior to habitat improvement.

	Pelican River	Ada Brook
Bankfull width (m)	12.7	5.1
Bankfull cross-sectional area (m^2)	4.78	2.98
Mean depth at bankfull (m)	0.91	0.87
Bankfull width / depth ratio	14.0	5.8
Floodprone area width (m)	22.8	41.8
Entrenchment ratio	1.8	8.2
Slope of reach – thalweg	0.0005	0.004
Water surface slope - bankfull	0.001	0.002
Sinuosity	1.26	1.30
Channel material	95% sand & silt, 5% gravel	77% sand, 21% gravel, 2% cobble

way to the lake, and in some areas there are multiple channels where the stream has cut a new path around a dam. The flood plain is wet and often holds standing water. Substrate is predominately sand with some gravel and cobble, and the banks are heavily vegetated with grasses, sedges and willows. The Rosgen classification for the reach is closest to E5, although the multiple channels due to beaver dams do not fit this stream type and are an indication of an unstable system.

Experimental design. Each stream was monitored to confirm spawning activity from 1999 to 2003. Fish were observed during the daytime and at night using a spotlight. The walleye's reflective eyes are conspicuous under the spotlight and clearly distinguish them from white sucker *Catostomus commersoni*, which use similar spawning habitat and also spawned in both streams each spring. The length of both study reaches were observed at least once during each spawning season, and in 2003 we recorded the location and number of walleye on one night at the peak of the run. In Ada Brook, we removed beaver dams each spring from the head of the study reach to the lake, ensuring that access would not be blocked. Each year walleye eggs were collected periodically in both streams to monitor egg development. Drift netting was initiated when freshly collected eggs hatched within a few hours of capture.

We sampled newly hatched walleye at two transects in each stream, one upstream of the habitat improvement area and one downstream, for two years before and after the habitat was modified. Drifting walleye fry were captured using 30x40 cm (frame opening), 750 µm mesh, drift nets, which were 150 cm long with a collection jar at the cod end. Nets were held in place with stakes pounded into the streambed. In the Pelican River, the two transects were 330 m apart and three nets were set in each transect. In Ada Brook, the study reach was 160 m long and two nets were set per transect. Each transect was located in a straight reach, and we set nets in random locations across that part of the transect having a velocity greater than 0.20 m/s. This is slightly lower than the minimum velocity of 0.25 m/s recommended by Franzin and Harbicht (1992) for sampling drifting walleye fry, but it is still almost three times the critical velocity of 0.07 m/s at which newly hatched walleye drift uncontrolled (Houde 1969). Velocity in the mouth of each net was measured initially and just prior to emptying each net, and the average of the two measurements was used to calculate catch per m^3 filtered. Nets were set in the same location in each transect each night within a year, but new net locations were selected each year.

Walleye fry drift primarily at night, with peak drift occurring shortly after sunset (Corbett and Powles 1986; Mitro and Parrish 1997). We sampled for approximately 2 hours each evening between 8:30 PM and 12 AM, which permitted sampling of peak walleye drift from immediately upstream. Each net was fished for no more than one hour, and was immediately replaced with a spare net before emptying so that there was virtually no gap in sampling when the nets were emptied. We sampled each stream on alternate nights until live, eyed eggs could no longer be found. Drift samples were collected on 2 nights in 1999 and 2000, and 3 nights in 2001 and 2002. The contents of each net were immediately fixed in a 7% Formalin solution. Samples were sorted in the laboratory under 2x magnification and all fish were removed, identified to species, and counted. A vital stain (phyloxine B or rose bengal) was used on fry samples in 2001 and 2002 to expedite sorting, and a random group of 5 samples each from 1999 and 2000 were re-picked after staining for quality assurance.

Fry catch per unit effort (CPUE), number/m^3, was analyzed for each stream separately, using a nested, mixed model analysis of variance (ANOVA; Underwood 1981). We added one to all data to enable $\log_e$ transformation of zero catches, and transformed using $\log_e(\mathrm{CPUE}+1)$ to stabilize variances. Sums of squares for the fully orthogonal model were calculated using the data analysis software, R (Ihaka and Gentleman 1996). Mean squares were calculated by adding up the appropriate sums of squares, and *F*-ratios were constructed using the appropriate mean squares and degrees of freedom for each term. The model equation was:

$$Catch_{ijklr} = \mu + A_i + B_j + AB_{ij} + C(B)_{k(j)} + AC(B)_{ik(j)} + e_{r(ijkl)}$$

The model terms A (Transect) and B (Treatment) are fixed effects. The treatment consisted of adding riffles after two years (four days) of sampling, so the two levels of B are Before and After building riffles. Since the treatment was applied in time, each Day (C) sampled can only occur once, either Before or After Treatment. Therefore, Day is nested within each Treatment. Because this is a nested, mixed model, the correct error term for constructing *F*-ratios for the terms A, B, and AB is not the residual error. The appropriate denominator for testing Transect (A) and Transect*Treatment (AB) is the Transect*Day(Treatment) mean square (AC(B)), and the appropriate denominator for testing Treatment (B) is the Day(Treatment) mean square (C(B)). A term for Year was not included in the model, because preliminary analysis indicated that the Day term adequately accounted for the different samples taken within Before and After. The null hypothesis for this experiment was that the riffles had no affect on walleye reproductive success, and thus the catch in the downstream transect (T2) would not change relative to the upstream transect (T1). The alternative hypothesis was that catch in T2 would increase relative to T1, in other words there would be a significant AB interaction.

Significant interactions between Transect and Treatment were examined by splitting the data into days Before and After habitat improvement, and performing 2-way ANOVAs with Day and Transect as factors on $\log_e(\mathrm{CPUE}+1)$. When a significant interaction between Transect and Day was found, inspection of the interaction plot revealed a pattern of difference between transects on three of the four After sample days. We put the first five days sampled in one set, and the last three days sampled in another and performed two-way ANOVAs as described above. Since this was an unanticipated post hoc examination, we maintained an overall rejection level of $\alpha = 0.10$ by adjusting the rejection level for each test to $\alpha = 0.05$. In both cases, this procedure removed the Treatment factor so that we could concentrate on the effects of Transect and Day.

In a nested analysis, unbalanced data has a greater impact on *F*-ratios than in an orthogonal model (Underwood 1997). Since there were nights with very low (or no) catch in 2001 and 2002, and since the overall variation in catch was not of interest, we dropped the day with the lowest catch from the analyses for these two years in order to have a balanced analysis.

