Effects of Stream Crossing Type on Fish Assemblages and Stream Ecosystem Conditions

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Department of Environmental Science at Allegheny College
and approved by the senior thesis committee.

Chris Shaffer	**Date**	**Dr. Mark A. Kirk**	**Date**

Pledge

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Abstract

Culverts are used as road crossings to connect the upstream and downstream reaches of a stream, but they can severely alter habitat characteristics and species assemblages. Many culvert features impede fish biodiversity, movement, and survival therefore restorations of these crossings can be completed to help address these ecological concerns. Paired upstream-downstream assessments determine the effects of restoration of old/to be replaced culverts and predict the future success of newly replaced culverts. We sampled stream crossing in stream orders 1st – 3rd in the French Creek watershed in northwestern Pennsylvania to evaluate the influence of different road crossing types. Three sites contain old, to be replaced culverts scheduled to be replaced in 2023, four sites contain newly recently replaced culverts, and the last four sites were bridges. We collected fish, abiotic, and stream crossing data at each sample site. We determined NAACC passability scores for each stream crossing. Findings from passability tests show that to be replaced crossings had the lowest passability scores from 0.03 - 0.597 on a scale of zero to one, whereas all bridges and newly replaced culverts had scores > 0.85. These to be replaced culverts were not allowing fish species to move effectively upstream and downstream. Specific species such as suckers and darters were not able to move upstream in these streams of the to be replaced culverts. The Crawford County Conservation District (CCCD) is replacing two of the three to be replaced culverts this year. Our research will set the baseline to see the effects of restoration.

Introduction

Stream connectivity is essential to maintain biotic integrity and the completeness of fish assemblages. Movement of fish is needed for many migratory species that spawn in different habitats. Biotic integrity is the ability to support and preserve organisms living within the ecosystem (Karr, 1987). Fragmentation, which is the separation of habitat, can negatively impact biotic integrity by altering the connectivity within a stream **(**Wood et al., 2018; Norman et al., 2009; Nathan et al., 2018; Maitland et al., 2016; MacPherson et al., 2012; Favaro et al., 2014; Evans et al., 2015; Benton et al., 2008). Humans impact streams by creating barriers, such as culverts that unintentionally can decrease stream connectivity (Cote et al., 2009). These passage barriers can reduce the productivity of fish populations when habitats are disrupted (Poplar-Jeffers et al., 2009; Fausch et al., 2002).

Fish Communities

Certain migratory species that spawn in different habitats require stream connectivity to thrive. Pennsylvania's native trout species, the Brook trout (*Salvelinus fontinalis*), are species that are representative of the condition and state of the stream, which makes them an ideal indicator species given that they can only survive in relatively undisturbed conditions (Kirk et al., 2017). As a cold-water species, brook trout also need to be able to migrate upstream to spawn for reproduction when water temperatures in downstream areas exceed 20 degrees Celsius (Fitch, 1995). Specific species that frequently move between habitats mostly for reproduction purposes, such as brook trout, will not flourish where fragmentation affects reproduction. In the French Creek watershed, darter species are also indicative of ideal, high quality stream conditions (Beggs & VanRy, 2017). Fish-based metrics can thus be used to show how the fish communities compare across different stream crossing types.

Crossing Structures

Human modifications such as stream crossings are most of the time necessary but can disrupt aquatic ecosystems. Stream crossings, such as bridges and culverts are permanent structures that are built to connect the upstream and downstream reaches which allows the stream to maintain longitudinal connectivity. Notable reach and crossing effects can be a result of barriers in the stream. A reach effect is a characteristic that only affects the upstream or downstream reach of the stream. A crossing effect is when the crossing structure has an effect on the stream. Culverts can have detrimental impacts on fish abundance and richness, and more so than bridges, can be potential barriers to fish passage (Katopodis & Williams 2012; Warren & Pardew, 1998; Gautam & Bhattarai, 2018; Evans et al., 2015) because they can cause habitat fragmentation (Poplar-Jeffers et al., 2009). Culverts are the preferred stream crossing structure due to the higher cost of installing bridges (Gibson et al., 2005; Clay, 1995). Common types of culverts are box or circular, which can be made of metal, concrete, or plastic (Baker & Votapka, 1990). When culverts are improperly designed or installed they become barriers to passage and consequently greatly impede the normal movements of fish (Bates et al., 2003; Benton et al., 2008; MacPherson et al., 2012; Norman et al., 2009; Price et al., 2010; Schaefer et al., 2003). In this study, old/to be replaced culverts are defined as culverts that are deteriorating, limiting passage, or hazardous. Culverts become an unnatural disruption that causes many negative effects, but when replaced with a better design, stream connectivity and passability can be restored to improve the biotic integrity of the stream (Ogren & Huckins, 2015).

Culvert Characteristics & Concerns

The specific physical characteristics of culverts that can negatively affect fish populations are outlet drop, slope, and lengths of the culverts (Briggs & Galarowicz, 2013). All of these factors can create greater problems such as increased current velocities (Feurich et al., 2012), increased turbulence, increased temperature, decreased dissolved oxygen (DO), higher sedimentation rates, flow alterations, and increased debris blockages (Maitland et al., 2016). When the flow is increased, increased current velocities and turbulence can make it difficult for movements upstream (Feurich et al., 2012). However, if there is not enough water to flow through the culvert, this can cause difficulties in movement as well as decreased water quality due to possible sediment buildup.

At times, culverts do not allow fish species to travel pass and become stranded on one side of the culvert. This greatly limits the amount of habitat that a species can occupy in a watershed and decreases genetic diversity over a period of time (Wood et al., 2018). Each fish species has a different niche where they best survive and reproduce, and when habitats are altered, the chance of survival becomes reduced (Poplar-Jeffers et al., 2009). As a result, there can be a decrease in migration or movement of species (Strayer, 2006), a decrease in biodiversity, and a decrease in genetic diversity among fish (Wood et al., 2018). While some species are able to exert more energy and travel further upstream during high flows, allowing them to pass through the culvert, others are not(Adams et al., 2000; Toepfer et al., 1999). This will affect each species differently, which directly influences the facilitation of gene flow through reproduction. Over time, this will decrease the genetic diversity of the fish populations as a result of reproductive isolation.

Stream Crossing Restorations

As stream crossings are replaced with more environmentally friendly designs, streams can be partially restored (Gautam & Bhattarai, 2018). The effects of replacement can begin instantly, such as reestablishing stream connectivity, but some effects take longer. In Evans et al. (2015), the authors describe the increase in Blacknose Dace (*Rhinichthys atratulus*) and Creek Chub (*Semotilus atromaculatus*) average mass after the replacement of culverts to bridges. Another example of this can be an increase in genetic diversity among species. Poor installation of culverts can result in the creation of deep poles due to the height of the outlet drop. This decreases connectivity by preventing the species from moving upstream or downstream through the culvert (Wood et al., 2018). Post-restoration, species should be able to move upstream and downstream to restore population connectivity, therefore increasing genetic diversity.

In order to facilitate the identification of which structures need restoration, surveys such as the North Atlantic Aquatic Connectivity Collaborative (NAACC) have been developed. The NAACC is made up of a group of researchers that have a shared goal of improving aquatic connectivity across 13 states, including Pennsylvania. NAACC assessments were conducted in the stream, which was then entered into the NAACC database to get a calculated passability score depending on the features of the stream crossing (North Atlantic Aquatic Connectivity Collaborative [NAACC]).

