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Effect of drain maintenance and reconstruction on the abundance and habitat of Grass Pickerel (*Esox americanus vermiculatus*) in Beaver Creek, Ontario

[1]William R. Glass, [1]Natalie A. Rook, [1]Edyta Ratajczyk, and [2]Nicholas E. Mandrak

[1]Fisheries and Oceans Canada
867 Lakeshore Rd.
Burlington, ON L7S 1A1

[2]University of Toronto Scarborough
1265 Military Trail
Toronto, ON M1C 1A4

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Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Many of the watersheds in southern Ontario have been highly modified to facilitate the removal of surface water from agricultural fields. These modified streams are often classed as municipal drains and are subject to periodic drain maintenance under the *Drainage Act*. Municipal (agricultural) drain maintenance involves removal of built-up sediment and associated aquatic vegetation, and may also include channelization of the stream and removal of riparian vegetation. Despite the periodic disturbance due to drain maintenance, agricultural drains are home to many fish species in southern Ontario, including species at risk. Beaver Creek, a tributary of the Niagara River in southwestern Ontario, is classed as a municipal drain and is home to a population of Grass Pickerel (*Esox americanus vermiculatus*), a species at risk in Canada. In the fall of 2011 a section of Beaver Creek was subjected to drain maintenance. In an effort to mitigate potential harmful effects of the drainage activities on the Grass Pickerel population, reconstruction incorporating natural stream channel design features was also implemented. The fish community of Beaver Creek was sampled in the impacted reach where maintenance occurred, an adjacent control reach that was not subject to maintenance, and a downstream reach where the two converged, from 2009–2013 and again in 2015. A series of before-after-control-impact (BACI) analyses were conducted to determine the effect of maintenance and reconstruction activities on the Grass Pickerel population and the physical and chemical habitat in Beaver Creek. BACI analyses were also conducted on three time scales to determine the most effective monitoring time frame for future drainage projects. Results of this study indicate that reconstruction incorporating natural stream channel design features had a positive impact on the Grass Pickerel catch per unit effort in the newly created pools and mitigated the effects of channelization on habitat characteristics such as stream velocity. The diversity of the stream fish community was not affected by the maintenance and reconstruction activities. Changing the amount of time that monitoring is conducted can influence the ability to detect effects of drainage activities. In this study, monitoring for at least three years prior to the drainage works, along with post-project monitoring of at least four years following was required to determine the effects of drainage activities.

INTRODUCTION

Historically, the landscape of southern Ontario has been highly modified by agriculture and other human activities. Likewise, many of the streams and wetlands in agricultural regions have been modified to facilitate removal of surface water and to prevent flooding of agricultural lands (Walters and Shrubsole 2003). These modified streams are often classed as municipal drains and, as such, are subject to periodic drain maintenance mandated by the *Drainage Act* to ensure adequate capacity and water flow. Traditionally, municipal (agricultural) drain maintenance involves the removal of accumulated sediment and the associated aquatic vegetation to improve water flow through straightening and channelization of the water course (*Drainage Act*). Despite the modifications that agricultural drains are subject to, they provide habitat for fishes (Stammler et al. 2008), thus, drain maintenance activity has the potential to impact fish populations. Agricultural drain maintenance often results in altered flow regimes (Bukaveckas 2007), reduced riparian cover (Hupp 1992), an increase in suspended sediment load (Simon 1989), and decreased variability of water levels in the affected stream (Walser and Bart 1999). Channelization of watercourses also removes the complexity of substrate, especially larger substrate particles such as cobble, and reduces the prevalence of pool habitats (Lau et al. 2006). These physical changes to stream morphology reduce the diversity in the fish assemblage, particularly affecting environmentally sensitive species (Lau et al. 2006). Incorporating the features of a natural stream channel during reconstruction following drain maintenance activities, including the restoration of riffle-pool habitats and substrate complexity, has the potential to enhance the amount of suitable habitat for aquatic species (reviewed in Newbury and Gaboury 1993).

The Grass Pickerel (*Esox americanus vermiculatus*), listed as Special Concern in Canada under Schedule 1 of the *Species at Risk Act*, is a small member of the Escoidae family. Grass Pickerel is at the northern edge of its range in Canada and is found in southern Ontario and Quebec (Scott and Crossman 1998). This species is a visual predator that prefers slow moving, heavily vegetated waters (Scott and Crossman 1998) and can often be found inhabiting agricultural drains throughout its range in southern Ontario (COSEWIC 2005). Threats to Grass Pickerel in Canada include vegetation removal, declining water levels, and loss or degradation of wetland habitat (COSEWIC 2005). The modification of wetland habitat through drain maintenance has been identified as one of the largest potential threats to Grass Pickerel in Canada (COSEWIC 2005).

The Beaver Creek watershed in southwestern Ontario encompasses 37.3 km^2 of primarily agricultural land (UEM 2011) and flows into Black Creek and subsequently, the Niagara River. Beaver Creek is classified as a municipal drain and, as such, is subject to drain maintenance activities, however, there is no record of recent maintenance activity and the drain is presumed to be in a naturalized state (UEM 2011). The watershed is also home to a large resident population of Grass Pickerel which would potentially be impacted by drain maintenance and channelization. The western branch of Beaver Creek was subjected to drain maintenance and artificial stream channel reconstruction, incorporating natural channel design features, in the fall of 2011, while the eastern branch of the creek was left in its naturalized state. The purpose of this study is to:

1. Determine the effect of drain maintenance and stream channel reconstruction on the Grass Pickerel population and habitat in Beaver Creek; and,
2. Develop effective monitoring techniques to detect impacts of drain maintenance on Grass Pickerel populations.

METHODS

The study was located on three reaches of Beaver Creek in the town of Fort Erie, Ontario: the eastern branch which remains in its naturalized state (control reach), western branch which was subjected to drain maintenance in the fall of 2011 (impact reach), and the northern reach where the impact and control reaches converge (Figure 1). The northern reach could be potentially affected by the maintenance activities due to its location downstream of the work site. Within the impact reach there is a 988 m segment where drain maintenance occurred, accompanied by reconstruction incorporating natural stream channel design features (reconstructed section). Sampling was conducted from 2009–2013, and again in 2015. Field collections were performed in pool habitats adjacent to road crossings. Sites were chosen due to similarity of habitat, as well as accessibility. In 2009 and 2010, four sites were sampled on the control reach (road crossings at Nigh Rd., Gorham Rd., Garrison Rd., and Bertie St.). In subsequent years the sites at Nigh Rd. and Gorham Rd. were replaced by a single site at a crossing on private land between Garrison Rd. and Bertie St. The sample locations were changed due to access issues. The impact reach was sampled at road crossings at Garrison Rd., House Rd., and Stevensville Rd. and the northern reach was sampled at Winger Rd., Bowen Rd., Eagle St., and College Rd. Within the impact reach the reconstruction, incorporating natural channel design features, conducted in the fall of 2011 created five pools within the main stem of the creek (one of which replaced the existing pool at Garrison Rd.) and two offline pools.

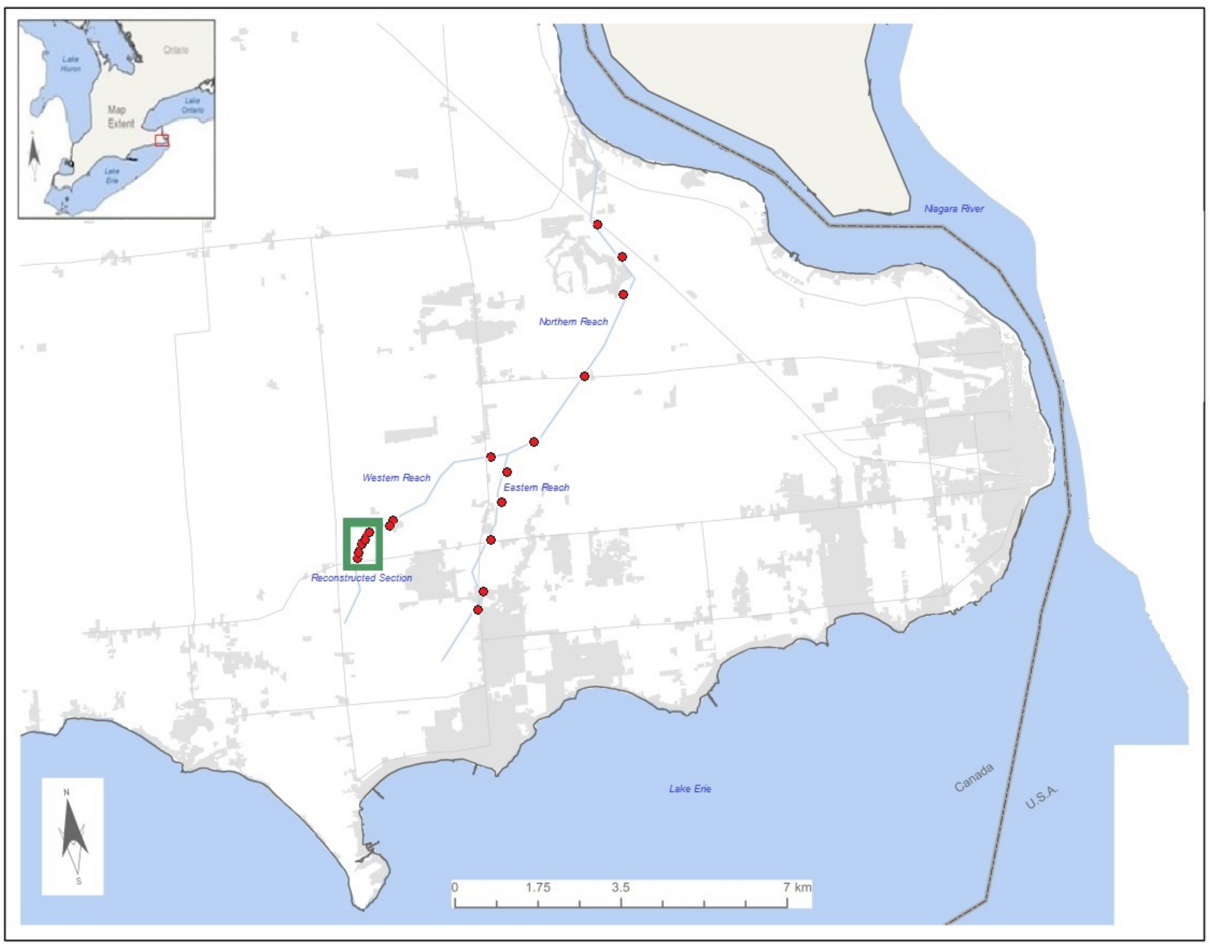

Figure 1. Study location of Beaver Creek, Fort Erie, ON. Green square indicates the section where drain maintenance and reconstruction activities were conducted.