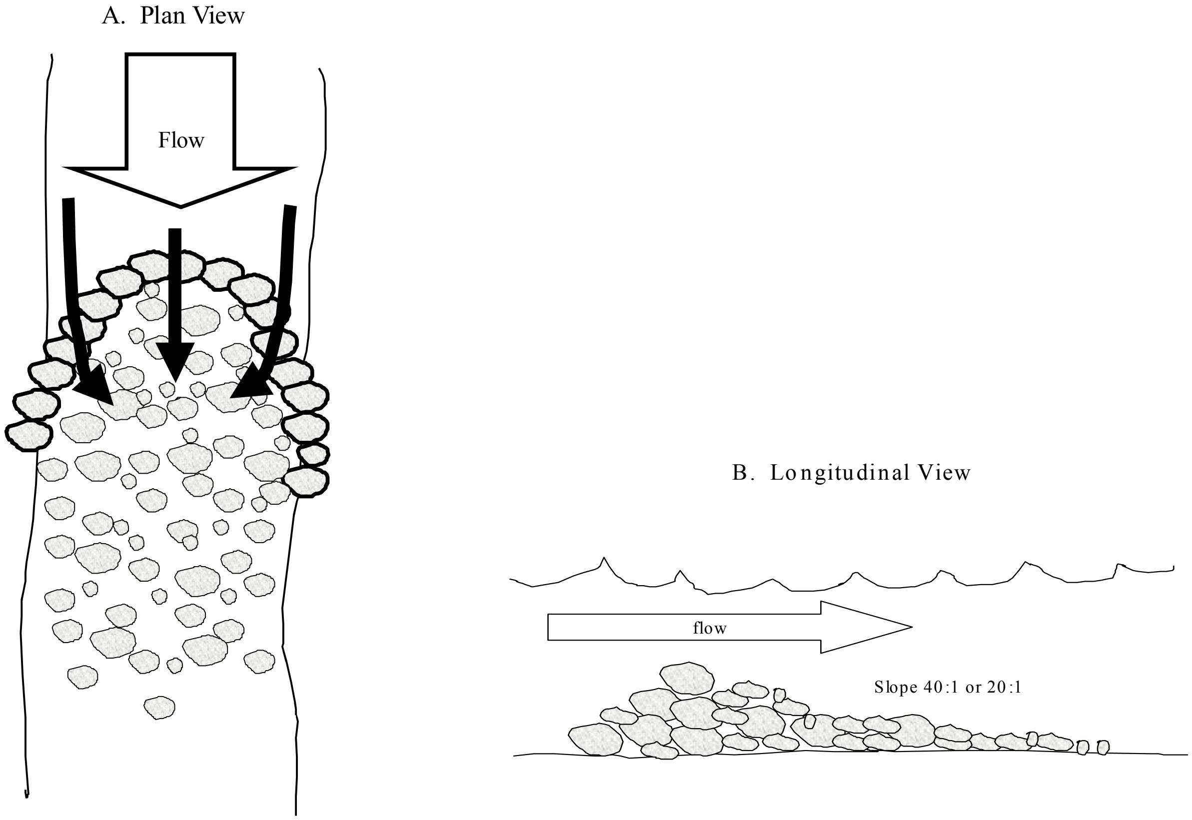
Walleye eggs were common in drift samples in Ada Brook and their abundance appeared to vary between transects. We followed the same statistical procedures described above on walleye egg CPUE for Ada Brook. We examined the eggs under a 10X-dissecting microscope and categorized them as alive or dead. Live eggs were translucent and the yolk and embryo were visible and intact. Eggs with broken yolks, but no other signs of decomposition were counted as alive. Dead eggs were opaque, or if translucent the embryo had clearly begun to decompose.

On 1 May 2003, kick samples were taken of the substrate throughout the study reach in the Pelican River to document the location and relative abundance of fish eggs just after walleye spawning had concluded. The kick net consisted of 1 m^2 of 1 mm mesh screening attached to two poles. The net poles were placed firmly on the streambed and the substrate was disturbed by kicking upstream of the net. The current then pushed the disturbed material onto the net. Each riffle was sampled in 5 random locations 0.2 m or deeper. Nine samples were also taken in random non-riffle locations with sand substrate, where the depth was less than 0.6 m. Kick samples consisted of five downstream and five upstream kicks, disturbing the substrate immediately upstream of the kick net. Approximately 0.16 m^2 of substrate was disturbed.

Egg counts were analyzed in R, using Welch's two-sample, unpaired t-test for unequal variances on live egg counts to compare riffle versus non-riffle egg abundance (Sokal and Rohlf 1981). Riffle egg counts were then analyzed separately to examine apparent differences between the three riffles using ANOVA and Tukey's Honest Significant Difference method (Yandell 1997) on $\log_e$ transformed data. Walleye egg counts from riffles were analyzed separately because heteroscedasticity could be reduced by $\log_e$ transformation only if the non-riffle egg counts were removed. The significance level for rejecting the null hypothesis for all statistical tests was $\alpha = 0.10$, unless otherwise noted.

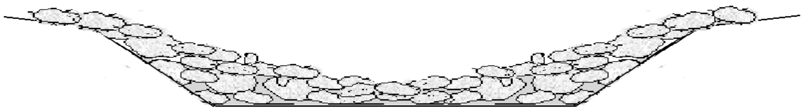
Habitat improvement. Fourteen streams in Minnesota containing habitat improvement projects were visited and evaluated (Appendix I). Many of these projects consisted of lining the stream bed with rock, an approach that was successful in many streams, but prone to failure in others, especially streams with high sediment loads. A "U" shaped riffle design was selected for use in this study because it complements the hydrology and geomorphology of streams and, if located and built properly, it should remain stable and free of sediment over time in a variety of stream types (Figure 1). A similar, design has been used effectively for walleye spawning habitat projects in two of the Minnesota projects as well as in Canada (Newbury and Gaboury 1993). For each stream, the channel cross sectional area at bankfull was calculated, the maximum depth at bankfull, and the estimated bankfull discharge were calculated. The riffles were designed to have either 40:1 or 20:1 slope. The tractive force at bankfull flow was calculated to determine the minimum rock size needed in each stream. Tractive force is a measure of shear stress on the streambed, and is a factor of the depth of flow and the slope of the water surface (Newbury and Gaboury 1993). The rock for the riffle structure in each stream was chosen for stability at bankfull flow. In addition, crushed rock (3-8 cm) was spread on top of each riffle, since spawning walleye prefer large gravel substrates (Aadland *et al.* 1991).

In the Pelican River, 25-38 cm diameter rock formed the "U" shaped crest of the three riffles, and 5-15 cm rock filled the rest of the riffle base. Heavy equipment placed the rock in the stream and shaped the riffles. Two riffles were 18 m long with a 40:1 slope, and the third was 12 m long with a 20:1 slope. The crest of each riffle raised the streambed by 45 cm, and the rock extended beyond the bankfull elevation on each side. The project, completed in September 2000, used approximately 300 cubic yards of rock at a cost of $5,000 and took 2.5 days.