Stream crossing restorations are essential for limiting long-term negative impacts due to faulty installations or poorly aging culverts. This senior comprehensive project occurred in collaboration with the Watershed Conservation Research Center (WCRC) and the Crawford County Conservation District (CCCD), which are overseeing numerous watershed restoration activities. In collaboration with multiple partners, our goal was to monitor streams that have been recently replaced with new culverts and to evaluate old, ineffective culverts in need of replacements in the future. The findings of this project will directly impact the future restoration of these to be replaced culverts. Long-term monitoring of the impacts of stream crossing restorations will follow the completion of this project where no current research exists on the effects of culverts within the French Creek watershed, a system of high fish diversity (Kirk & Wissinger, 2020).

Objectives

In this study, I determined the effects of different stream crossings on fish communities and stream ecosystems. The objective of this senior project is to (1) determine passability scores for three different stream crossing classifications (new crossings, to be replaced crossings, reference bridges); (2) determine if restoration actions for newly replaced culverts increases the similarity between upstream and downstream fish assemblages by comparing the three different stream crossings, and (3) determine whether old/to be replaced crossings have reduced biotic integrity for fish assemblages relative to bridges and newly replaced crossings. These results can act as a model for assessing the success of restored stream crossings.

Methods

Sample Sites

This study focused on small streams (1st - 3rd order) located in the French Creek watershed in northwestern Pennsylvania. A total of 11 sample sites were analyzed; three sites that have old, to be replaced culverts, four sites that have newly replaced culverts, and four sites are bridges, which serve as reference streams (Figure 1). The reference sites portray normal stream conditions with a less invasive type of stream crossing. This is a non-random selection of streams because the old culverts are scheduled to be replaced by the CCCD in the summer of 2023, whereas newly replaced culverts have occurred only in the past five years. All data collection was conducted from mid-September through the end of November when baseflow conditions occurred. Each stream was sampled from 50 meters to 120 meters upstream and downstream of the road crossing, with the majority sampling reaches equaling 100 meters in length. Sampling distance was determined by the stream characteristics (e.g., watershed area and stream width), but was sufficient enough for accurately capturing community representation based on prior studies (e.g., Kirk et al., 2017).

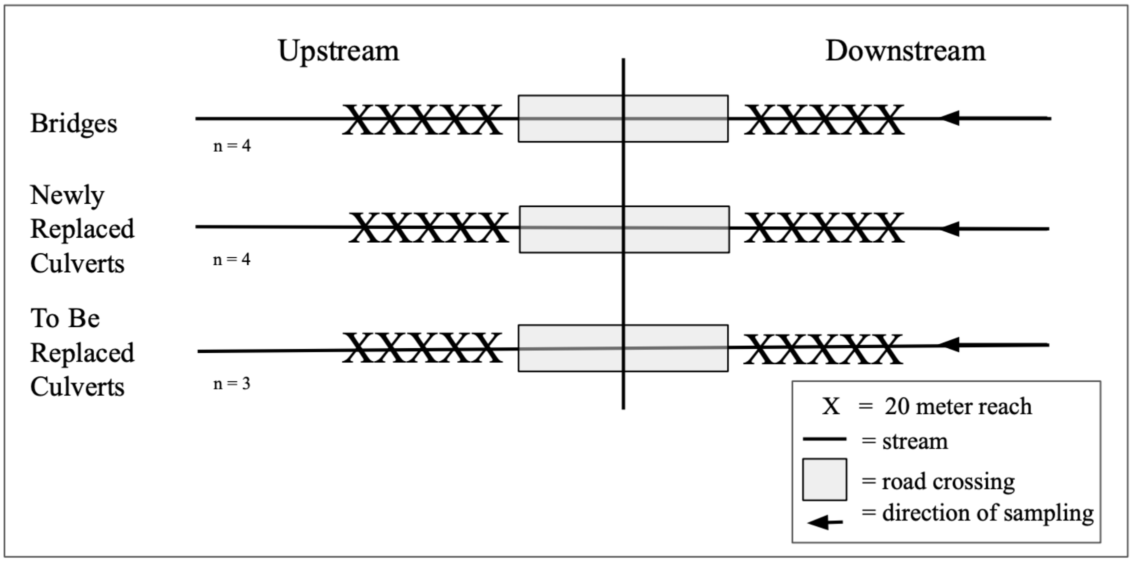

Figure 1: The sampling design for the three different stream crossing types in our study. The key is in the bottom right corner.

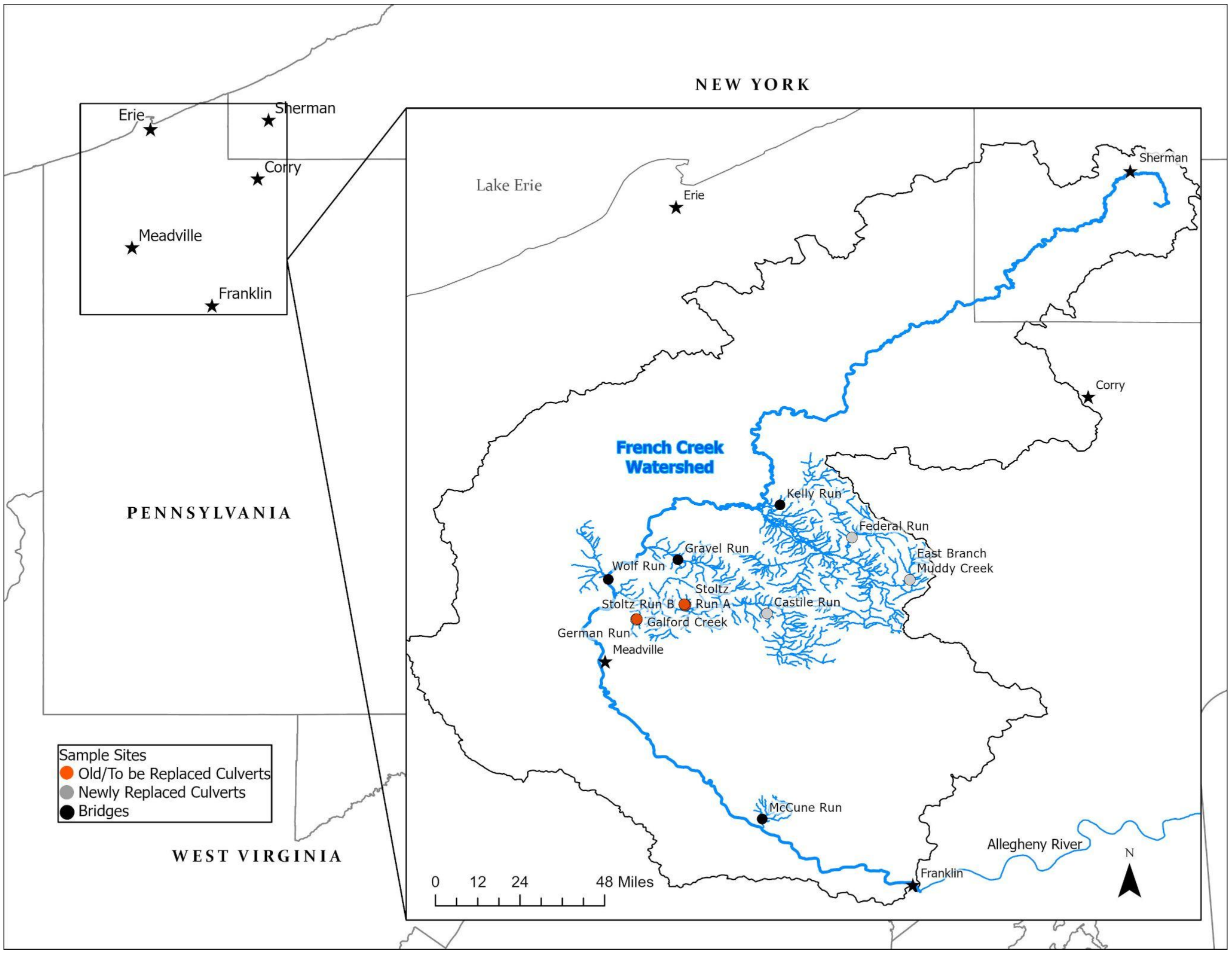

Figure 2: Location of the different stream crossing locations in northwest Pennsylvania in the French Creek Watershed.