The fish community at each site was sampled using a 9.1 m bag seine with 3.2 mm mesh. A minimum of three and a maximum of twelve seine hauls per site were conducted during each sampling event and fishes were identified to species level, counted, and released at the same location after all seine hauls were conducted. Seine hauls were typically conducted so as not to overlap spatially with previous hauls in the same sampling event and fish collections for each haul were processed separately. Sampling effort for each of the stream reaches is summarized in Table 1. Sites were sampled from one to six times per year, in the summer open water period between May and August. Habitat variables including water temperature (˚C), conductivity (µS), secchi depth (m), aquatic vegetation cover (%), water depth (m), and water velocity (m/s) were also measured at the time of fish community survey.

Table 1. Sampling effort in each of the reaches in Beaver Creek, before and after drain maintenance and reconstruction incorporating natural stream channel design features.

	Pooled Before Maintenance		1 Year Before Maintenance		1 Year After Maintenance		Pooled After Maintenance	
Reach	Sampling Events	Seine Hauls	Sampling Events	Seine Hauls	Sampling Events	Seine Hauls	Sampling Events	Seine Hauls
Control	29	79	7	16	14	31	24	63
Impact (incl. reconstructed)	30	108	8	27	22	72	41	123
Reconstructed	10	37	2	7	11	33	22	64
North	40	184	9	26	20	58	36	105

The catch per unit effort (CPUE) was used as a surrogate for abundance of Grass Pickerel at a site during each sampling event and was calculated as the average number of Grass Pickerel captured per seine haul.

A series of before-after-control-impact (BACI) analyses were conducted using factorial ANOVA in Statistica v6.0 to determine the effects of the drainage activities on CPUE and each of the habitat variables. It was presumed that drain maintenance and reconstruction activities had an effect on the variable of interest if the interaction term of the factorial ANOVA was significant ($P < 0.05$). To determine the spatial extent of the effects of the drain maintenance and reconstruction separate BACI analyses were conducted comparing the control reach with the impact reach, the control reach with the reconstructed section of the impact reach, and the control reach with the northern reach. To determine the temporal extent of the effects, and to inform monitoring decisions, analyses were also conducted on three different time scales: one year before maintenance, one year after reconstruction; pooled samples before maintenance compared with one year after; and, all samples before reconstruction compared to all samples after reconstruction.

The fish community analyses were conducted using a non-parametric multivariate analysis of variance using distance matrices. CPUE was used to represent the abundance of each species. The CPUE for each species per site was log+1 transformed to help normalize the data. The analysis was completed with the function *adonis* in the vegan package in R (Oksanen et al. 2009). The *adonis* function was used as it was developed to test differences in species communities of different treatments. Similar to the analysis on habitat variables and Grass

Pickerel CPUE, this analysis was conducted comparing the control reach with the impact reach, the control reach with the reconstructed section of the impact reach, and the control reach with the northern reach. It was also conducted under the same three time scales to determine the magnitude of temporal effects.

RESULTS

The seine net sampling conducted from 2009–2015 resulted in the capture of 27,310 fishes from 37 different species in 677 seine hauls from throughout the sampled area of Beaver Creek. The most abundant species captured across all sites and years were Emerald Shiner (*Notropis atherinoides*; 36% of all fishes captured), Grass Pickerel (18%), and Golden Shiner (*Notemigonus crysoleucas*; 16%). The most frequently detected species were Grass Pickerel (91% of sampling events), Golden Shiner (75%), and Pumpkinseed (*Lepomis gibbosus*; 74%). Of the fishes captured, 4,971 were Grass Pickerel. Five of the Grass Pickerel captures came from the offline pools that were constructed. These individuals were captured in the first sampling event in the offline pools. All subsequent sampling events in the offline pools were unsuccessful, and thus, we removed the offline pool data from BACI calculations. Fish captures by reach and year are found in Appendix 1; for a detailed summary of the fishes captured during the sampling for this project refer to Colm and Mandrak (2021).

CPUE ranged from a high of 29.13 Grass Pickerel per seine haul in the eastern (control) reach in 2009 to a low of 0.5 Grass Pickerel per seine haul in the reconstructed reach in 2013. In all cases, CPUE was highest in the first year of the study period and lowest in 2013 for all but the northern reach which was lowest in 2015 (Table 2, Figure 2).

Table 2. Average number of Grass Pickerel captured per seine haul in each of the sampled reaches. Drain maintenance and reconstruction activities were conducted in the fall of 2011 after sampling was competed that year.

Year	Control Reach	Reconstructed Section	Impact Reach	Northern Reach
2009	29.1	6.2	25.6	9.5
2010	13.8	1.9	6.8	6.5
2011	12.4	1.2	3.6	8.6
2012	6.7	1.5	2.6	2.1
2013	1.9	0.5	2.1	2.3
2015	4.3	4.1	3.3	1.9

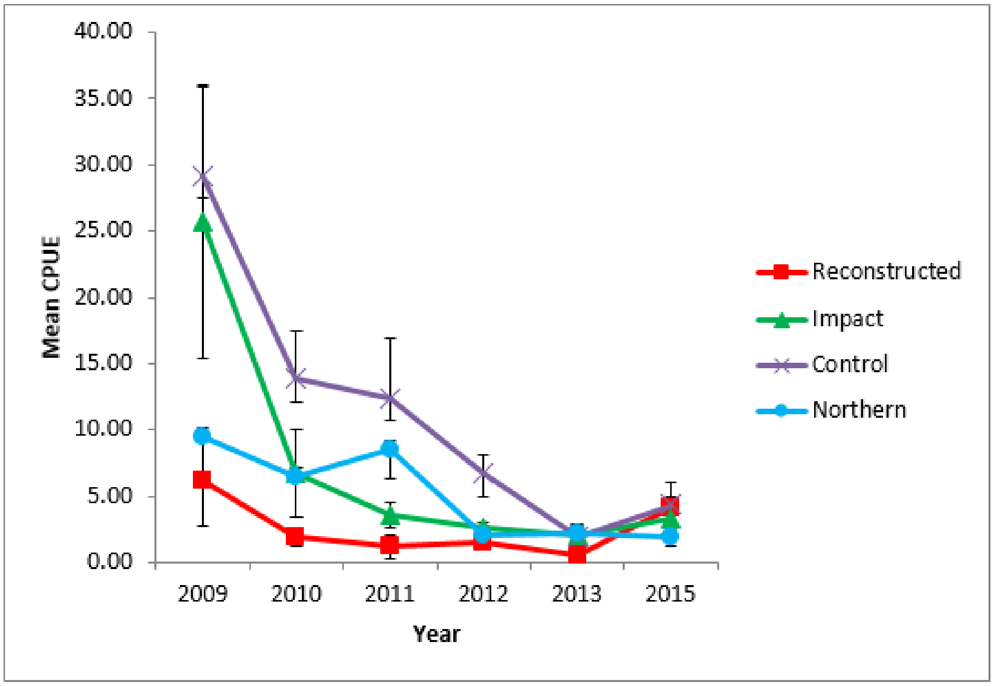

Figure 2. Mean CPUE for Grass Pickerel captured in each sampled reach by year. Drain maintenance and reconstruction activities were conducted following the 2011 sampling period.

Mean water temperature exhibited wide variability between years and stream reaches (Figure 3). The highest mean water temperature (26.25 ˚C) was observed in the reconstructed reach in 2012 while the lowest mean water temperature (15.46 ˚C) was observed in the same reach the following year.

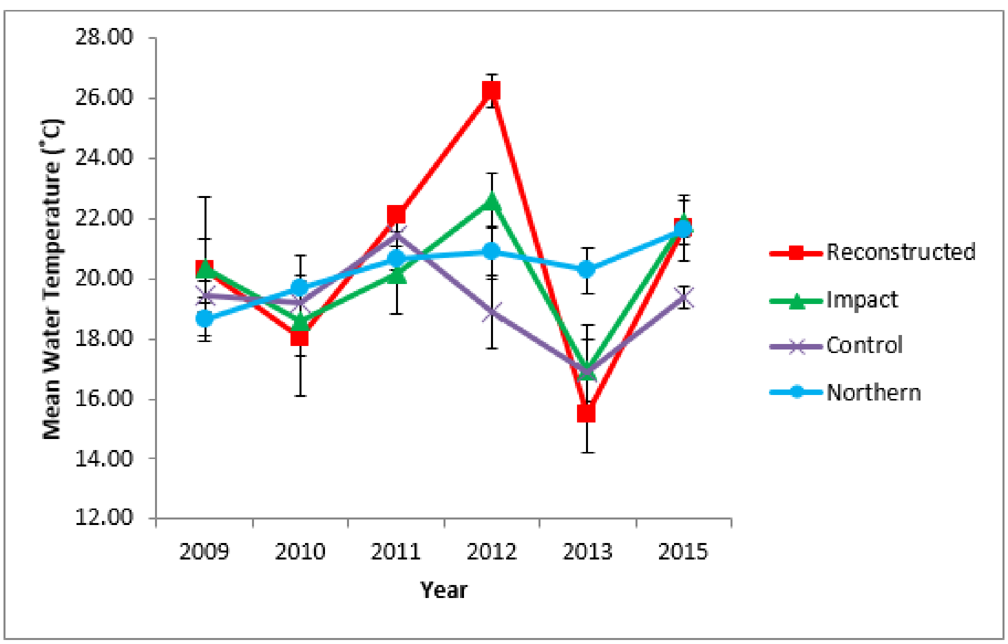

Figure 3. Mean water temperature for each sampled reach by year. Drain maintenance and reconstruction activities were conducted following the 2011 sampling period.