A. Plan View

B. Longitudinal View



C. Riffle Crest Cross Section

Figure 1. Schematic of “U” shaped riffles showing: A. Plan view with the bottom of the “U” facing upstream, which directs the flow towards the center of the channel (arrows) and protects the banks from erosion; B. The new stream slope in the longitudinal view, vertical scale is inflated; C. Rocks forming the new channel cross section at the riffle crest.

The boggy nature of the stream banks and flood plain at Ada Brook precluded the use of heavy equipment for riffle construction. Rock of similar sizes to the Pelican River project was trucked to the site, moved to the stream bank with a skid steer, and floated down to the riffle sites in a canoe, where the riffles were built by hand. The crest of each of the two riffles raised the streambed by 15 cm and the slope was 40:1, which resulted in a length of 4.6 m. In addition to the two riffles, a channel constrictor was constructed which was expected to scour a pool that would provide cover for adult fish and might produce some sorting of gravels. It was built of 25-38 cm rock and consisted of a rock base to prevent downcutting and rock walls about 30 cm high with a 50 cm notch in the center. Construction took 2 days in August 2000. The Ada Brook project used approximately 30 cubic yards of rock at a cost of $500.

The study reaches were surveyed using a laser level and standard survey methods before and after the riffles were built (Rosgen 1996). We surveyed cross sections in various locations along each reach, including at the crest of each riffle, at the middle of each riffle, and immediately downstream from each riffle. The longitudinal profile of the study reaches was also surveyed. Sketch plans with descriptive notes were also made of each riffle at various times. We noted the embeddedness of cobble and gravel on the sketches, as this reflects the quality of the substrate for egg retention and incubation. Embeddedness is a descriptive term that relates the pavement material, on the surface of the streambed, to the subpavement material, which surrounds or underlies the surface layer. It was categorized using a scale of 1 to 5, where 1 corresponds to rock or cobble fully embedded in the subpavement material (usually sand) with just the surface of the cobble or rock showing. A score of 5 would indicate rock or cobble being the only material visible and no sand filling the interstitial spaces at least as far down as the top layer (Bain 1999).

Results

Physical evaluation. In the Pelican River, the stability of the newly constructed riffles was tested in April 2001 when flood flows occurred for about 10 days. The river level was approximately 30 cm above bankfull elevation during this time. The riffles lost some of the crushed rock that had been placed on them, particularly in the center of the stream, and some shifting of the larger rock occurred, resulting in a two-stepped profile. Figure 2 shows the thalweg elevation before and after the riffles were constructed. A pool developed downstream from each riffle. The survey data from the riffles showed that Riffle 1 had a narrower channel and smaller cross-sectional area than Riffle 3 (Figure 3).

The riffles have maintained their form and structure, and the rock has remained generally clean. About 10% of the wetted area of the Pelican River riffles had an embeddedness rating of 2 or 3 in April 2003. These areas were primarily near the banks and the remaining area was rated 4 or 5. Sketches of the riffle substrates over time indicate a dynamic system where sand and silt are alternately deposited and washed away in various parts of the riffles as the water rises and falls. While there was significant macrophyte growth in the riffles each summer, by spring the rocks were clean with the exception of some periphyton.

Ada Brook also experienced a flood in 2001, due to upstream beaver dam demolition unrelated to this project. Water flowed at a depth of approximately 0.3 meters over the flood plain on May 3 and discharge was conservatively estimated at 0.92 m/s, which is 2.8 times the bankfull discharge. Figure 2 shows the pools that formed below each riffle. These riffles also developed a two-stepped profile, but it was not evident in the survey data. There was little apparent loss of crushed rock from the riffle surfaces. This stream channel is not embedded and is well connected to its flood plain, so the high water