Landscape-level Data Collection

Geographic information systems (GIS) were used to map the sample sites and collect landscape-level data. The GPS chips in smartphones were used to collect exact coordinates at each sample site (Figure 2) (Environmental Systems Research Institute [ESRI], 2022). Each set of coordinates was uploaded into ArcGIS Pro Version 2.5 (ESRI, 2022). Landscape data was collected for all streams, which included watershed area (km2), stream slope (m/km elevation change), and watershed-level land cover associated with forest cover and agricultural cover (e.g., row crops and pasture/hay) (National Land Cover Dataset, 2019). Landscape data was collected from prior studies (Kirk & Wissinger, 2020).

NAACC Assessments

At each stream crossing, a NAACC assessment was completed. NAACC assessments were used to find a passability score by quantifying the parameter of each stream-crossing structure. Passability ratings are used as a scoring system to determine if fish are able to pass through certain stream crossings. The passability score was calculated by a weighted system of 13 variables which produced a score on a scale from 0 to 1; 0 being poor and 1 being excellent. A low passability score indicates an impassable culvert and a higher passability score indicates a passable culvert in terms of Aquatic Organism Passage (AOP) (Scoring Road‑Stream Crossings, 2015).

Parameter	Weight
Outlet drop	0.161
Physical barriers	0.135
Constriction	0.09
Inlet grade	0.088
Water depth	0.082
Water velocity	0.08
Scour pool	0.071
Substrate matches stream	0.07
Substrate coverage	0.057
Openness	0.052
Height	0.045
Outlet armoring	0.037
Internal structures	0.032

Table 1. The thirteen parameters used to calculate the NAACC passability score and the weighting criteria that was given to the scores.

Passability Scores

NAACC Aquatic Passability Scores (APS) are calculated in three steps for us within the NAACC database. The first step is to calculate component scores by scoring each part of the culvert or bridge, this was completed in the field. Next, the scores get weighted with each of the 13 parameters weighting 0.161 to 0.032 to produce a composite score (Table 1). The final step is to calculate APS using the formula Min[Composite score, Outlet Drop score]. The calculated APS is the lower of either the composite score or the outlet drop component score since the outlet drop is the biggest determining factor of passability (Scoring Road‐Stream Crossings, 2015). Once completed, the data was entered into the NAACC database and a passability score was given.

Hydrology Data Collection

Hydrology data was collected at transects along the stream. The upstream and downstream reaches of each site had five transects to get a representation of the whole stream.

Each transect was taken at approximately 20 m intervals, depending on the total meters surveyed (see Figure 1). If the stream was not deep enough to get depth and velocity readings, a zero was marked in the data. Depths (cm), velocity (m/sec), and stream widths (m) were measured at all 5 transects. Additionally, depths and velocities were taken at the left bank, center, and right bank of each transect, when the stream had enough representative flow for bank measurements. Depths (cm) and velocity (m/s) were measured using a Marsh McBirney meter (Hach FH950) and discharge (feet^3/sec)was calculated for each transect.

Chemical Data Collection

Data was collected on the chemical properties of each stream. Water chemistry for hardness (mg/L) and alkalinity (mg/L) was completed once upstream and downstream in one selected transect. All other data were collected at all five transects per reach. An ecotestr ph2 (EcoTestr pH 2) was used to find pH and a YSI probe (Pro20 Dissolved Oxygen Meter) was used for dissolved oxygen (DO; mg/L). A LaMotte Tracer Pocketester 1749 (Salt/TDS/conductivity/TEMP TRACER pocketester™) was used to collect information on total dissolved solids (TDS; ppm and µs) and temperature (°C).

Biotic Data Collection

To collect data on fish assemblages, electrofishing was completed using a Smith Root LR-24 under base-flow conditions on downstream to upstream reaches using previously established sampling methods (Kirk et al., 2017). Electrofishing was conducted in the upstream direction. We did a single pass sample with two to three people netting in a zig-zig motion to ensure fish were captured. In the stream, all different habitat areas were sampled to ensure full species representation was captured. Each fish caught was identified, tallied, and then put back into the stream. Lengths (mm) were also documented for a subset of certain fish species. The fish selected are blacknose dace and creek chub because they were the only species consistently caught in high abundance across all streams. We only collected this data for newly replaced culverts and poor culverts.

Data Analysis

Microsoft Excel was used to analyze the data. We used ANOVA; an analysis of variance framework for determining the differences between the three crossing types (old/to be replaced, newly replaced, bridges) and the two reach types downstream vs. upstream (Vasavada, 2016). F-values were calculated as the effect size of our ANOVA and treatment-wide p-values of the three types of stream crossings were calculated for statistical significance. The statistical significance was determined when $p < 0.05$.

Results

Passability Scores

We observed a significant crossing effect with respect to the passability score ($F = 19.8$, $p = < 0.001$; Figure 3). All bridges and newly replaced culverts had passability scores in the 0.80 - 0.99 range which qualifies them as insignificant barriers. In contrast, the old culverts were considered to be much greater barriers; one in the range of 0.40 - 0.59 (moderate barrier) and two in the range of 0.00 - 0.19 (severe barrier).

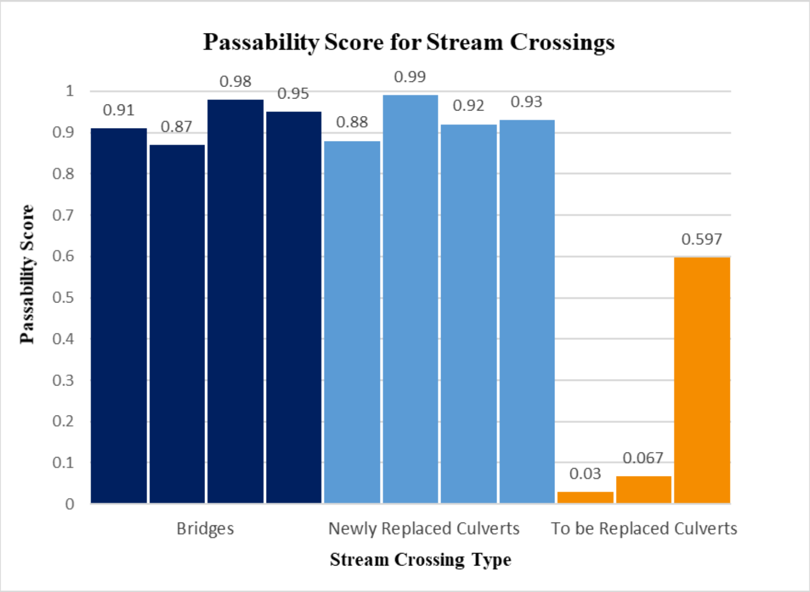

Figure 3: NAACC Passability Scores for all three stream crossing types.