Conductivity was higher in the control reach than the other reaches that were sampled, ranging from 1111.3 µS to 1545.3 µS. This elevated conductivity on the control reach compared to other reaches (Figure 4) was observed in all years that sampling was conducted except for the first year post-construction. In 2012 the mean conductivity in the reconstructed reach was highest (1585.7 µS), followed by the control reach (1545.3 µS).

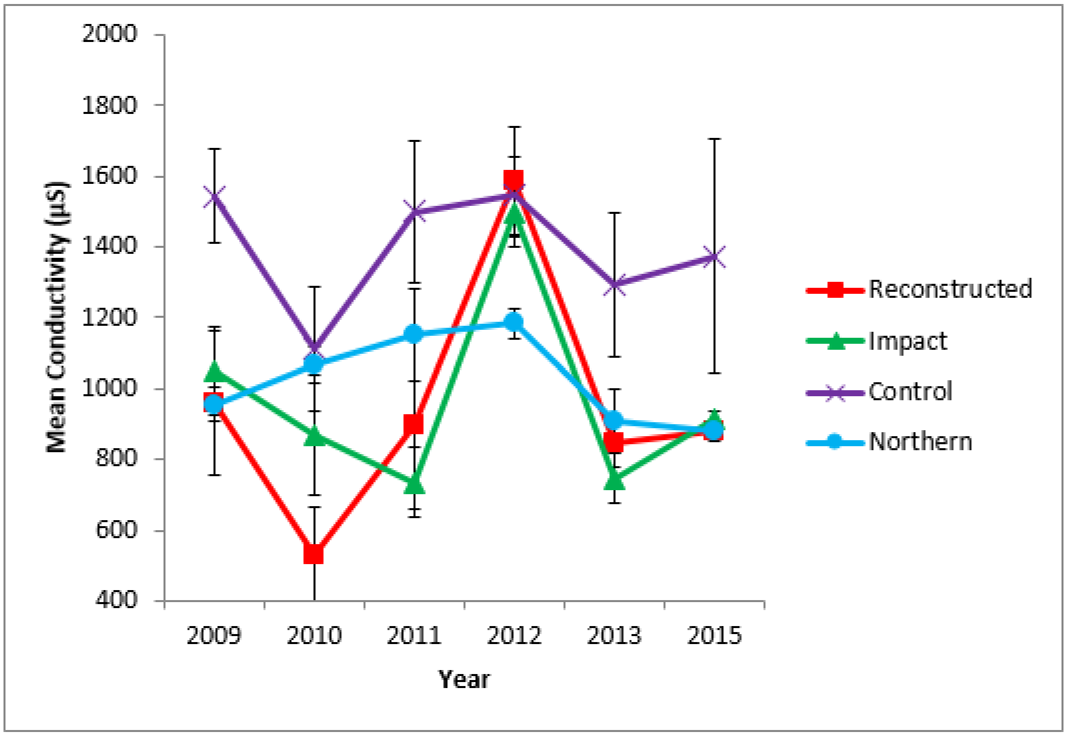

Figure 4. Mean conductivity for each sampled reach by year. Drain maintenance and reconstruction activities were conducted following the 2011 sampling period.

The mean total aquatic vegetation cover was consistently lowest in the impact and reconstructed reach across all years of observation (Figure 5). Mean aquatic vegetation coverage ranged from 14.2 percent coverage in the impact reach in 2015 to a high of 78.7 percent coverage in the control reach in 2012.

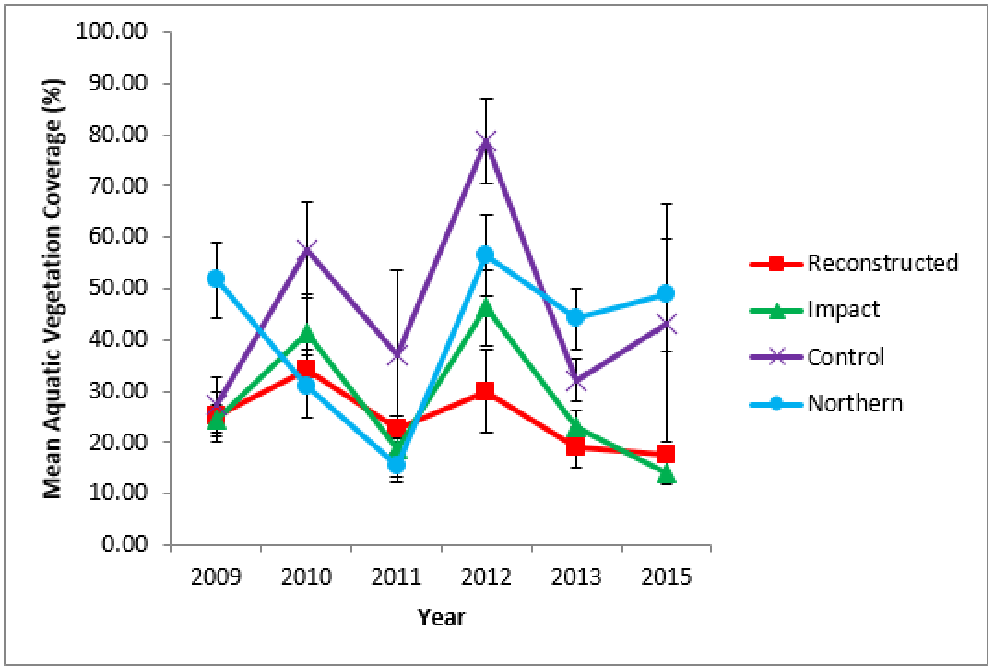

Figure 5. Mean percent aquatic vegetation coverage for each of the sampled reaches by year. Drain maintenance and reconstruction activities were conducted following the 2011 sampling period.

Mean secchi depth was consistently lowest in the impact and reconstructed reaches across all years (Figure 6). The lowest mean secchi depth (0.04 m) was observed in the reconstructed portion of the impact reach in 2011 and the highest mean secchi depth (0.59 m) was observed in the northern reach in 2015.

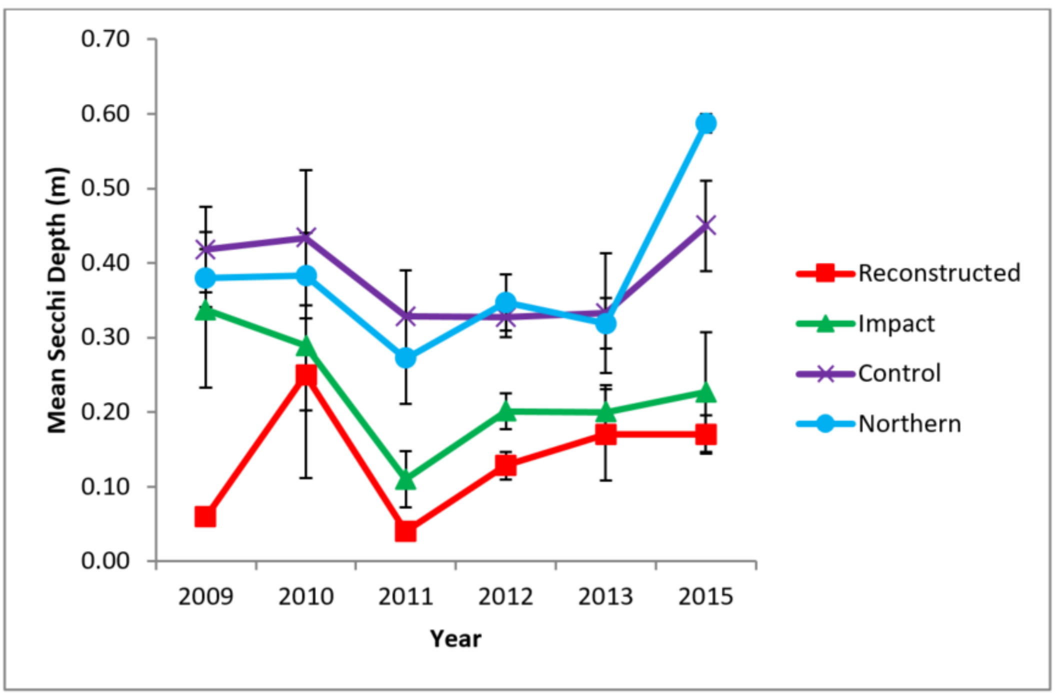

Figure 6. Mean secchi depth at each sampled reach by year. Drain maintenance and reconstruction activities were conducted following the 2011 sampling period.

The observed mean water depth was lower in the impact and reconstructed reach (Figure 7) compared to the northern and control reaches across all years sampled. The mean depth in the reconstructed portion of Beaver Creek increased in the first year post construction when the new pools were created.