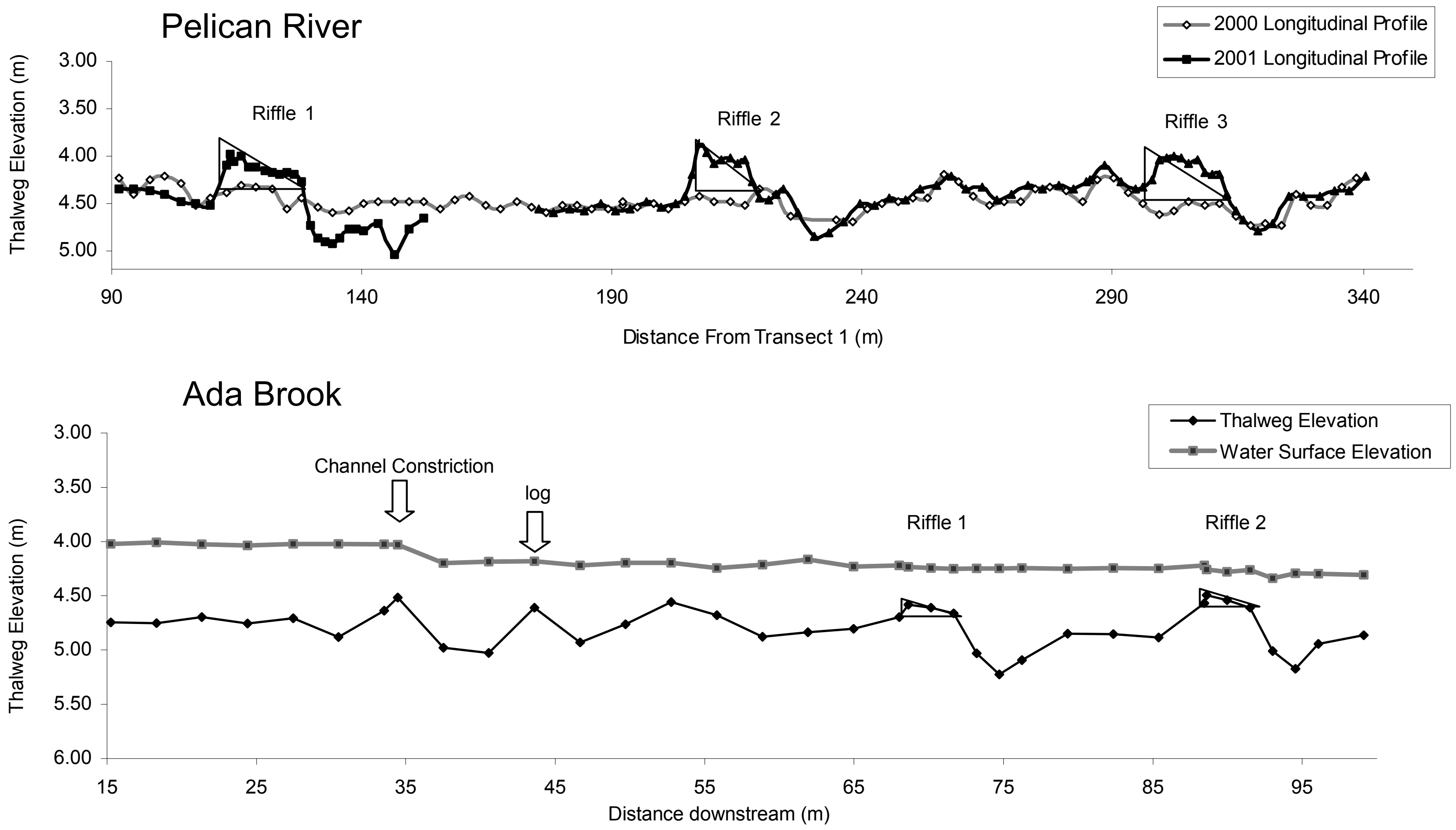


Figure 2. Longitudinal profile with thalweg elevations for: Pelican River in 2000, prior to riffle construction and in 2001, after construction; Ada Brook thalweg and water surface elevations in 2001, after construction of two riffles and one channel constrictor. Survey data collected prior to riffle construction were spaced too far apart to illustrate changes in the streambed and are not shown. Triangles denote location of riffles as planned.

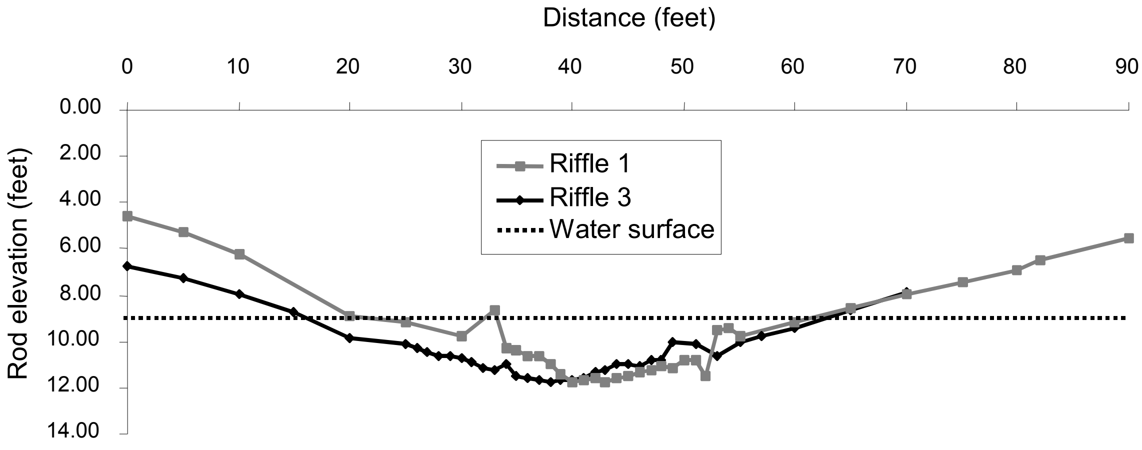


Figure 3. Pelican River: Cross-section of Riffle 1 and Riffle 3 at midpoint of riffles in August 2001. Rod elevation was adjusted for water surface elevation so that riffles can be compared.

dispersed over the flood plain rather than being confined to the channel, as it was in the more entrenched Pelican River.

Two weeks after construction the riffles had embeddedness ratings of 2-3 over about 85% of the rock area. Two weeks after that the sand had vanished and embeddedness was rated at 4-5 on the riffles. During the spawning seasons of 2001 and 2002, substrate conditions on the riffles were good, with embeddedness ratings remaining at 4-5. In April 2003, 90% of both riffles had embeddedness scores of 2 or 3. At this time, the discharge was so low that portions of the stream downstream from the riffles were impassable to fish and there was no spawning run. By June 19, discharge had increased and the two riffles were clean again, with embeddedness scores of 4 or 5 over 75% of one and 90% of the other.

The channel constrictor was not damaged in the 2001 flood, but it proved to be irresistible to the local beaver population. The structure was dammed every year after construction and Figure 2 shows the increase in water surface elevation behind the dam. The crest of Riffle 2 was also the site of a small beaver dam in 2001, but it was not rebuilt after removal.

Walleye reproduction. Walleye were observed on and around the spawning riffles in the Pelican River in each of the three years since their construction. Two walleye were spotted on Riffle 2, and 7 walleye eggs were collected on the riffles using a kick net on 30 April 2001. Egg sampling in the study reach was done sparingly in 2001 and 2002, since we did not want to impact subsequent fry sampling. In 2002 and 2003, walleye were observed on all three riffles. On the night of 26 April 2003, 24 walleye were counted on Riffle 1, most of them holding their position at or just upstream from the riffle crest. One walleye was seen on Riffle 2 and two were seen on Riffle 3. No walleye were seen in the unmodified portions of the reach. White suckers were observed on all three riffles and we witnessed both species actively spawning.

Kick samples were collected on 1 May 2003 and live walleye eggs were found exclusively on the riffles (Figure 4). The mean walleye egg abundance was 7 live eggs per kick sample on riffles (95% CI 3-12), and 0 (range=0) on sand. The two means were significantly different (Welch's two sample t-test for unequal variance, t=3.3621, df=20, p=0.003). The live walleye egg count was highest on Riffle 1, which was also the riffle

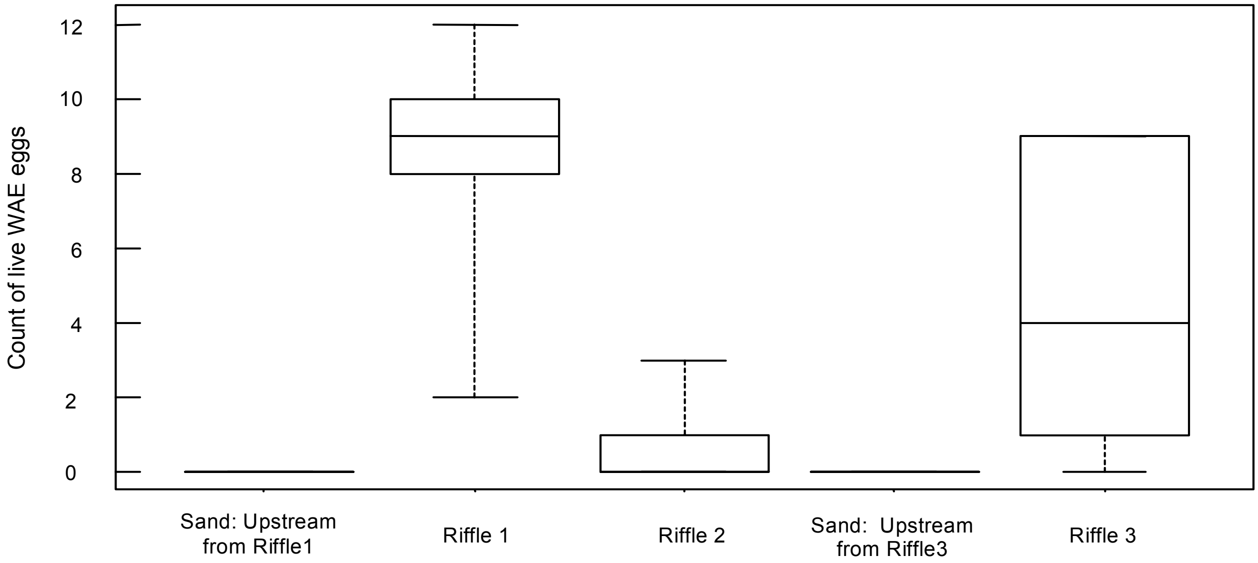


Figure 4. Box and whiskers plots (median, quartiles, range) for total live walleye egg counts from 1 May 2003 kick samples in the Pelican River, on riffles and in unmodified sections of the Pelican River study reach.