Hydrology Data

Hydrology data was quantified based on stream width, stream depth, stream velocity, and discharge. We observed a significant crossing effect with respect to stream widths ($F = 13.7$, $p = < 0.001$), depth ($F = 9.17$, $p < 0.001$), and velocity ($F = 14.4$, $p < 0.001$), in which bridges were on larger, deeper, and faster streams compared with newly replaced and old culverts (Figure 4). There was an insignificant crossing effect with respect to discharge (F = 1.7093, p = 0.1896). In contrast, we observed no significant reach effects for hydrology data.

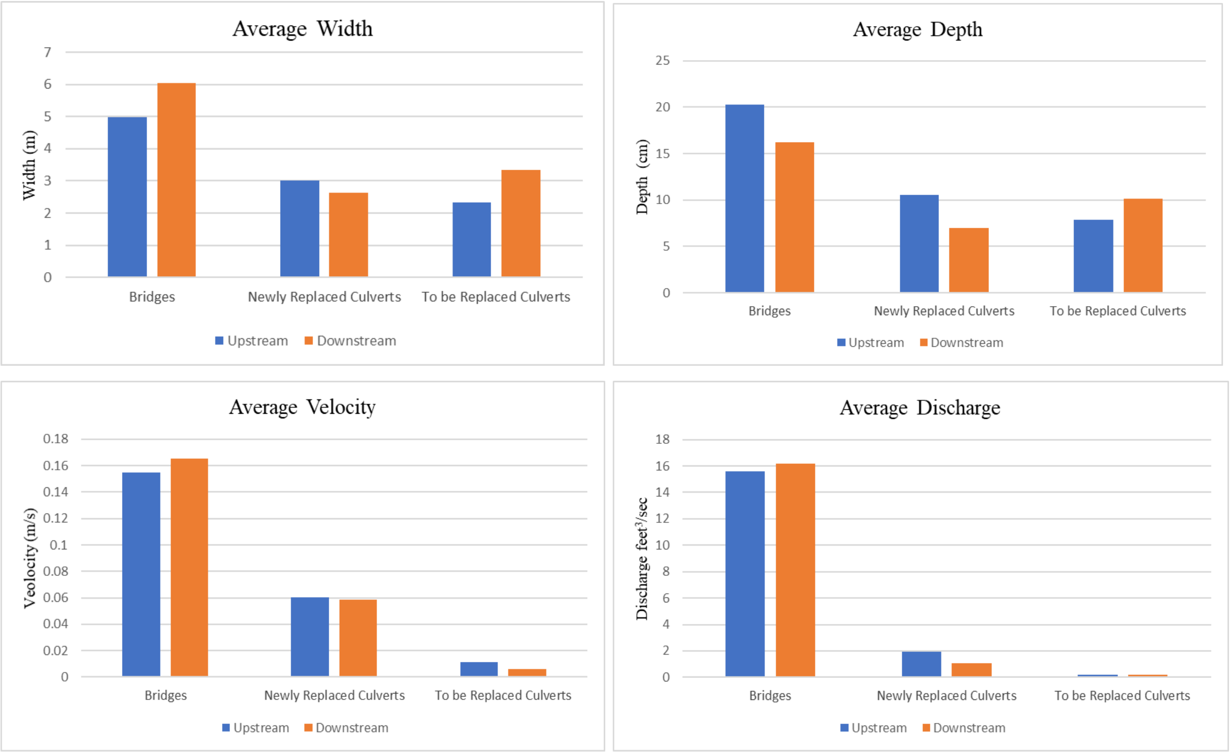

Figure 4: Hydrology data collection for average stream widths, depths, velocities, and discharge across the three different stream crossing types.

Chemical Data

We observed a significant crossing effect with respect to temperature (F = 8.08, $p < 0.001$) and with respect to dissolved oxygen (F = 7.97, $p < 0.001$), in which newly replaced culverts tended to have warmer temperatures and lower DO than bridges and old culverts (Figure 5). No significant differences were observed for crossings and reaches with respect to TDS (F = 2.44, p = 0.039), pH (F = 1.74, p = 0.1316), Alkalinity (F = 4.5, p = 0.0118), and hardness (F = 0.9467, p = 0.4815).

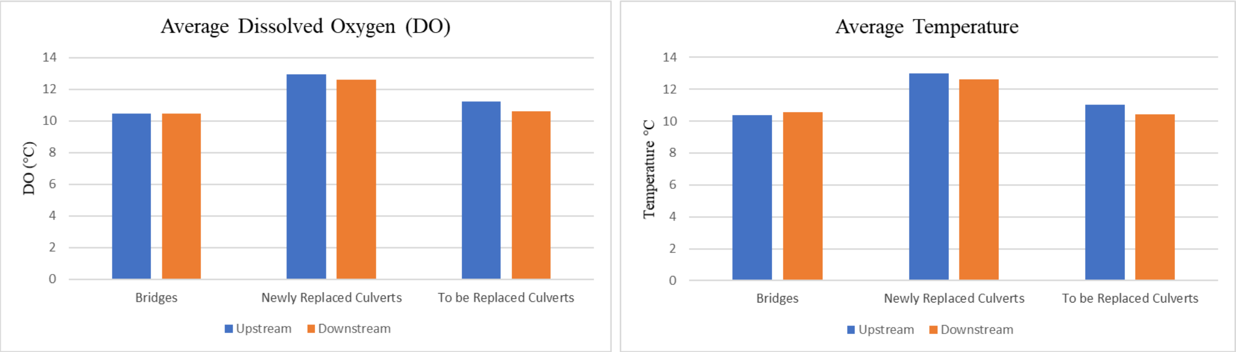

Figure 5: Chemical data collection of average dissolved oxygen and average temperature across the three different stream crossing types.

Stream Fish Communities

There were no significant differences between the crossing types for fish density. The average number of fish across the 11 sites ranged greatly, but was similar for the different crossing types (F = 1.729, p = .1851). There was a significant difference for crossing type with respect to the average number of species though (F = 3.778, p = .0189) because the old culverts had the lowest species richness. Importantly though, there appeared to be a reach effect for the to be replaced culverts, with richness and density much lower upstream compared with downstream (Figure 6). Values were more similar for upstream and downstream reaches in the other two crossing types.