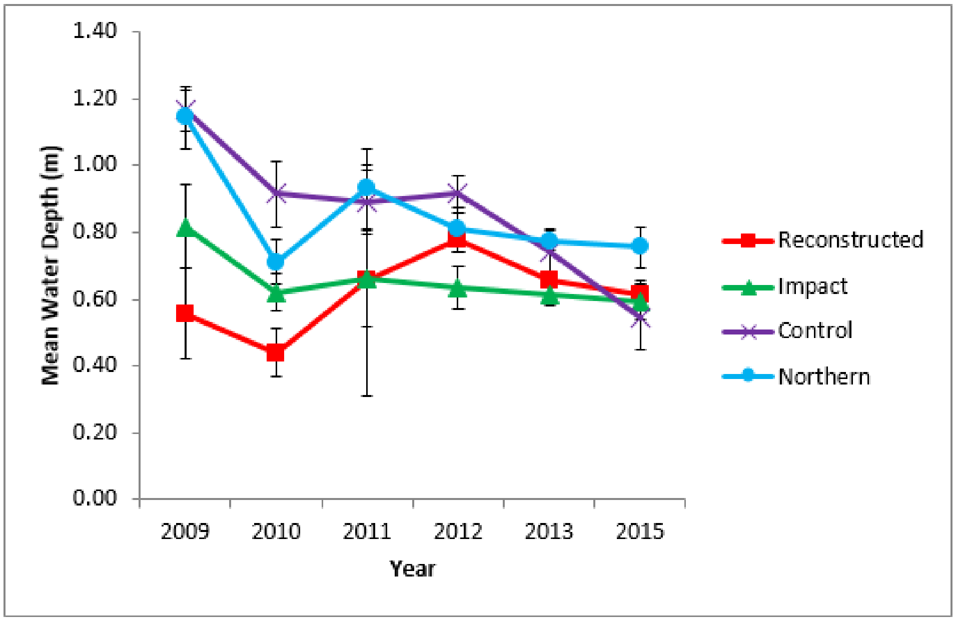

Figure 7. Mean water depth at each of the sampled reaches by year. Drain maintenance and reconstruction activities were conducted following the 2011 sampling period.

Mean water velocity peaked for all sites in 2011, followed by consistent observations of no measurable flow at all sites (Figure 8) during the sampling period. Water velocity data was unavailable for 2009.

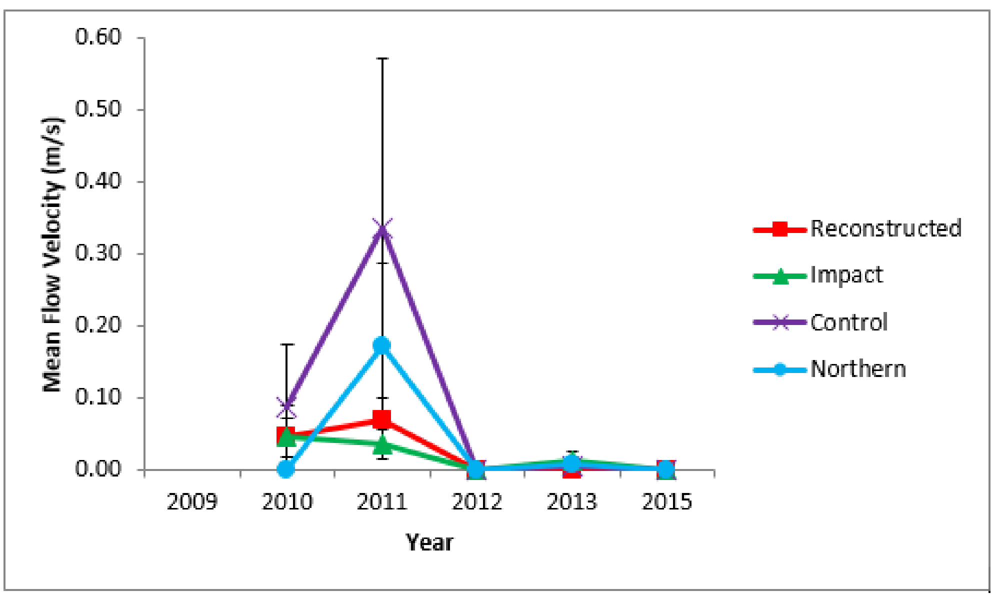

Figure 8. Mean water velocity at each sampled reach by year. Drain maintenance and reconstruction activities were conducted following the 2011 sampling period.

When the ANOVA analyses were conducted examining the effect of drain maintenance and reconstruction several significant effects were observed (Table 3, Appendix 2). A statistically significant interaction term in the BACI ANOVA, indicating an effect of the maintenance and reconstruction, was most often evidenced when comparing the reconstructed section with the control reach. A significant effect of maintenance on the reconstructed section was seen in Grass Pickerel CPUE for the comparison of pooled observations before construction compared to pooled observations after construction. The maintenance and reconstruction led to a relative increase in CPUE of Grass Pickerel in the reconstructed segment. The increase in CPUE was particularly evident in the 2015 sampling period. A significant effect on CPUE between control and northern reaches was also observed when comparing the pooled samples before maintenance with pooled samples after maintenance. Grass Pickerel CPUE in the northern reach was relatively unchanged from 2012–2015 while the control reach exhibited decline in CPUE from 2012–2013, followed by an increase in 2015.

A significant effect of maintenance activities on water temperature was seen for all three time scales when comparing the control reach with the reconstructed section. In all cases, temperature was increased in the reconstructed section relative to the control reach. Similar effects were noted when comparing the control and impact reaches, in both the before / after and before / 1 year after reconstruction time frames. A significant elevation in water temperature was also demonstrated in the northern reach compared to the control reach at the pooled before / after time scale.

Conductivity was significantly increased in the reconstructed section compared to the control reach when comparing the sampling period before construction to the first year post-construction. Elevated conductivity relative to the control reach was also seen in the impact reach as a whole, at all three time scales.

The reconstructed section also exhibited significant effect of maintenance and reconstruction activities on vegetation coverage, which was decreased relative to the control reach when the before construction period and one year post-construction periods were compared. Water depth in the reconstructed section was increased relative to the control reach at the time scales of before / after construction and before / one year post-construction. No significant effect of maintenance activities on the water velocity was observed in any of the comparisons.

Table 3. Interaction term P values for each of the BACI comparisons. For control reach: A) reconstructed section, B) impact reach, C) northern reach.

A)	Control Reach – Reconstructed Section		
	Pooled Before - After	Pooled Before – 1 year after	1 year before – 1 year after
Abundance	0.004*	0.054	0.317
Temperature	0.018*	0.000*	0.038*
Conductivity	0.075	0.015*	0.138
Vegetation Coverage	0.105	0.029*	0.245
Secchi Depth	0.589	0.703	0.345
Water Depth	0.002*	0.009*	0.423
Water Velocity	0.204	0.357	0.422

*Indicates a significant interaction and, thus, a significant effect of the drain maintenance and reconstruction activities on the particular variable at that reach.

B)	Control Reach – Impact Reach		
	Pooled Before - After	Pooled Before – 1 year after	1 year before – 1 year after
Abundance	0.122	0.392	0.164
Temperature	0.049*	0.014*	0.060
Conductivity	0.240	0.045*	0.010*
Vegetation Coverage	0.218	0.125	0.507
Secchi Depth	0.797	0.716	0.194
Water Depth	0.291	0.870	0.792
Water Velocity	0.057	0.152	0.131

*Indicates a significant interaction and, thus, a significant effect of the drain maintenance and reconstruction activities on the particular variable at that reach.

C)	Control Reach – Northern Reach		
	Pooled Before - After	Pooled Before – 1 year after	1 year before – 1 year after
Abundance	0.019*	0.163	0.832
Temperature	0.029*	0.125	0.230
Conductivity	0.521	0.746	0.955
Vegetation Coverage	0.920	0.307	0.977
Secchi Depth	0.258	0.382	0.420
Water Depth	0.491	0.269	0.395
Water Velocity	0.256	0.420	0.417

*Indicates a significant interaction and, thus, a significant effect of the drain maintenance and reconstruction activities on the particular variable at that reach.

A total of 27,310 fishes comprising 37 families were captured during the sampling period among the three reaches of Beaver Creek. The greatest number of species was found in the northern reach, and the fewest were found in the control reach and reconstructed section before maintenance. Maintenance and reconstruction did not have a significant effect on the fish community when comparing the reconstructed section with the control reach, the impacted reach with the control reach, or the northern reach with the control reach (Table 4). All of the reaches including the control reach increased in species richness in 2012.

Table 4. Interaction term P values for each of the adonis comparisons of fish assemblages relative to the control.

	Pooled Before – After	Pooled Before – 1 year after	1 year before –1 year after
Control Reach - Reconstructed Section	0.453	0.071	0.910
Control Reach - Impact Reach	0.605	0.109	0.259
Control Reach - Northern Reach	0.673	0.605	0.525

*Indicates a significant interaction and, thus, a significant effect of the drain maintenance and reconstruction activities.

DISCUSSION

EFFECT OF DRAIN MAINTENANCE ON HABITAT AND GRASS PICKEREL ABUNDANCE

The drain maintenance and reconstruction incorporating natural stream channel design principles conducted in Beaver Creek in the fall of 2011 affected the habitat characteristics and the Grass Pickerel CPUE. The majority of the effects were seen within the reconstructed section of the creek, but were also evident in the entire western branch of the creek as well as downstream of the confluence of the two branches. Changes in habitat due to drainage activities relative to the control reach were manifest in a number of parameters including: increase in conductivity; decrease in aquatic vegetation; increase in depth; and, increase in water temperature. These effects were most prevalent within the reconstructed section of Beaver Creek, especially in the first year post-reconstruction.