where the most walleye were observed during night spotlighting. ANOVA confirmed that there were significant differences between riffles (*F*=16.911, df=2/28, p<0.001), and Tukey's Honest Significant Difference test indicated that Riffle 1 was significantly different from Riffles 2 and 3 (90% confidence level) while Riffles 2 and 3 did not differ significantly from each other.

Walleye fry were caught in the Pelican River each year, with a median catch rate of 27 walleye fry/m^3 (WAE/m^3). There was no consistent pattern of catch rates between the upstream and downstream transects, and there were no apparent changes after the riffles were built (Figure 5). ANOVA on the log$_e$-transformed data confirmed that there was no significant Transect*Treatment interaction (*F*=0.21, df=1/6, p=0.662).

In Ada Brook, walleye were observed on the riffles as well as in other sections of the study reach. There was a narrow side channel upstream from the study reach, which skirted a beaver dam, that was used by walleye and white sucker in 1999-2002. This channel was scoured during the spring flood in 2001, leaving areas of fine gravel, which appeared to be used heavily for spawning in 2001 and 2002. Numerous eggs were collected in this reach during egg monitoring in 2002. Unfortunately, intensive egg sampling planned for 2003 was not possible due to low stream flows that prevented fish from accessing the stream during the spawning season.

Live walleye eggs were more common in the drift samples collected at Ada Brook after riffle construction (Figure 6b). The ANOVA of log$_e$(CPUE+1) live egg counts revealed a significant Transect* Treatment interaction, indicating that the catch rate of live eggs in one transect changed relative to the other transect after the habitat work was done (*F*=10.115, df=1/6, p=0.019). After splitting the data to examine the interaction, there were no significant effects in the Before data; however, After adding riffles, the Transect*Day(Treatment) interaction was significant, indicating that the difference between the two transects varied over the days sampled (Table 2). Closer

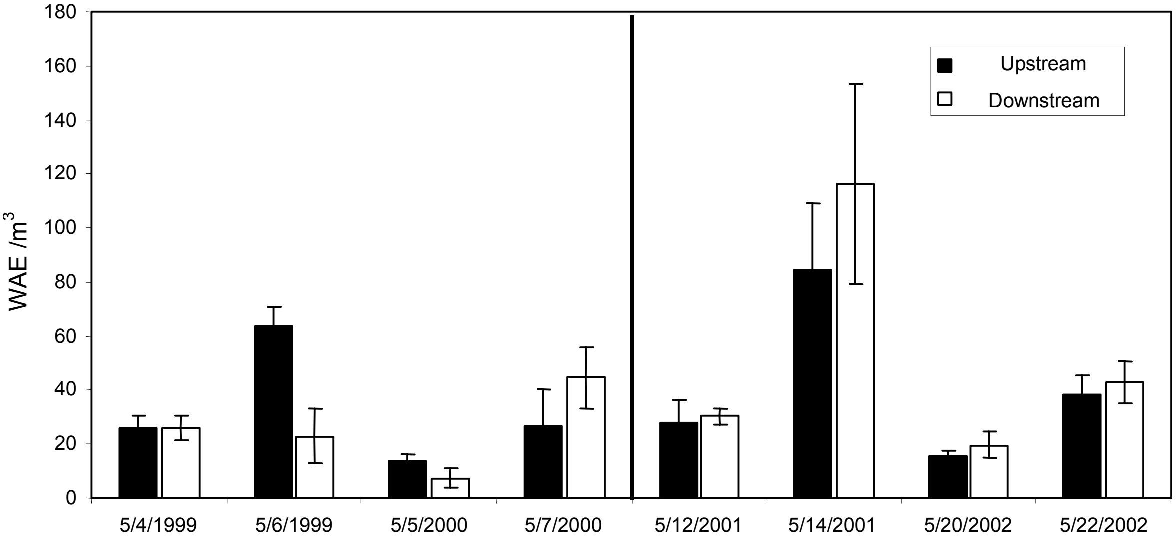


Figure 5. Pelican River mean walleye fry CPUE (number/m^3) from drift nets for each day sampled. Error bars indicate plus or minus one standard error. The vertical line indicates construction of artificial riffles in the stream.

Table 2. ANOVA for Ada Brook live walleye eggs ($\log_e$(CPUE+1)). Data was split into Before and After habitat work to isolate Transect and Day from Treatment.

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*	*p*
Transect	2.286	1	2.286	1.737	0.224
Day (Before: 1-4 only)	8.963	3	2.988	2.271	0.157
Transect*Day	1.599	3	0.533	0.405	0.754
residual	10.525	8	1.316		
Transect	4.995	1	4.995	60.141	<0.001
Day (After: 5-8 only)	50.101	3	16.700	201.07	<0.001
Transect*Day	2.548	3	0.849	10.225	0.004*
residual	0.664	8	0.083		