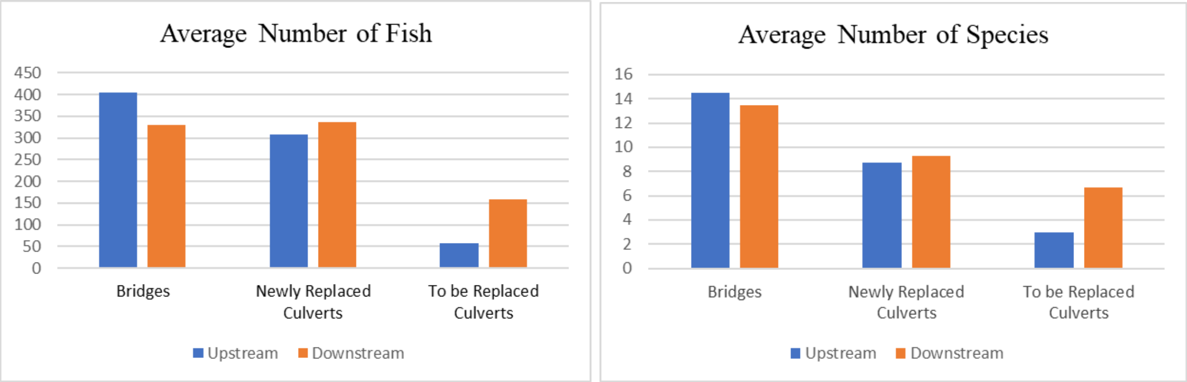

Figure 6: Fish data collection for the average number of fish and the average number of species across the three different stream crossing types.

We observed a significant crossing effect with respect to the average number of darter species ($p < 0.001$) and near significance with respect to suckers abundance (F = 2.6589, p = 0.0453), in which to be replaced culverts had lower sucker and darter abundances. Furthermore, we observed a reach effect for the to be replaced culverts, which tended to have zero darters and zero suckers upstream of these crossings (Figure 7). No significant differences were observed for darter species abundance (F = 1.1641, p = 0.3441), Brown trout abundance (F = 1.6309, p = .2563), and the average number of minnow species (F = 0.1429, p = 0.9752), although minnow species richness was much lower above the to be replaced culverts.

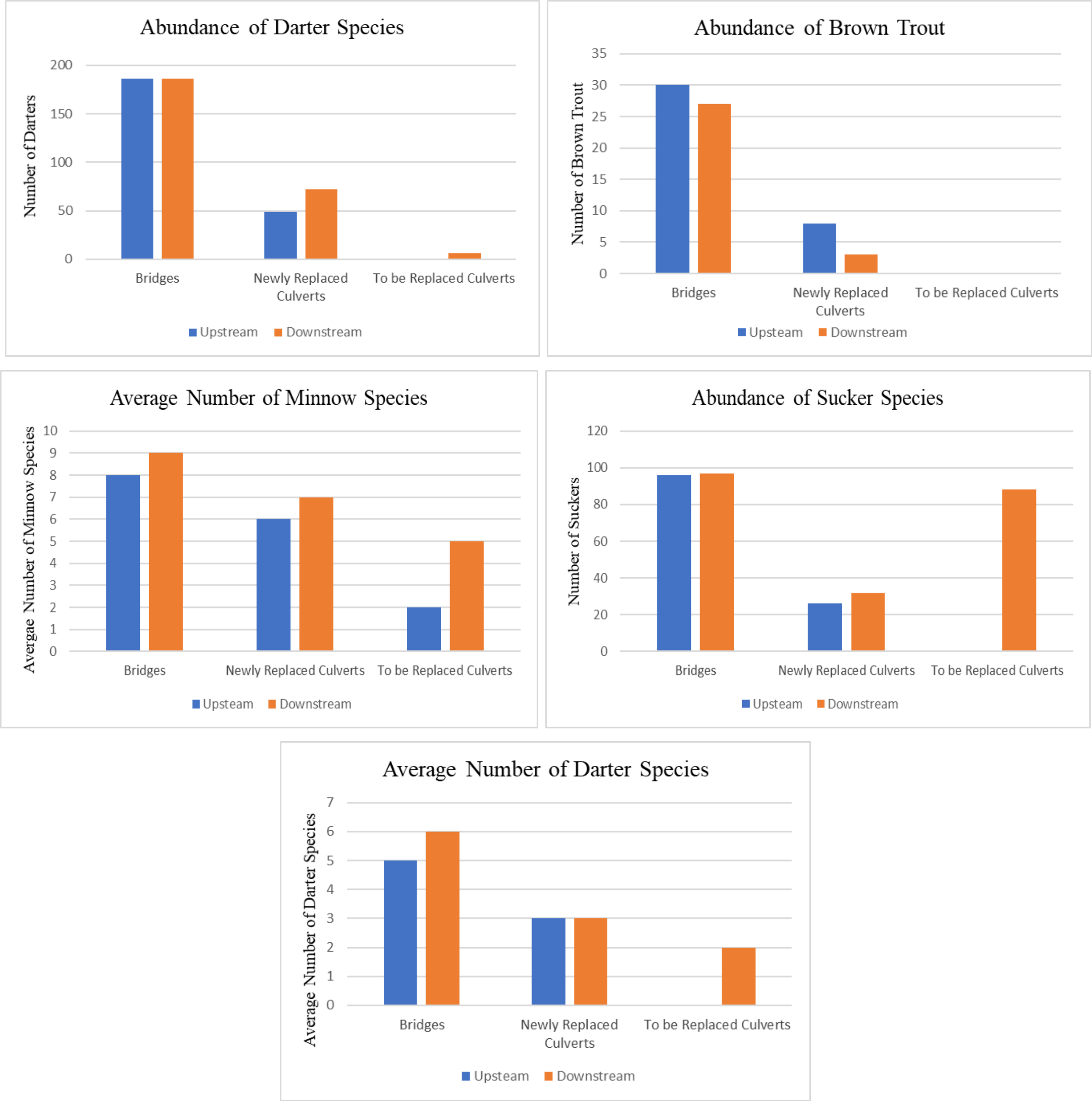

Figure 7: Specific fish assemblage metrics across the different stream crossing types. In particular, note the decreased values of fish assemblage metrics in upstream reaches of the to be replaced culverts.

No significant differences were observed for the average length of creek chub (*F* = 0.42; *P* = 0.746) or blacknose dace (*F* = 0.73; *P* = 0.565) for crossings and reach types. Standard error bars are not overlapping for blacknose dace (Figure 8) or creek chub, although creek chub length was much smaller in upstream reaches (mean length = 80.98 mm) compared to downstream reaches (mean length = 93.87 mm) of to be replaced stream crossings (Figure 9). For creek chub abundance, standard error bars are not overlapping, but again we observed fewer individuals in upstream reaches (mean length = 24.33) compared with downstream reaches (mean length = 59.67) of to be replaced crossings (Figure 10). Hence, downstream reaches have a ~2.45 times greater abundance of creek chub than upstream reaches for the to be replaced culverts.

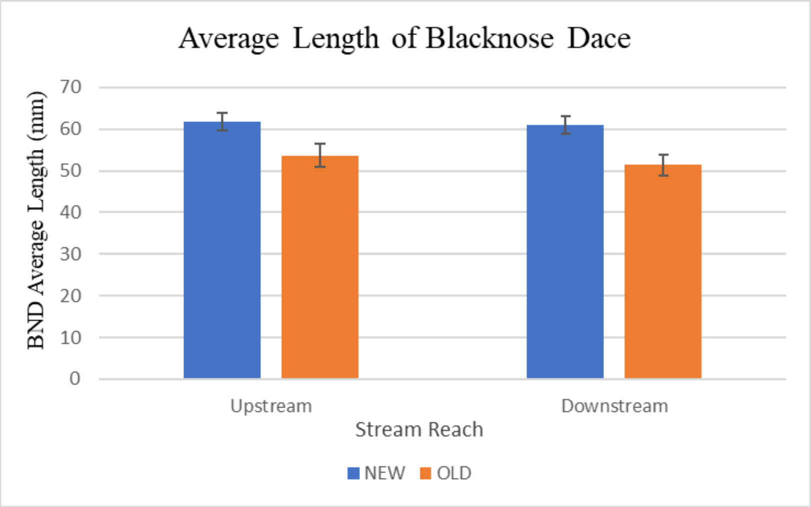

Figure 8: Average length of blacknose dace (BND) for the subset of new stream crossings and old/to be replaced stream crossings based on upstream and downstream reaches. No significant differences were observed (*F* = 0.73; *P* = 0.565).