An increase in water depth in the section of the creek subjected to maintenance was expected since the reconstruction created five pools where only a single, shallow pool existed prior to dredging. This effect was evident throughout the duration of the study post-reconstruction. Removal of aquatic vegetation during drain maintenance activities is also standard practice (*Drainage Act*), thus, the observed decrease in aquatic vegetation coverage in the reconstructed section was expected, however, the effect on vegetation coverage was short-lived and was only evident when the first year post-construction was compared with the sampling period prior to construction, indicating that the aquatic vegetation began to regenerate in the subsequent years.

The increase in conductivity that was observed in both the reconstructed section and the impact reach as a whole may be due to the suspension of sediments and associated chemical compounds from the stream bed. An increase in soluble reactive phosphorus and dissolved inorganic nitrogen was observed by Licursi and Gomez (2008) following the dredging of a lowland stream, leading to higher observed conductivity in the post-dredging period. This increase in conductivity is expected to be short-lived as there was no observed effect in turbidity, as measured by secchi depth, due to the maintenance activities.

Water temperature showed a significant effect in the reconstructed reach, as well as downstream of the maintenance site in the entire impact reach and the northern reach. In all three reaches the water temperature was elevated compared to the control reach in the first year post-reconstruction. Riparian vegetation blocks incoming solar radiation helping to maintain lower stream temperatures (Poole and Berman 2001), thus, removal of riparian vegetation during construction would lead to increased water temperature in the reconstructed section of the creek and downstream reaches.

Although the intent of drain maintenance is to increase the capacity for the drain to remove surface water from the landscape, no effect of the maintenance and reconstruction activities was observed for water velocity in Beaver Creek. This may be a positive effect of the reconstruction efforts to include natural stream channel principles. Bukaveckas (2007) demonstrated that water velocity was lower in naturalized (restored) stream segments than in channelized segments of similar streams. Additionally, sampling for this project was conducted in the summer and consistent observations of no measurable flow were recorded at all sites. Field observations during the spring freshet would likely be more effective in elucidating the consequence of drain maintenance and reconstruction activities on the flow regime.

The abundance of Grass Pickerel throughout all reaches of Beaver Creek went through substantial declines at two different time periods during our study. The first decline came after the 2009 sample period. Age and growth evidence suggests that this decline may have been caused by density dependence (Colm et al. 2020). The second decline in abundance occurred in 2012 and was likely due to an extreme drought and warmer than normal summer temperatures experienced in southern Ontario (Colm and Mandrak 2021). The drought and extreme temperature led to decline in available habitat as water levels in Beaver Creek receded, likely causing mortality in the Grass Pickerel population. The BACI analysis of Grass Pickerel CPUE showed that the maintenance and reconstruction activities had a significant effect in both the reconstructed section of Beaver Creek and the entire impact reach. The CPUE in the reconstructed section of Beaver Creek was higher in 2012 than the previous year, despite the drought that caused substantial decline in abundance in other locations in Beaver Creek, indicating a positive effect of the creation of pool habitat. In the final year of sampling the abundance of Grass Pickerel in the reconstructed section of Beaver Creek was at its highest point since the first year of the study (2009) and, unlike all previous study years, was as high as in the control reach and higher than the northern reach. It is uncertain whether the increase in CPUE following drain maintenance and reconstruction activities is due to the movement of individuals into the reconstructed section, or due to increased production of Grass Pickerel.

The fish assemblages in the reconstructed section, impact reach, and northern reach did not significantly differ after maintenance and reconstruction when comparing them to the control reach. This indicates that maintenance and reconstruction had no effect on fish assemblages. Although maintenance activities can negatively impact stream fish community diversity due to a loss of suitable habitat (Lau et al. 2006), the reconstruction incorporating natural stream channel design features appears to have offset the effect of maintenance. The increase in species richness after maintenance and reconstruction that was observed in 2012 can be attributed to greater sampling effort compared to 2011, which would increase the probability of rare species being detected. In all years that sampling occurred, the northern reach had a more diverse fish assemblage compared to the eastern (control) and western (impacted) reaches. This is likely due to the northern reach being a higher order stream (Whiteside and McNatt 1972), and cannot be attributed to the maintenance and reconstruction activities, as the differences were found both before and after maintenance occurred.

Previous research has shown that traditional drain maintenance activities have the potential for negative impacts on fish abundance and diversity through loss or degradation of habitat (Lau et al. 2006). Maintenance and dredging of agricultural drain channels leads to declines in habitat quality due to loss of structural heterogeneity (Lau et al. 2006), removal of vegetation (*Drainage Act*), increase in water temperature (Poole and Berman 2001), increase in P and N levels (Licursi and Gomez 2008), and increase in flow velocity (Brooker 1985). These adverse effects of drain maintenance and channelization are more likely to impact environmentally sensitive species than tolerant ones (Lau et al. 2006). Grass Pickerel is sensitive to environmental perturbations such as loss of vegetation and decline in water level leading to winter mortality (COSEWIC 2005), and is likely to be negatively affected by agricultural drain maintenance. Although some of the potential negative effects of drain maintenance and channelization (higher conductivity, higher water temperature, loss of vegetation) were observed in Beaver Creek after the in-stream activities conducted in the fall of 2011, the Grass Pickerel CPUE was, in fact, positively affected by the drain maintenance and reconstruction activities. The positive influence on CPUE was likely due to the reconstruction of a stream channel with natural channel features. The creation of deeper pools likely provided refuge areas during the drought in 2012, potentially insulating the population from a large mortality event. Reconstruction of the riffle-pool morphology also negated the expected increase in water velocity that would normally be caused by channelization (Bukaveckas 2007), resulting in the creation of low-velocity habitat that the Grass Pickerel relies on (COSEWIC 2005). A previous study of the diversity of fishes in channelized warmwater streams in Ohio has shown that creation of riffle and pool habitats increased diversity to the level seen in natural systems (Edwards et al. 1984). Future drain maintenance activities conducted in areas that sustain Grass Pickerel populations should incorporate natural stream channel features to mitigate effects of drain maintenance on the habitat that supports functions vital to maintaining, or enhancing, Grass Pickerel populations. These habitat features include: deeper pools that serve as refuge habitat during winter or low-water periods and provide low velocity habitat preferred by Grass Pickerel; access to shallow waters (< 0.5 m) with ample aquatic or flooded terrestrial vegetation; and, a functioning floodplain habitat with a connection maintained to the main stream channel. The presence and dispersal ability of a source population for the reconstructed section should also be considered when planning drain maintenance activities (Bond and Lake 2003). Projects should be implemented in a staggered fashion over multiple years, rather than maintaining the entire stream at once, to ensure sufficient source population to recolonize the affected area. In this study, effects of the maintenance and reconstruction were noticeable as far downstream as the northern reach, beyond the confluence of the impact and control reaches. The anticipated distance downstream that would be affected by maintenance and reconstruction, in conjunction with the dispersal ability of the species in question, should be considered when designing future drain maintenance projects.

EFFECTIVE MONITORING TECHNIQUES FOR DRAIN MAINTENANCE ACTIVITIES

Monitoring of stream restoration projects, such as the drain maintenance and reconstruction in Beaver Creek, is an important, yet often overlooked, device to evaluate project success (Alexander and Allan 2007, Kondolf and Micheli 1995). Project monitoring should involve baseline observations before the project is implemented, as well as long-term observations after project completion to properly assess the impacts (Kondolf 1995).

Beaver Creek was sampled for three years prior to the drain maintenance and reconstruction and was sampled in three of four years post construction. This sampling design, along with analyzing the data at different time scales has allowed for an examination of the effectiveness of monitoring for different lengths of time pre- and post-construction. For all of the comparisons, except for conductivity in the impact reach and temperature in the reconstructed section, no significant effect of the maintenance and reconstruction activity was seen when comparing one year prior to reconstruction with one year after. This lack of detection for most variables was likely due to the low sample size in the year prior to construction. Monitoring for three years prior to construction and one year post construction detected the same effects to temperature and conductivity, along with several additional effects on abundance and habitat measures. When the monitoring was extended to include all years pre- and post-construction effects of the maintenance and reconstruction work on abundance were still evident for the reconstructed section and the northern reach. There was also a lasting effect on depth at the reconstructed section and on water temperature within the reconstructed section, impact reach, and northern reach. The effect on vegetation coverage and conductivity were no longer present when all post-construction samples were considered, indicating that these effects were short-lived and the habitat recovered from the disturbance within four years post-construction.

Our results indicate that changing the amount of time that monitoring is conducted can influence the ability to detect effects of drainage activities. In this study, monitoring for three years prior to construction and four years post-construction was required in order to determine the full effect of the in-stream activities. This time frame for post-construction monitoring to detect population increase in the reconstructed segment was similar to observations of the effect of stream restoration on wild trout populations in the Blackfoot River (Pierce et al. 2013), where trout populations had increased in abundance by three years post-restoration. Other studies of stream restoration projects have suggested that baseline monitoring should be conducted for as long as possible prior to the construction and for up to ten years post-construction (Kondolf 1995). Baseline data collection and post-construction monitoring should be long enough to encompass the climatic variation between years and to allow fish populations to adjust to potential changes in carrying capacity (Kondolf 1995).

Study design is an important factor in the success of monitoring a restoration project (Kondolf and Micheli 1995). Our study suffers from two design flaws: differences in sampling frequency between sites and among years; and, inherent differences in the control and impacted habitats prior to the maintenance and reconstruction activities. Due to site access issues we replaced two sites that were sampled in 2009 and 2010 with a different site which was sampled in the ensuing years. Additionally, the sampling effort was not consistent between years due to availability of field staff and the creation of new pools during the reconstruction that were added to the sampling scheme post-reconstruction. Inequality in sampling frequency between years can lead to differences in variances and potentially to false detection of differences (Smith et al. 1993). The second flaw in our experimental design is the choice of control reach for comparison. In many of our BACI analyses significant differences were seen between the control reach and its comparison, both before and after maintenance and reconstruction activities, despite the geographic proximity of the reaches. The conductivity in the control reach, for example, was extremely high in all years compared to the other stream reaches. These inherent differences in habitat between the control and impact reaches can be problematic if changes in environmental conditions from year to year affect one of the reaches disproportionately (Smith et al. 1993).