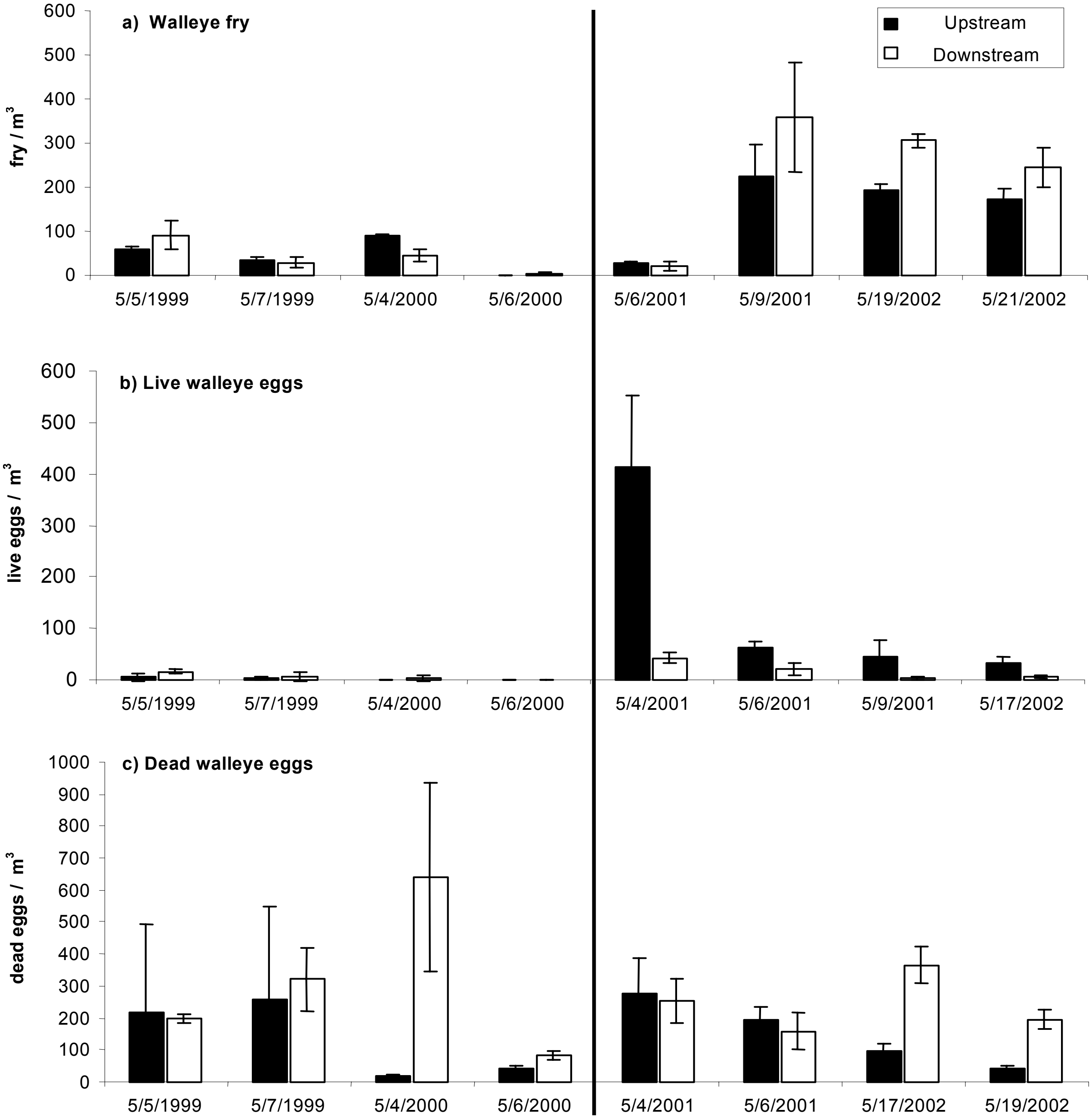


Figure 6. Ada Brook mean drift net CPUE (number/m^3) with standard error for: a) walleye fry, b) live walleye eggs, and c) dead walleye eggs for each day sampled. The vertical line indicates the addition of riffles to the stream.

examination of this interaction showed that upstream transect always had a higher CPUE of live walleye eggs than the downstream transect, although the magnitude of that difference varied, accounting for the significant interaction.

Dead eggs were also common in the drift samples, but there was no obvious pattern that could be attributed to the habitat work. (Figure 6c). The ANOVA on dead eggs did indicate a significant Transect*Day(Treatment) interaction (*F*=2.435, df=6/16, p=0.073). Further examination of this interaction by plotting dead egg CPUE by Transect over all eight days sampled indicated no consistent relationship between the two factors.

The fry catch rate in Ada Brook was higher after the riffles were built, but CPUE increased in both transects (Figure 6a). ANOVA on the $\log_e$ transformed data failed to show the significant Transect*Treatment interaction, which would have resulted from a clear treatment effect. There was however, a significant Transect*Day(Treatment) interaction (*F*=8.771, df=6/16, p<0.001). Examination of this interaction indicated a consistently higher catch rate in the downstream transect on Days 6-8 and a low CPUE in both transects on Day 5. After splitting the data, we found a significant Transect effect for the last 3 days (*F*=8.4160, df=1/6, p=0.027) and a significant Transect*Day interaction for the first 5 days (*F*=10.413, df=1/6, p=0.001). The difference between transects varied between days over the first five days sampled, but on the last three days CPUE was consistently higher in the downstream transect.

Discussion

Spawning habitat in streams may be more likely to attract walleye in stocked lakes in Minnesota. Walleye have heritable preferences for spawning habitat type (lotic versus lentic) and Jennings et al. (1996) concluded that the reproductive success of stocked walleye might depend on the availability of spawning habitat compatible with that stock's genetically based preference. All of the walleye stocked in Minnesota lakes are produced using gametes collected from river spawning fish, and in many stocked lakes with inlet streams the flowing water attracts walleye during the spring spawning season.

Walleye spawning on riffles. It was clear that walleye used the artificial riffles for spawning, both from observations of fish during the spawning season, and from the relative abundance of eggs on and off of the riffles. In the Pelican River in 2003, the fish used Riffle 1 more than the similarly constructed Riffle 3. The favored riffle had a smaller channel width and cross-sectional area, creating deeper water over most of the area than in the wider riffle with the same slope. Knowledge of typical spring discharge should be used when designing riffles, so that the design will optimize spawning area in most years. Despite the evidence of riffle use in the Pelican River, there was no measurable increase in fry drift downstream from the riffles after their construction.

In Ada Brook, there was evidence of increased walleye production after addition of riffles and it appears that the riffles, functioned by trapping and holding incubating eggs. Fry CPUE was higher below the riffle reach, after riffles were built, than upstream for three of the four days sampled. Conversely, live egg catch was consistently higher upstream from the riffles after they were built than downstream. Drifting eggs, although alive when caught, are vulnerable to physical damage and predation, and are unlikely to stay alive for long. It is plausible that the fine gravel and sand substrate used by fish in the unmodified, upstream reach of Ada Brook did not have sufficient interstitial spaces to prevent eggs from drifting, while the rocky, riffle areas held walleye eggs. Newbury and Gaboury (1993) had similar findings in Mink Creek, Manitoba, where egg drift was 1.5 times higher below a channelized section of stream, with sand and fine gravel substrate, than downstream from a series of constructed boulder and cobble riffles. The riffles appeared to trap and retain drifting eggs entering the reach as well as holding eggs that were deposited there by spawning fish. It appears that survival of walleye eggs was higher on the constructed riffles than on unmodified substrates which led to higher fry density downstream from the riffles than upstream. However, live eggs were rare in drift samples from both transects before the riffles were built, so there is little data available to compare egg drift before and after riffle construction.