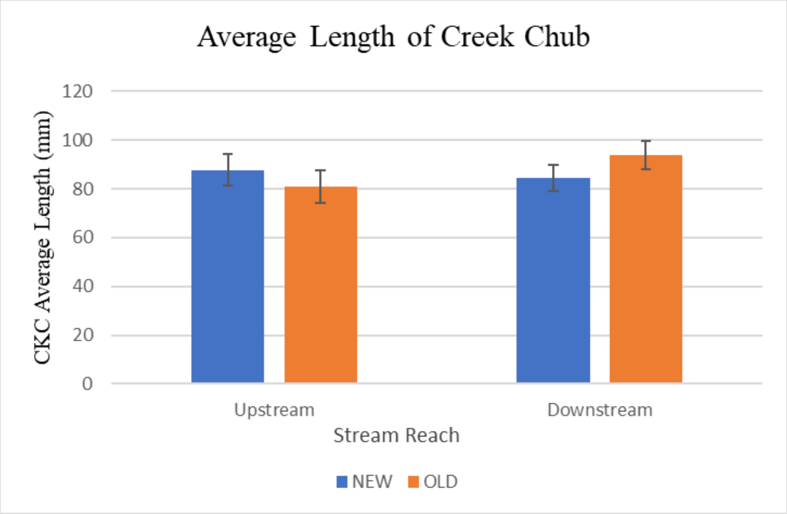

Figure 9: Average length of creek chub (CKC) for the subset of newly replaced stream crossings and to be replaced stream crossings based on upstream and downstream reaches.

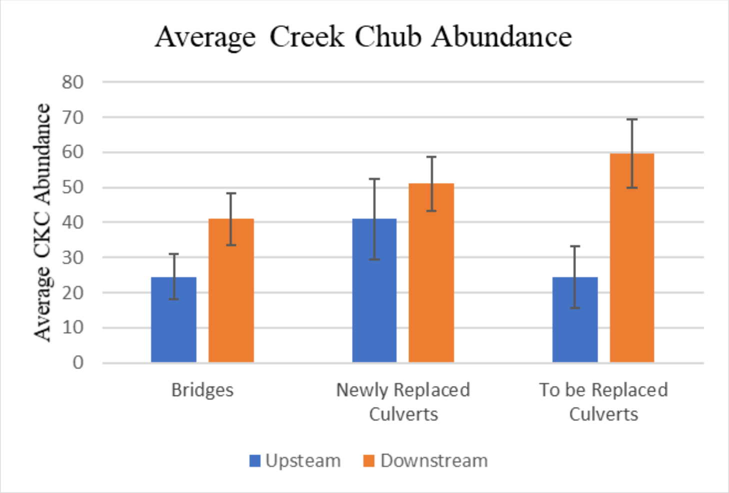

Figure 10: Average abundance of creek chub (CKC) for reference bridges, newly replaced stream crossings, and to be replaced stream crossings based on upstream and downstream reaches. No significant differences were observed ($F = 2.40$; $P = 0.083$).

Discussion

Interpretation of results

This work builds on prior knowledge regarding the impacts of road crossings on stream ecosystems and how culverts specifically influence the upstream and downstream movement of fish. We identified the passability scores of 11 stream crossings and discovered that the three to be replaced culverts are disturbances to their respective stream ecosystems. The results of our data suggest that to be replaced culverts do not allow for total stream connectivity by limiting upstream passage. We found that most crossing effects of the physical and chemical data are directly associated with the stream size differences rather than the reach effects associated with different crossings. Though our study does not solely focus on the replacement of culverts with bridges, the newly replaced culverts did represent similar qualities as the bridges in terms of connectivity. Our results also provide valuable insights into past and future restorations that will happen in streams in the French Creek watershed.

Passability Analysis

There was a significant crossing effect for the passability scores. Our findings show that the to be replaced culverts had the lowest passability scores. Due to increased outlet drop to water surface (0.64 and 0.49 meters, respectively) for the sample sites Galford Creek and Stoltz Run B, these two sites had the lowest passability scores. Stoltz Run A had a 0.09-meter outlet drop to stream bottom resulting in a 0.597 passability score, which can be seen as a partial barrier similar to observations in Nathan et al. (2018). The tailwater scours pools in the downstream reach also have an effect on the passability score as these pools can be indicative of increased velocity (Bates et al., 2003; Briggs & Galarowicz, 2013; Scoring Road-Stream Crossings; Warren & Pardew, 1998). This could also be another barrier to certain species trying to pass upstream. Energetic stress can be increased for fish due to higher velocities, so their passage through the culverts is less likely (Adams et al., 2000; Toepfer et al., 1999). Galford Creek (old culvert), Gravel Run (bridge), and Stoltz Run A & B (old culverts) all had large tailwater scour pools, while the other stream crossings all had none or small pools. McCune Run had a small tailwater scour pool, which did not affect the passability score since it is a bridge. Since Gravel Run has a bridge for the stream crossing, the large tailwater scour pool had little effect on fish passage as its passability score was 0.91. Also, bridges and newly replaced culverts had similar scores of “insignificant barriers”, which indicated that restoration of old culverts can be effective for fish passage.

Chemical & Physical Analysis

There was a significant crossing effect with respect to stream widths, depth, and velocity in which bridges had increased values. This is likely due to the stream size difference. The total average width of all bridges was 5.5 meters while it was 2.8 meters for the average culvert width. Further landscape-level data indicated that watershed areas were also larger for the bridged streams in our study (average = 16.1 km^2) compared with streams with the culvert crossing types (average = 5.3 km^2). The crossing effect is associated with widths, depths, and velocity because bridges tend to be found on larger streams while culverts are found on much smaller streams. As streams get bigger, it can be more difficult to install culverts that are long enough and wide enough to fit the whole stream. As a result for wider streams, if a culvert is placed, it creates a bigger crossing effect which could cause increased constriction and passability could be decreased.

It was not expected to have a significant crossing effect with respect to temperature and DO for newly replaced culverts. These culverts had higher temperatures and lower DO when compared with bridges and to be replaced culverts. One possible explanation for this could be that newly replaced culverts had recent construction that affected stream ecosystem conditions. When machinery has to remove old culverts and supporting structures (ex: concrete, dirt, etc), to install new culverts into the stream, the riparian zone will be stripped away and can cause further damage to the stream (Cholewa et al., 2018). Therefore, trees, shrubs, grasses, and rocks will all be removed from the area which results in increased penetration from solar radiation (Naiman et al., 2010). As there is less coverage from the riparian zone, the temperatures will be increased which can also affect the fish if they are thermally sensitive (Kirk et al., 2017). Additionally, DO will be decreased (Warren et al., 2022) which can force the fish to adapt to low oxygen conditions (Kirk et al., 2017). Also, it is estimated that as time passes and more of the riparian zone grows back, the change in DO and temperatures will go back to normal, but that restoration timeline can be on the scale of years to decades depending upon other environmental variables (Reich et al., 2023).