Future monitoring of agricultural drain maintenance and reconstruction activities should strive to standardize sampling effort between sites and among years and to include control sites that are as similar to the impact sites as possible.

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APPENDIX 1. FISH COMMUNITY DATA BY YEAR

Table A1. Fish species captured by seine in each reach of Beaver Creek from 2009 – 2015. Drain maintenance and reconstruction activities were conducted following the sampling period in 2011. C = Control reach, R = reconstructed section, I = Impact reach, N = Northern reach. Species are listed in phylogenetic order.

Species	2009				2010				2011				2012				2013				2015			
	C	R	I	N	C	R	I	N	C	R	I	N	C	R	I	N	C	R	I	N	C	R	I	N
Dorosoma cepedianum	-	-	-	X	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
Carassius auratus	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
Couesius plumbeus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-
Cyprinus carpio	-	-	-	-	-	-	-	X	X	-	-	-	X	X	X	-	-	X	X	X	-	X	X	-
Luxilus chrysocephalus	-	-	X	X	-	-	-	X	-	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-
Luxilus cornutus	-	-	-	X	-	-	-	X	-	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-
Notemigonus crysoleucas	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Notropis atherinoides	-	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	-	-
Notropis hudsonius	-	-	-	X	-	-	-	X	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-
Notropis volucellus	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
Pimephales notatus	-	-	-	X	-	-	-	X	-	-	-	-	X	-	-	X	-	X	X	X	-	X	X	-
Scardinius erythrophthalmus	-	-	-	-	-	-	X	X	-	X	X	-	X	-	-	-	-	-	-	X	-	-	-	-
Catostomus commersoni	-	X	X	X	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Species	2009				2010				2011				2012				2013				2015			
	C	R	I	N	C	R	I	N	C	R	I	N	C	R	I	N	C	R	I	N	C	R	I	N
Moxostoma valenciennesi	-	-	-	X	-	-	-	-	-	-	-	X	-	-	-	X	-	-	-	X	-	-	-	-
Ameiurus melas	-	-	-	-	-	-	-	X	X	-	X	-	X	X	X	X	-	-	X	X	-	-	-	X
Ameiurus natalis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
Ameiurus nebulosus	-	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	-	X	X	X
Ictalurus punctatus	-	-	-	-	-	--	-	-	-	-	-	-	-	-	-	X	-	X	X	-	-	-	-	-
Noturus gyrinus	-	X	X	X	-	X	X	-	X	-	X	-	-	X	X	X	-	X	X	X	-	X	X	-
Oncorhynchus mykiss	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Esox americanus vermiculatus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Esox lucius	-	-	-	X	-	-	X	X	X	X	X	X	-	X	X	X	X	X	X	X	-	X	X	X
Esox masquinongy	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Umbra limi	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Labidesthes sicculus	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ambloplites rupestris	-	-	-	X	-	-	-	X	-	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-
Lepomis cyanellus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	X	X	X
Lepomis gibbosus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Lepomis macrochirus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	-	X

Species	2009				2010				2011				2012				2013				2015			
	C	R	I	N	C	R	I	N	C	R	I	N	C	R	I	N	C	R	I	N	C	R	I	N
Lepomis megalotis	X	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	-	-	-	-	-	-	-	-
Micropterus dolomieu	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
Micropterus salmoides	X	-	X	X	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pomoxis nigromaculatus	-	-	X	-	-	-	-	-	-	X	-	-	X	X	X	-	-	-	-	-	-	-	-	-
Etheostoma nigrum	-	-	-	X	-	-	-	X	-	-	-	-	-	X	X	X	-	X	X	X	-	X	X	X
Perca flavescens	-	X	X	X	-	-	-	X	X	-	X	X	X	-	-	X	-	-	X	X	-	X	X	X
Neogobius melanostomus	-	-	-	X	-	-	-	X	-	-	-	X	-	-	-	X	-	-	-	X	-	-	-	X

APPENDIX 2. COMPLETE BACI FACTORIAL ANOVA RESULTS

The complete set of BACI factorial ANOVA analysis results for each comparison. Red text indicates significant P value (P < 0.05).

Table A2.1. Abundance: pooled before – after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	5135.02	1	5135.02	50.61050	0.000000
Before-After	1207.62	1	1207.62	11.90230	0.000704
Control-Recon	2286.70	1	2286.70	22.53759	0.000004
Interaction	861.53	1	861.53	8.49120	0.004040
Error	17552.84	173	101.462	-	-

Table A2.2. Abundance: pooled before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	4834.36	1	4834.36	34.47209	0.000000
Before-After	841.83	1	841.83	6.00281	0.015714
Control-Recon	2343.65	1	2343.65	16.71168	0.000079
Interaction	531.55	1	531.55	3.79031	0.053867
Error	16969.04	121	140.240	-	-

Table A2.3. Abundance: 1 year before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	1291.094	1	1291.094	13.15938	0.000472
Before-After	77.682	1	77.682	0.79177	0.375912
Control-Recon	725.799	1	725.799	7.39765	0.007823
Interaction	99.386	1	99.386	1.01299	0.316857
Error	8928.202	91	98.112	-	-

Table A2.4. Abundance: pooled before – after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	15984.7	1	15984.7	131.8574	0.000000
Before-After	4925.00	1	4925.00	40.6262	0.000000
Control-Impact	1306.48	1	2306.48	10.7771	0.001171
Interaction	290.6	1	290.6	2.3972	0.122791
Error	31034.16	256	121.23	-	-

Table A2.5. Abundance: pooled before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	14728.10	1	14728.10	89.76034	0.000000
Before-After	3520.37	1	3520.37	21.45487	0.000007
Control-Impact	1436.79	1	2436.79	8.75648	0.003493
Interaction	120.58	1	120.58	0.73490	0.392421
Error	30027.10	183	-	-	-

Table A2.6. Abundance: 1 year before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	3926.554	1	3926.554	55.49734	0.000000
Before-After	270.612	1	270.612	3.82480	0.052505
Control-Impact	1013.894	1	1013.894	14.33023	0.000227
Interaction	138.828	1	138.828	1.96218	0.163509
Error	9834.542	139	70.752	-	-

Table A2.7. Abundance: pooled before – after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	15696.20	1	15696.20	155.2336	0.000000
Before-After	4745.66	1	4745.66	46.9341	0.000000
Control-North	2233.92	1	2233.92	22.0932	0.000004
Interaction	561.09	1	561.09	5.5491	0.019230
Error	26390.59	261	101.11	-	-

Table A2.8. Abundance: pooled before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	13846.43	1	13846.43	105.3154	0.000000
Before-After	3245.16	1	3245.16	24.6826	0.000001
Control-North	2279.91	1	2279.91	17.3409	0.000047
Interaction	258.08	1	258.08	1.9629	0.162798
Error	25506.31	194	131.48	-	-

Table A2.9. Abundance: 1 year before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	6142.95	1	6142.95	67.62095	0.000000
Before-After	1027.70	1	1027.70	11.31276	0.001002
Control-North	490.62	1	490.62	5.40074	0.021621
Interaction	4.10	1	4.10	0.04516	0.832031
Error	12263.93	135	90.844	-	-

Table A2.10. Water temperature: pooled before – after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	28766.48	1	28766.48	1833.103	0.000000
Before-After	12.99	1	12.99	0.828	0.365622
Control-Recon	69.68	1	69.68	4.440	0.038236
Interaction	91.91	1	91.91	5.857	0.017784
Error	1255.42	80	15.69	-	-

Table A2.11. Water temperature: pooled before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	24440.41	1	24440.41	2215.163	0.000000
Before-After	116.60	1	116.60	10.568	0.001875
Control-Recon	170.38	1	170.38	15.443	0.000220
Interaction	199.94	1	199.94	18.121	0.000073
Error	673.03	61	11.03	-	-

Table A2.12. Water temperature: 1 year before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	9831.462	1	9831.462	817.0244	0.000000
Before-After	3.249	1	3.249	0.2700	0.607021
Control-Recon	79.145	1	79.145	6.5772	0.015394
Interaction	56.694	1	56.694	4.7114	0.037741
Error	373.031	31	12.033	-	-

-*Table A2.13. Water temperature: pooled before – after, control reach – impact reach.*

	SS	Deg. Freedom	MS	F	P
Intercept	46623.77	1	46623.77	3048.060	0.000000
Before-After	0.00	1	0.00	0.000	0.996133
Control-Impact	39.40	1	39.40	2.576	0.111131
Interaction	60.20	1	60.20	3.935	0.049560
Error	1835.55	120	15.30	-	-

Table A2.14. Water temperature: pooled before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	36752.45	1	36752.45	2588.868	0.000000
Before-After	26.58	1	26.58	1.872	0.174540
Control-Impact	66.52	1	66.52	4.686	0.032970
Interaction	89.04	1	89.04	6.272	0.014006
Error	1320.26	93	14.20	-	-

Table A2.15. Water temperature: 1 year before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	18303.41	1	18303.41	1029.292	0.000000
Before-After	0.05	1	0.05	0.003	0.959980
Control-Impact	15.60	1	15.60	0.877	0.353533
Interaction	65.95	1	65.95	3.709	0.059936
Error	871.34	49	17.78	-	-