We did not collect enough data on walleye production to allow a cost benefit analysis of the habitat projects, however, the material costs were fairly modest. It is likely that such projects in small streams can be highly productive in some years, but probably not in most years. The variability of spring flows are much more critical in small streams than larger rivers, as demonstrated by the lack of a spawning run in Ada Brook during the dry spring of 2003. Combined with the vagaries of the weather, it may be that such streams rarely experience the right conditions for producing large numbers of walleye. However, it is also true that in the absence of suitable spawning habitat, such streams would never produce many fish.

The "U" shaped riffle design appears stable and self-cleaning, even in streams with high sediment loads. Riffles can be adapted to different stream types and sizes, and provide habitat that is used by walleye for spawning. While it is difficult to assess cost-effectiveness, they are likely a worthwhile project in certain cases. It is unlikely that spawning riffles will effectively replace stocking in lakes that have historically lacked natural reproduction. However, it is possible that natural reproduction can be enhanced in many streams, maybe substantially in some years.

Riffle stability. The riffles installed for this study have been structurally stable and self-cleaning over the three years since construction. The Pelican River riffles maintained clean, rocky spawning habitat for all three years since construction. In Ada Brook, the riffles twice became somewhat embedded with sand, which was subsequently flushed. Similar projects in Minnesota have shown the same pattern of sand deposition and removal as water levels fluctuate. In contrast, two sites with rock-lined channels have been covered with sand and have not shown a tendency to self-clean (Appendix I). If habitat projects are to be built in highly unstable streams, grade control, which can be accomplished with riffles, should be a companion goal of the project to ensure long-term stability (Newbury and Gaboury 1993).

Beaver control issues should be considered before undertaking spawning habitat improvements. Both study streams had beaver activity, but it was more pervasive in Ada Brook, where a riffle crest was once used to form the base of a dam. The beaver did follow the "U" shape as it built the dam, so rather than widening the channel like a typical beaver dam, the overflow was directed toward the center of the stream. While the inverted shape of the dam was a plus, beaver dams do not facilitate walleye spawning and dam removal may be an ongoing maintenance concern for some projects.

Beaver dam removal should be coordinated with walleye spawning to enhance the size of the spawning run in a given year. In 2001, a large beaver dam was removed from Ada Brook with dynamite, upstream from the study reach, resulting in significant flooding. There was a late surge of walleye spawning upon initiation of flooding, evident from the undeveloped live eggs caught in early drift samples that year, and also noted by local residents who observed the biggest walleye run in recent memory in 2001. Water velocity is an important factor in the initiation of walleye spawning (Kerr et al. 1997), and in the case of small streams like Ada Brook it is likely that low flows do not attract large numbers of fish. Interestingly, the 2002 fry CPUE was also high, relative to 1999 and 2000. Adult walleye tend to return to the same spawning sites (Crowe 1962; Olson and Scidmore 1962; Olson *et al.* 1978), and it is possible that, having found the stream in 2001, more fish returned in 2002. It is also possible that we missed the peak fry hatch in 1999 and 2000, which may account for the lower catch rates in those years.

Early spring flooding, when the ground was frozen, also had negligible negative impacts on the stream itself. A smaller flood event in June 2000, which was also due to beaver dam removal, resulted in a discharge exceeding bankfull flow. This flood event caused more bank erosion than the larger flood in 2001, which occurred when the banks and surrounding bog were still frozen. Floodwaters flowed over the flood plain without producing obvious erosion of the frozen banks (personal observations). Thus the timing of beaver dam removal can be planned in such a way that minimizes damage to the stream while increasing the number of walleye attracted to the area for spawning.

Management Recommendations

Streams being considered for spawning riffles should meet certain criteria. Walleye should have been observed in the candidate stream during the spawning season. There is no reason to think that fish will discover a stream after habitat is installed if they did not visit it before the work was done. Substrate surveys should be done to assess the quality of available habitat in the stream. It may be worthwhile to collect short duration drift samples just after spawning is completed, to look for drifting live walleye eggs, which would confirm spawning use as well as a lack of suitable substrate for successful egg incubation. Holding a screen kick net in the stream for several minutes would be an efficient way to collect such samples.

In streams with active beaver populations, beaver control measures must be considered. It may not be possible to maintain a free flowing stream connected to the lake without ongoing beaver control measures, including long-term trapping and repeated dam removal. If there is no commitment to keeping beaver from blocking fish access to the spawning habitat, there is little point in building spawning habitat. Channel constrictors, such as the one built for this study, seem highly attractive to beavers as dam sites. We do not recommend the construction of channel constrictors.

When the above factors have been considered and the decision is made to build spawning riffles, it is important to plan and implement a physical and biological monitoring program. Newbury and Gaboury (1993) provide extensive information on the planning and design of spawning riffles as well as outlining a monitoring plan. Stream surveys should include enough information to determine the Level II Rosgen classification (Rosgen 1996).

Ideally, night spotlight counts of spawning fish will be done. Often lake associations are willing to do such surveys. In addition, kick net samples of eggs on the spawning area should be collected before and after building riffles. Kick sampling is not time consuming and is highly recommended as an evaluation of projects where the water conditions allow it. Fry sampling is exceedingly time consuming and is not recommended for routine monitoring of habitat projects. Kick samples that are taken just prior to egg hatch, when the embryo is fully pigmented and active, should yield a relative indicator of the forthcoming fry hatch. If this data is collected for future management projects, it should help us to refine the criteria for streams that are good prospects for habitat work, and may also allow some conclusions about natural reproductive success to be inferred from subsequent lake surveys in lakes that are not stocked annually.

References

Aadland, L.P., C.M. Cook, M.T. Negus, H.G. Drewes, and C.S. Anderson. 1991. Microhabitat preferences of selected stream fishes and a community-oriented approach to instream flow assessments. Minnesota Department of Natural Resources, Section of Fisheries Investigational Report 406, St. Paul.

Bain, M.B. 1999. Substrate. Pages 95-104 in M.B. Bain and N.J. Stevenson, editors. Aquatic habitat assessment: Common methods. American Fisheries Society, Bethesda, MD.

Corbett, B.W., and P.M. Powles. 1986. Spawning and larva drift of sympatric walleyes and white suckers in an Ontario stream. Transactions of the American Fisheries Society 115: 41-46.

Crowe, W.R. 1962. Homing behavior in walleyes. Transactions of the American Fisheries Society 91: 350-354.

Franzin, W.G., and S.M. Harbicht. 1992. Tests of drift samplers for estimating abundance of recently hatched walleye larvae in small rivers. North American Journal of Fisheries Management 12: 396-405.

Houde, E.D. 1969. Sustained swimming ability of larvae of walleye (*Stizostedion vitreum vitreum*) and yellow perch (*Perca flavascens*). Journal of the Fisheries Research Board of Canada 26: 1647-1659.

Ihaka, R., and R. Gentleman, editors. 1996. R: A language for data analysis and graphics. Journal of Computational and Graphical Statistics 5: 299-314.