Stream Fish Communities Analysis

Fish communities were the only response variable to provide any evidence of a reach effect for to be replaced culverts that were in agreement with the initial hypothesis. Darters had a significant crossing effect for the average number of darter species, which could be explained by darter richness increasing with bridges due to larger stream size (Kirk et al., 2017). However, to be replaced culverts had zero darter species in the upstream reach which was indicative of a crossing and reach effect for this taxonomic group. The richness of minnow species (Family *Cyprinidae*) and the abundance of sucker species (*Catostomus spp.*) was also lowest in the upstream reaches of to be replaced culverts. Notably, White Suckers (*Catostomus commersonii*), which are a common species for all streams in our study region, were not found upstream, above the to be replaced culverts, but there were 83 white suckers found downstream of Galford Creek and five downstream of Stoltz Run B.

A possible explanation for this could be that the outlet drop made the culverts impassable for these different species. The higher the outlet drop, the harder it is for species to swim upstream unless they are able to jump or swim upstream during higher flows. Only certain migratory species are able to exhibit leaping behaviors, such as trout and salmon species (Kondratieff & Myrick, 2006). There seems to be limited research available on the leaping abilities of specific smaller fish species (Prenosil et al., 2016). As discussed in the passability analysis, energetic stress can be increased for fish due to higher velocities at high flows, so they might not be able to swim upstream through the culvert (Adams et al., 2000; Toepfer et al., 1999). This was likely the case regarding the abundance of suckers, which are known as a strong-swimming and highly migratory taxonomic group. Another possible explanation could be due to decreased widths of the to be replaced culvert streams, which are too small for larger sucker species. It is also important to note that stream widths averaged out to be the same for all culverts, therefore having an average of three species for newly replaced culverts shows that this might not be the case.

Another species, the creek chub, had no significant differences observed for the average length of creek chub ($F = 0.42$; $P = 0.746$) across crossings and reach types. Although creek chub had different mean lengths for both the upstream and downstream values of to be replaced crossings, there was no significant difference. This could change if all creek chub were measured instead of the small subset that was measured. For the to be replaced culverts, 63% of creek chub were measured. For newly replaced culverts, 51% of creek chub were measured. This result was not predicted from our results. We assumed that since there were fewer fish species upstream of the to be replaced culverts, there would be fewer species and also only smaller and medium-length fish due to low passability culverts (Evans et al., 2015). These insignificant results may be significant in the future based on the recommendations made for the study below.

In Figure 10, the average abundance of creek chub shows no significance, but downstream reaches have a ~2.45 times greater abundance of creek chub than upstream reaches for to be replaced culverts. The reason for this could be the outlet drop at the end of the to be replaced culverts. These fish are not able to travel upstream unless high flows allow for increased passage. More research should be completed in the future to better understand how creek chub are affected by different stream crossings.

Limitations & Recommendations

One limitation of this study is the small sample size. Due to the distance of sample sites, we were only able to have a small sample size of 11 stream crossings, which was also an unbalanced sample size (i.e., only n = 3 for to be replaced culverts). We were also denied permission by land owners to sample another to be replaced culvert scheduled for installation in 2023. We would also sample bridges and culverts across a larger range of stream sizes for each category to better account for stream size differences across the different crossing types. With more sample sites spanning a similar range of widths, depths, and velocities, we would ideally be able to detect more reach effects rather than only crossing effects due to the caveat of bigger bridges and smaller culverts.

A recommendation for future studies is to get all creek chub and blacknose dace lengths measured for all sample sites. For this study, we collected a random amount of fish lengths only for the culverts and not the bridges. If all fish collected were measured, there could be a relationship between fish lengths for old versus new culverts. Also, if the bridge crossings had lengths for all creek chub and blacknose dace collected, there could be significance in regard to fish lengths for crossing effects by exploring another reference category. Further research is needed to find the relationship between fish lengths and different types of stream crossings.

The passability scores for to be replaced culverts versus the newly replaced culverts showed us that the restoration of culverts impacts passability. Having passability scores of under 0.5, which is partially impassible, will negatively affect all aquatic organisms within the stream. To be replaced culverts, Galford Creek and Stoltz Run should be replaced within the next few years, as this is the goal of the CCCD. This study has shown that replacing these culverts as soon as possible will benefit the fish communities and restore the biotic integrity of the stream.

With increasing precipitation, higher flows will increase the passability of some of these ‘impassable’ culverts. MacPherson et al. (2012) discusses that not all outlet drops will be as drastic during higher flows. It is also important to note that once snowmelt begins in northeastern PA, flows will naturally increase. This would be particularly important for migratory species during the spring seasons when high flows may improve passage. In the future, a culvert assessment by taking measurements of outlet drops through high and low flows could determine long term the passability for these need to be replaced culverts.

Three out of four of the newly replaced culverts (Castile Run, Federal Run, and German Run) had baffles. A baffle is a structure inside a culvert, typically a panel, that creates various flows to help fish pass through (Favaro et al., 2014). Restoration projects tend to favor the addition of baffles due to their lower cost than building alternate pathways, but it takes more time to see this change within the fish communities (Favaro et al., 2014). Other studies such as Bates et al. (2003) and Love and Taylor (2003) state that baffles have a tendency to catch woody debris over time which can create another barrier. This divide in the research shows that further research is needed and would be a great recommendation for future research on baffles in the French Creek watershed.

Related Literature

Similarly to MacPherson et al (2012), outlet drop is one very important culvert characteristic that acts like a barrier. In that study that was completed in the Alberta foothills in Canada, when culverts were hanging, there were no Burbot (*Lota lota*) upstream, which is a benthic dwelling species. Their data suggested that for upstream movements of fish, 47% of culvert crossings were complete barriers to burbot and were a partial barrier to spoonhead sculpin, sucker, and minnow passage (MacPherson et al., 2012). Though the location of our study and this study are far away from each other, similar species and findings were found. That concludes that outlet drop has a major impact on fish passage.

Another study similar looked at culvert replacement in Michigan. Their results were similar regarding species richness when looking at upstream versus downstream reaches. In three study streams, prior to their culvert removal, richness was greater downstream than upstream as it was in our to be replaced culverts (Evans et al., 2015). But, all of these culverts in this study were replaced with bridges, not new culverts. This study complements our research on culvert replacement by highlighting the value of restored connectivity.

Future Directions & Conclusions

Future analysis will be needed on streams that are currently being restored. Galford Creek and German Run are two tributary streams that feed into a tributary not too far downstream and they both cross under Fisher Road within about 100 meters from each other. Allegheny College personnel had previously sampled German Run for fish communities in the downstream and upstream reaches in 2008 and 2018, respectively. Currently, Galford Creek and German Run are going through restoration activities. In 2021, a culvert was replaced on Fisher Road near the headwaters. Galford Creek, the tributary to German Run will be replaced in 2023. Our data will help future researchers study the effects of restoration on the biotic integrity and the fish in the stream.

Currently, there are multiple restoration projects developing in the French Creek watershed. The WCRC is performing a stream bank restoration on the Telliho property in the downstream reaches of German Run. The WCRC staff sampled all three locations; the Telliho property, and the two Fisher Road crossings for fish and macroinvertebrate communities in the fall of 2022 and will do so again later in the spring of 2023. This will provide baseline information on the watershed-scale effects of these restoration projects.