Table A2.16. Water temperature: pooled before – after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	48149.82	1	48149.82	4284.386	0.000000
Before-After	0.26	1	0.26	0.023	0.879209
Control-North	33.55	1	33.55	2.986	0.086479
Interaction	54.99	1	54.99	4.893	0.028788
Error	1404.81	125	11.24	-	-

Table A2.17. Water temperature: pooled before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	35396.31	1	35396.31	2946.580	0.000000
Before-After	1.13	1	1.13	0.094	0.759419
Control-North	15.84	1	15.84	1.318	0.253683
Interaction	28.72	1	28.72	2.391	0.125210
Error	1189.25	99	12.01	-	-

Table A2.18. Water temperature: 1 year before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	18102.88	1	18102.88	1300.269	0.000000
Before-After	15.01	1	15.01	1.078	0.304448
Control-North	3.64	1	3.64	0.261	0.611546
Interaction	20.63	1	20.63	1.482	0.229562
Error	654.35	47	13.92	-	-

Table A2.19. Conductivity: pooled before – after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	102635377	1	102635377	406.7505	0.000000
Before-After	1757322	1	1757322	6.9644	0.009991
Control-Recon	2971101	1	2971101	11.7747	0.000953
Interaction	822242	1	822242	3.2586	0.074812
Error	20186404	80	252330	-	-

Table A2.20. Conductivity: pooled before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	93188593	1	93188593	384.1758	0.000000
Before-After	3739364	1	3739364	15.4158	0.000222
Control-Recon	1162537	1	1162537	4.7926	0.032418
Interaction	1507853	1	1507853	6.2162	0.015387
Error	14796621	61	242568	-	-

Table A2.21. Conductivity: 1 year before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	38208328	1	38208328	172.9401	0.000000
Before-After	669015	1	669015	3.0281	0.091753
Control-Recon	391443	1	391443	1.7718	0.192871
Interaction	512803	1	512803	2.3211	0.137770
Error	6848951	31	220934	-	-

Table A2.22. Conductivity: pooled before – after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	180649217	1	180649217	713.5114	0.000000
Before-After	1295765	1	1295765	5.1179	0.025480
Control-Impact	3885661	1	3885661	15.3472	0.000149
Interaction	352555	1	352555	1.3925	0.240319
Error	30382005	120	253183	-	-

Table A2.23. Conductivity: pooled before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	156893473	1	156893473	654.1999	0.000000
Before-After	3601645	1	3601645	15.0178	0.000198
Control-Impact	1493896	1	1493896	6.2291	0.014328
Interaction	987292	1	987292	4.1167	0.045320
Error	22303722	93	239825	-	-

Table A2.24. Conductivity: 1 year before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	73661545	1	73661545	385.7623	0.000000
Before-After	1726539	1	1726539	9.0418	0.004155
Control-Impact	1749446	1	1749446	9.1618	0.003932
Interaction	1359082	1	1359082	7.1175	0.010319
Error	9356581	49	190951	-	-

Table A2.25. Conductivity: pooled before – after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	187292676	1	187292676	1235.556	0.000000
Before-After	91468	1	91468	0.603	0.438759
Control-North	3885233	1	3885233	25.631	0.000001
Interaction	62883	1	62883	0.415	0.520715
Error	18796637	124	151586	-	-

Table A2.26. Conductivity: pooled before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	146676156	1	146676156	1006.072	0.000000
Before-After	603097	1	603097	4.137	0.044665
Control-North	2499186	1	2499186	17.142	0.000074
Interaction	15349	1	15349	0.105	0.746270
Error	14287506	98	145791	-	-

Table A2.27. Conductivity: 1 year before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	77558654	1	77558654	578.8255	0.000000
Before-After	16479	1	16479	0.1230	0.727418
Control-North	1348369	1	1348369	10.0630	0.002694
Interaction	430	1	430	0.0032	0.955048
Error	6163686	46	133993	-	-

Table A2.27. Vegetation coverage: pooled before – after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	111890.3	1	111890.3	129.9348	0.000000
Before-After	970.4	1	970.4	1.1269	0.291635
Control-Recon	11229.2	1	11229.2	13.0402	0.000530
Interaction	2311.6	1	2311.6	2.6844	0.105261
Error	68890.1	80	861.1	-	-

Table A2.28. Vegetation coverage: pooled before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	113835.4	1	113835.4	132.4237	0.000000
Before-After	4788.4	1	4788.4	5.5703	0.021482
Control-Recon	13604.3	1	13604.3	15.8257	0.000187
Interaction	4284.6	1	4284.6	4.9842	0.029261
Error	52437.4	61	859.6	-	-

Table A2.29. Vegetation coverage: 1 year before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	35729.13	1	35729.13	34.25336	0.000002
Before-After	3031.23	1	3031.23	2.90603	0.097941
Control-Recon	5055.26	1	5055.26	4.84645	0.035032
Interaction	1460.06	1	1460.06	1.39975	0.245480
Error	33378.69	32	1043.08	-	-

Table A2.30. Vegetation coverage: pooled before – after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	213181.0	1	213181.0	224.3903	0.000000
Before-After	4022.2	1	4022.2	4.2337	0.041831
Control-Impact	10630.9	1	10630.9	11.1899	0.001103
Interaction	1457.5	1	1457.5	1.5342	0.217945
Error	112105.3	118	950.0	-	-

Table A2.31. Vegetation coverage: pooled before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	218770.9	1	218770.9	225.2164	0.000000
Before-After	14767.9	1	14767.9	15.2030	0.000184
Control-Impact	10957.1	1	10957.1	11.2799	0.001146
Interaction	2327.0	1	2327.0	2.3955	0.125154
Error	88395.7	91	971.4	-	-

Table A2.32. Vegetation coverage: 1 year before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	86903.01	1	86903.01	74.31903	0.000000
Before-After	12664.56	1	12664.56	10.83067	0.001835
Control-Impact	6862.50	1	6862.50	5.86878	0.019077
Interaction	522.79	1	522.79	0.44708	0.506798
Error	58466.19	50	1169.32	-	-

Table A2.33. Vegetation coverage: pooled before – after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	275207.5	1	275207.5	295.4329	0.000000
Before-After	10112.6	1	10112.6	10.8558	0.001290
Control-North	2659.7	1	2659.7	2.8552	0.093632
Interaction	9.5	1	9.5	0.0102	0.919796
Error	113647.8	122	931.5	-	-

Table A2.34. Vegetation coverage: pooled before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	249955.8	1	249955.8	263.5182	0.000000
Before-After	19120.4	1	19120.4	20.1578	0.000020
Control-North	5331.1	1	5331.1	5.6203	0.019751
Interaction	1001.9	1	1001.9	1.0563	0.306653
Error	91059.2	96	948.5	-	-

Table A2.35. Vegetation coverage: 1 year before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	95223.86	1	95223.86	91.34945	0.000000
Before-After	18349.63	1	18349.63	17.60303	0.000120
Control-North	5165.22	1	5165.22	4.95506	0.030847
Interaction	0.91	1	0.91	0.00087	0.976610
Error	48993.41	47	1042.41	-	-

Table A2.36. Secchi depth: pooled before – after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	4.411218	1	4.411218	134.6441	0.000000
Before-After	0.018175	1	0.018175	0.5548	0.458868
Control-Recon	0.745376	1	0.745376	22.7512	0.000010
Interaction	0.009666	1	0.009666	0.2950	0.588740
Error	2.293345	70	0.032762	-	-

Table A2.37. Secchi depth: pooled before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	2.833549	1	2.833549	75.54124	0.000000
Before-After	0.032923	1	0.032923	0.87772	0.353157
Control-Recon	0.530227	1	0.530227	14.13564	0.000432
Interaction	0.005499	1	0.005499	0.14661	0.703358
Error	1.950518	52	0.037510	-	-

Table A2.38. Secchi depth: 1 year before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	0.765632	1	0.765632	77.84574	0.000000
Before-After	0.008570	1	0.008570	0.87138	0.359870
Control-Recon	0.267204	1	0.267204	27.16801	0.000024
Interaction	0.009134	1	0.009134	0.92869	0.344814
Error	0.236046	24	0.009835	-	-

Table A2.39. Secchi depth: pooled before – after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	9.674395	1	9.674395	263.9920	0.000000
Before-After	0.065647	1	0.065647	1.7913	0.183626
Control-Impact	0.601933	1	0.601933	16.4254	0.000097
Interaction	0.002449	1	0.002449	0.0668	0.796512
Error	3.884533	106	0.036647	-	-

Table A2.40. Secchi depth: pooled before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	6.714471	1	6.714471	164.6503	0.000000
Before-After	0.071582	1	0.071582	1.7553	0.188936
Control-Impact	0.393438	1	0.393438	9.6478	0.002613
Interaction	0.005416	1	0.005416	0.1328	0.716482
Error	3.303195	81	0.040780	-	-

Table A2.41. Secchi depth: 1 year before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	2.201760	1	2.201760	190.4725	0.000000
Before-After	0.018970	1	0.018970	1.6411	0.207370
Control-Impact	0.279234	1	0.279234	24.1564	0.000015
Interaction	0.020182	1	0.020182	1.7459	0.193713
Error	0.473938	41	0.011559	-	-

Table A2.42. Secchi depth: pooled before – after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	14.94358	1	14.94358	472.4782	0.000000
Before-After	0.01156	1	0.01156	0.3654	0.546769
Control-North	0.00487	1	0.00487	0.1539	0.695637
Interaction	0.04083	1	0.04083	1.2910	0.258348
Error	3.44746	109	0.03163	-	-

Table A2.43. Secchi depth: pooled before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	10.12867	1	10.12867	305.1906	0.000000
Before-After	0.03416	1	0.03416	1.0293	0.313132
Control-North	0.00496	1	0.00496	0.1494	0.700065
Interaction	0.02559	1	0.02559	0.7711	0.382299
Error	2.88736	87	0.03319	-	-