Jennings, M.J., J.E. Claussen, and D.P. Philipp. 1996. Evidence for heritable preferences for spawning habitat between two walleye populations. Transactions of the American Fisheries Society 125: 978-982.

Johnson, F.H. 1961. Walleye egg survival during incubation on several types of bottom in Lake Winnibigoshish, Minnesota, and connecting waters. Transactions of the American Fisheries Society 90: 312-322.

Kerr, S. J., B.W. Corbett, N.J. Hutchinson, D. Kinsman, J.H. Leach, D. Puddister, L. Stanfield, and N. Ward. 1997. Walleye habitat: a synthesis of current knowledge with guidelines for conservation. Ontario Ministry of Natural Resources, Toronto.

McMahon, T.E., J.W. Terrell, and P.C. Nelson. 1984. Habitat suitability information: walleye. U.S. Fish & Wildlife Service, No. FWS/OBS-82/10.56.

Mitro, M.G., and D.L. Parrish. 1997. Temporal and spatial abundances of larval walleyes in two tributaries of Lake Champlain. Transactions of the American Fisheries Society 126: 273-287.

Newburg, H.J. 1975. Evaluation of an improved walleye (*Stizostedion vitreum*) spawning shoal with criteria for design and placement. Minnesota Department of Natural Resources, Section of Fisheries Investigational Report 340, St. Paul.

Newbury, R.W., and M.N. Gaboury. 1993. Stream Analysis and Fish Habitat Design: A Field Manual. Newbury Hydraulics Ltd., Gibsons, British Columbia.

Olson, D.E., D.H. Schupp, and V. Macins. 1978. An hypothesis of homing behavior of walleyes as related to observed patterns of passive and active movement. American Fisheries Society Special Publication 11: 52-57.

Olson, D.E., and W.J. Scidmore. 1962. Homing behavior of spawning walleyes. Transactions of the American Fisheries Society 91: 355-361.

Priegel, G.R. 1970. Reproduction and early life history of the walleye in the Lake Winnebago region. Wisconsin Department of Natural Resources Technical Bulletin 45, Madison.

Rosgen, D.L. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO.

Sokal, R.R., and F.J. Rohlf. 1981. Biometry: The Principles and Practice of Statistics in Biological Research. W.H. Freeman and Company, New York.

Underwood, A.J. 1981. Techniques of analysis of variance in experimental marine biology and ecology. Oceanography and Marine Biology Annual Review 19: 513-605.

Underwood, A.J. 1997. Experiments in Ecology: Their Logical Design and Interpretation Using Analysis of Variance. Cambridge University Press, Cambridge.

Waters, T.F. 1995. Sediment in streams: sources, biological effects and control. American Fisheries Society, Bethesda.

Yandell, B. S. (1997) Practical Data Analysis for Designed Experiments. Chapman & Hall.

Appendix I. Walleye spawning habitat projects in Minnesota streams that were evaluated in 2001. Habitat condition was subjectively assigned based on average embeddedness ratings. Many of the noted problems were patchy, and other sections of the project often contained good habitat.

Site Number	*Location*	*Lake Name (DOW)*	*Year*	*Type of Project*	*Material Used*
1	Ripple River	Farm Island (01015900)	1997	Settling basin dug upstream. Excavated 1' of stream bed, lined with filter cloth and filled with rock. Narrowed channel to 16' with large rock.	Crushed rock on bed, banks lined with 3" to 12" rock
2	Ripple River	Hickory (01017900)	1991	Lined channel, ~150'	5" to 15" rock
3	Ripple River	Diamond (01017100)	1997	Lined channel at old bridge abutment	1" to 2" rock
4	Fulton Creek	Big Sandy (01006200)	1987	Excavated 1' of stream bed and filled back in with rock, ~300'	3" to 8" rock
5	Rat Creek	Big Sandy (01006200)	1990	Excavated 1' of stream bed and filled back in with rock, ~200'	3" to 8" rock
6	Nokasippi River	South Long (18013600)	2000	Lined channel, ~80'	1" to 8" rock
7	Deer Inlet	Deer Lake (31033400)	1998	Lined channel below culvert	3" to 5" rock
8	Moses Inlet	Moses (21024500)	1993	Lined channel, ~150'	8" to 18" rock
9	Victoria Inlet	Victoria (21005400)	1990, cleaned 1994	Lined channel, 300' Cleaned 300' with jet pump in 1994	6" rock
10	Gizzard Creek	West Battle (56023900)	1998	Lined channel, 6" deep, ~200'	1" to 4" rock
11	Boedigheimer Creek	Rush (56014100)	1997	Lined channel, >400'	4" to 12" rock
12	Third River (3 sites)	Dixon (31092100)	1998, 2000, 2001	Lined channel, ~50' each	3" to 6" rock
13	Spring Creek	Jessie (31078600)	1998, 1999	"U" shaped riffle, 40', two locations	2" to 10" rock
14	Moody's Creek	Split Hand (31035300)	1999	"U" shaped riffle, 40'	3" to 8" rock

Appendix I. continued.

Site Number	*Location*	*Year*	*Slope*	*Spawning Habitat Condition (Excellent, Very Good, Good, Fair, Poor)*	*Problems noted*
1	Ripple River	1997	NA	Very Good	Sand deposition downstream where stream leaves bog
2	Ripple River	1991	0.0003	Very Good	Sand deposition upstream, otherwise clean
3	Ripple River	1997	NA	Excellent	Clean
4	Fulton Creek	1987	0.004	Good	Bank erosion and point bar deposition, not severe
5	Rat Creek	1990	0.005	Excellent	Small area of sand and muck deposition upstream, otherwise clean
6	Nokasippi River	2000	0.0055	Very Good	Sand deposition upstream, otherwise clean
7	Deer Lake Inlet	1998	NA	Good	Small project, deposition and vegetation growth at edges, center clean
8	Moses Lake Inlet	1993	0.006	Very Good	Bank erosion where rocks do not reach bankfull elevation
9	Victoria Inlet	1990, 1994	NA	Poor	Small areas of fine gravel, scattered embedded rocks. Could not define project area. This is the second time this project has failed.
10	Gizzard Creek	1998	0.0012	Poor	Rock mostly embedded or covered with sand
11	Boedigheimer Creek	1997	0.003	Good	Some areas covered with sand, but reach is long and has much clean rock available
12	Third River: woods	1998	0.0035	Fair to Poor	Sand deposition in center of stream, some clean rock at edges
12	Third River: bridge	2000	0.009	Good	Sand deposition upstream, otherwise clean
12	Third River: downstream	2001	NA	Very Good	Clean
13	Spring Creek	1998, 1999	0.001	Very Good	Two riffles: some sand embedded rock at edges and upstream edge
14	Moody’s Creek	1999	0.0004	Good	Has been buried in sand and cleaned itself several times.