Table A2.44. Secchi depth: 1 year before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	3.928295	1	3.928295	185.0268	0.000000
Before-After	0.013038	1	0.013038	0.6141	0.437755
Control-North	0.003130	1	0.003130	0.1474	0.703003
Interaction	0.014059	1	0.014059	0.6622	0.420494
Error	0.870469	41	0.021231	-	-

Table A2.45. Water depth: pooled before – after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	40.67365	1	40.67365	597.8936	0.000000
Before-After	0.02158	1	0.02158	0.3172	0.574887
Control-Recon	1.19031	1	1.19031	17.4973	0.000073
Interaction	0.72674	1	0.72674	10.6829	0.001595
Error	5.44226	80	0.06803	-	-

Table A2.46. Water depth: pooled before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	33.11678	1	33.11678	449.0986	0.000000
Before-After	0.22980	1	0.22980	3.1163	0.082435
Control-Recon	0.82645	1	0.82645	11.2076	0.001389
Interaction	0.54230	1	0.54230	7.3542	0.008647
Error	4.57191	62	0.07374	-	-

Table A2.47. Water depth: 1 year before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	14.04343	1	14.04343	209.4538	0.000000
Before-After	0.06918	1	0.06918	1.0317	0.317614
Control-Recon	0.10331	1	0.10331	1.5408	0.223814
Interaction	0.04424	1	0.04424	0.6598	0.422838
Error	2.07848	31	0.06705	-	-

Table A2.48. Water depth: pooled before – after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	71.06478	1	71.06478	1006.617	0.000000
Before-After	0.41100	1	0.41100	5.822	0.017382
Control-Impact	1.78889	1	1.78889	25.339	0.000002
Interaction	0.07935	1	0.07935	1.124	0.291240
Error	8.25992	117	0.07060	-	-

Table A2.49. Water depth: pooled before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	54.97248	1	54.97248	671.1611	0.000000
Before-After	0.08430	1	0.08430	1.0292	0.313071
Control-Impact	1.76465	1	1.76465	21.5446	0.000012
Interaction	0.00220	1	0.00220	0.0268	0.870234
Error	7.37159	90	0.08191	-	-

Table A2.50. Water depth: 1 year before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	23.31659	1	23.31659	296.4742	0.000000
Before-After	0.00000	1	0.00000	0.0000	0.995050
Control-Impact	0.63004	1	0.63004	8.0110	0.006871
Interaction	0.00556	1	0.00556	0.0707	0.791533
Error	3.61773	46	0.07865	-	-

Table A2.51. Water depth: pooled before – after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	105.5120	1	105.5120	1208.116	0.000000
Before-After	1.3691	1	1.3691	15.676	0.000123
Control-North	0.0023	1	0.0023	0.026	0.872158
Interaction	0.0417	1	0.0417	0.477	0.490943
Error	11.3537	130	0.0873	-	-

Table A2.52. Water depth: pooled before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	76.53696	1	76.53696	758.2990	0.000000
Before-After	0.48485	1	0.48485	4.8037	0.030629
Control-North	0.02115	1	0.02115	0.2095	0.648113
Interaction	0.12479	1	0.12479	1.2364	0.268735
Error	10.49697	104	0.10093	-	-

Table A2.53. Water depth: 1 year before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	41.24092	1	41.24092	430.3791	0.000000
Before-After	0.03272	1	0.03272	0.3414	0.561638
Control-North	0.01462	1	0.01462	0.1525	0.697779
Interaction	0.07055	1	0.07055	0.7362	0.394978
Error	4.79123	50	0.09582	-	-

Table A2.54. Water velocity: pooled before – after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	0.169191	1	0.169191	4.042464	0.050522
Before-After	0.165024	1	0.165024	3.942910	0.053323
Control-Recon	0.072160	1	0.072160	1.724122	0.195970
Interaction	0.069448	1	0.069448	1.659321	0.204428
Error	1.841546	44	0.041853	-	-

Table A2.55. Water velocity: pooled before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	0.141385	1	0.141385	2.074649	0.161261
Before-After	0.141385	1	0.141385	2.074649	0.161261
Control-Recon	0.059902	1	0.059902	0.878993	0.356789
Interaction	0.059902	1	0.059902	0.878993	0.356789
Error	1.840022	27	0.068149	-	-

Table A2.56. Water velocity: 1 year before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Intercept	0.118637	1	0.118637	1.565558	0.223996
Before-After	0.118637	1	0.118637	1.565558	0.223996
Control-Recon	0.050793	1	0.050793	0.670272	0.421737
Interaction	0.050793	1	0.050793	0.670272	0.421737
Error	1.667150	22	0.075780	-	-

Table A2.57. Water velocity: pooled before – after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	0.258479	1	0.258479	7.488343	0.008388
Before-After	0.232930	1	0.232930	6.748161	0.012070
Control-Impact	0.122718	1	0.122718	3.555237	0.064742
Interaction	0.130388	1	0.130388	3.777430	0.057168
Error	1.863948	54	0.034518	-	-

Table A2.58. Water velocity: pooled before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	0.207133	1	0.207133	4.151099	0.048807
Before-After	0.207133	1	0.207133	4.151099	0.048807
Control-Impact	0.106734	1	0.106734	2.139024	0.152036
Interaction	0.106734	1	0.106734	2.139024	0.152036
Error	1.846241	37	0.049898	-	-

Table A2.59. Water velocity: 1 year before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Intercept	0.208558	1	0.208558	3.747419	0.062362
Before-After	0.208558	1	0.208558	3.747419	0.062362
Control-Impact	0.134377	1	0.134377	2.414508	0.130703
Interaction	0.134377	1	0.134377	2.414508	0.130703
Error	1.669617	30	0.055654	-	-

Table A2.60. Water velocity: pooled before – after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	0.370871	1	0.370871	9.463269	0.003339
Before-After	0.347766	1	0.347766	8.873721	0.004388
Control-North	0.048640	1	0.048640	1.241115	0.270379
Interaction	0.051704	1	0.051704	1.319286	0.255976
Error	2.037909	52	0.039191	-	-

Table A2.61. Water velocity: pooled before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	0.293415	1	0.293415	4.769076	0.036188
Before-After	0.293415	1	0.293415	4.769076	0.036188
Control-North	0.040971	1	0.040971	0.665925	0.420328
Interaction	0.040971	1	0.040971	0.665925	0.420328
Error	2.030306	33	0.061524	-	-

Table A2.62. Water velocity: 1 year before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Intercept	0.430347	1	0.430347	6.612641	0.015726
Before-After	0.430347	1	0.430347	6.612641	0.015726
Control-North	0.044122	1	0.044122	0.677969	0.417245
Interaction	0.044122	1	0.044122	0.677969	0.417245
Error	1.822225	28	0.065079	-	-

Table A2.63. Fish Assemblage: pooled before – after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Before-After	11.008	1	11.008	5.58951	0.001
Control-Recon	9.887	1	9,887	5.2946	0.001
Interaction	1.771	1	1,771	0.9483	0.453
Error	63.491	34	1.8674	-	-

Table A2.64. Fish Assemblage: pooled before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Before-After	7.628	1	7.628	5.2137	0.001
Control-Recon	4.775	1	4.775	3.2636	0.010
Interaction	2.850	1	2.850	1.9478	0.071
Error	27.799	19	1.4631	-	-

Table A2.65. Fish Assemblage: 1 year before – 1 year after, control reach – reconstructed section.

	SS	Deg. Freedom	MS	F	P
Before-After	3.247	1	3.247	2.05502	0.075
Control-Recon	1.5851	1	1.5851	1.00318	0.430
Interaction	0.7118	1	0.7118	0.45046	0.910
Error	14.2205	9	1.5801	-	-

Table A2.66. Fish Assemblage: pooled before – after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Before-After	0.65665	1	0.65665	4.23	0.001
Control-Impact	1.0351	1	1.0351	6.668	0.001
Interaction	0.1181	1	0.1181	0.7608	0.605
Error	7.1408	46	0.15523	-	-

Table A2.67. Fish Assemblage: pooled before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Before-After	0.5492	1	0.5492	4.4767	0.002
Control-Impact	0.5585	1	0.5585	4.5530	0.003
Interaction	0.2051	1	0.2051	1.6720	0.109
Error	3.3122	27	-	-	-

Table A2.68. Fish Assemblage: 1 year before – 1 year after, control reach – impact reach.

	SS	Deg. Freedom	MS	F	P
Before-After	0.28424	1	0.28424	2.0084	0.051
Control-Impact	0.210	1	0.210	1.4838	0.159
Interaction	0.17621	1	0.17621	1.2450	0.259
Error	1.83987	13	-	-	-

Table A2.69. Fish Assemblage: pooled before – after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Before-After	0.3849	1	0.3849	1.979	0.070
Control-North	1.4334	1	1.4334	7.3703	0.001
Interaction	0.1281	1	0.1281	0.6584	0.673
Error	7.7795	40	0.19449	-	-

Table A2.70. Fish Assemblage: pooled before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Before-After	0.8089	1	0.8089	4.4116	0.004
Control-North	1.4532	1	1.4532	7.9258	0.001
Interaction	0.12813	1	0.12813	0.6988	0.605
Error	4.7671	26	0.18335	-	-

Table A2.70. Fish Assemblage: 1 year before – 1 year after, control reach – northern reach.

	SS	Deg. Freedom	MS	F	P
Before-After	0.6219	1	0.6219	3.10268	0.003
Control-North	0.4604	1	0.4604	2.29674	0.031
Interaction	0.1806	1	0.1806	0.90107	0.525
Error	2.0044	10	2.0044	-	-