There is great importance in monitoring fish passage to ensure connectivity and the ability to maintain gene flow and avoid reproductive isolation in a stream (Roscoe & Hinch, 2010). If monitoring is completed on all crossings in a specific area, we can see the effect of poor crossing, evaluate this, and hopefully replace them with better stream crossings. Also, the past and future restorations that are happening in the French Creek watershed allow for a more comprehensive understanding of stream restoration and how it affects aquatic organism passage and longitudinal connectivity. Our work in the small tributaries can have a great impact on fish population connectivity at the larger watershed scale.

References:

Adams, R.S., Hoover, J.J., Killgore, J.K. (2000), Swimming Performance of the Topeka Shiner (*Notropis topeka*) an Endangered Midwestern Minnow, The American Midland Naturalist, 144(1), 178-186, https://doi.org/10.1674/0003-0031(2000)144[0178:SPOTTS]2.0.CO;2

Baker, C., & Votapka, F. (1990). Fish Passage Through Culverts (Vol. 990). United States Department of Agriculture.

Bates, K., Barnard, B., Heiner, B., Klavas, J., and Powers, P., (2003). Design of Road Culverts for Fish Passage Washington Department of Fish and Wildlife https://www.fs.usda.gov/biology/nsaec/fishxing/fplibrary/Bates%20and%20others_2003_culvert_manual_final.pdf

Beggs, L., & VanRy, H., (2017). "The Darters of French Creek - French Creek Valley Conservancy." *The French Creek Watershed Fact Sheet* www.frenchcreekconservancy.org/wp-content/uploads/2017/09/FactSheet_Dartersfinal.pdf.

Benton, P.D., Ensign, W.E., Freeman, B.J., (2008)"The Effect of Road Crossings on Fish Movements in Small Etowah Basin Streams," Southeastern Naturalist, 7(2), 301-310, https://doi.org/10.1656/1528-7092(2008)7[301:TEORCO]2.0.CO;2

Briggs, A.S. and Galarowicz, T.L. (2013), Fish Passage Through Culverts in Central Michigan Warmwater Streams. North American Journal of Fisheries Management, 33: 652-664. https://doi.org/10.1080/02755947.2013.788589

Cholewa, M., Plesiński, K., Kamińska, K., & Wójcik, I. (2018). Stability evaluation of modernized bank protections in a culvert construction. Les Ulis: EDP Sciences. doi:https://doi.org/10.1051/e3sconf/20183001020

Clay, C. (1995). Design of Fishways and Other Fish Facilities. (Second Edition) Lewis Publishers. https://books.google.com/books?hl=en&lr=&id=YYUfX6Njd6AC&oi=fnd&pg=PA1&ots=tZbKSmRx57&sig=cqemuuIjq5Kt7FeUBRqIRb7NMKU#v=onepage&q=culverts&f=false

Cote, D., Kehler, D.G., Bourne, C., and Wiersma, YF. (2009), A new measure of longitudinal connectivity for stream networks.Landscape Ecol 24, 101–113. https://doi.org/10.1007/s10980-008-9283-y

"EcoTestr pH 2." Thermo Scientific, www.eutechinst.com/pdt-type-pocket-testers-ecotestrph2.html

Environmental Systems Research Institute (ESRI). (2022). ArcGIS. Redlands, CA. Accessed Feb 9, 2023.

Evans, N.T., Riley, C.W. and Lamberti, G.A. (2015), Culvert Replacement Enhances Connectivity of Stream Fish Communities in a Michigan Drainage Network. Transactions of the American Fisheries Society, 144: 967-976. https://doi.org/10.1080/00028487.2015.1054519

Fausch, K.D., Torgersen, C.E., Baxter, C.V., and Li, H.W. (2002), Landscapes to Riverscapes: Bridging the Gap between Research and Conservation of Stream Fishes: A Continuous View of the River is Needed to Understand How Processes Interacting among Scales Set the Context for Stream Fishes and Their Habitat, BioScience, Volume 52, Issue 6, Pages 483–498, https://doi.org/10.1641/0006-3568(2002)052[0483:LTRBTG]2.0.CO;2

Favaro, C., Moore J, W., Reynolds, J, D., and Beakes, M, P. (2014). Potential loss and rehabilitation of stream longitudinal connectivity: fish populations in urban streams with culverts. *Canadian Journal of Fisheries and Aquatic Sciences*. 71(12): 1805-1816. https://doi.org/10.1139/cjfas-2014-0199

Feurich, R., Boubée, J., Olsen, N., (2012). Improvement of fish passage in culverts using CFD https://doi.org/10.1016/j.ecoleng.2012.06.013

Fitch, M., (1995). Nonanadromous fish passage in highway culverts. https://rosap.ntl.bts.gov/view/dot/19399

Gautam, S., & Bhattarai, R. (2018). Low-Water Crossings: An Overview of Designs Implemented along Rural, Low-Volume Roads. Environments, 5(2)https://doi.org/10.3390/environments5020022

Gibson, R.J., Haedrich, R.L., and Wernerheim, C.M. (2005), Loss of Fish Habitat as a Consequence of Inappropriately Constructed Stream Crossings. Fisheries, 30: 10-17. https://doi.org/10.1577/1548-8446(2005)30[10:LOFHAA]2.0.CO;2

“Hach FH950 Portable Velocity Meter with 20' Cable.” Hach, www.hach.com/p-fh950-handheld-flow-meters/FH950.10020

Karr, J.R., Yant, P.R., Fausch, K.D. and Schlosser, I.J. (1987), Spatial and Temporal Variability of the Index of Biotic Integrity in Three Midwestern Streams. Transactions of the American Fisheries Society, 116: 1-11. https://doi.org/10.1577/1548-8659(1987)116<1:SATVOT>2.0.CO;2

Katopodis, C. & Williams, J. (2012). The development of fish passage research in a historical context, Ecological Engineering, https://doi.org/10.1016/j.ecoleng.2011.07.004.

Kirk, M.A., Wissinger, S.A., Goeller, B.C. and Rieck, L.O. (2017), Co-varying impacts of land use and non-native brown trout on fish communities in small streams. Freshw Biol, 62: 600-614. https://doi.org/10.1111/fwb.12889

Kirk, M.A., and Wissinger, S.A. (2020), Assessment of long-term trends in fish distributions at multiple scales decreases uncertainty associated with historical datasets. Environmental Management 66: 136-148. doi:https://doi.org/10.1007/s00267-020-01298-1

Kondratieff, M.C. and Myrick, C.A. (2006), How High Can Brook Trout Jump? A Laboratory Evaluation of Brook Trout Jumping Performance. Transactions of the American Fisheries Society, 135: 361-370. https://doi.org/10.1577/T04-210.1

Love, M. & Taylor, R.N. (2003) Fish passage evaluation at stream crossings. California salmonid stream habitat restoration manual part IX. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=105810

MacPherson, L.M., Sullivan, M.G., Lee Foote, A. and Stevens, C.E. (2012), Effects of Culverts on Stream Fish Assemblages in the Alberta Foothills. North American Journal of Fisheries Management, 32: 480-490. https://doi.org/10.1080/02755947.2012.686004

Maitland, B.M., Poesch, M., Anderson, A.E., and Pandit, S.N. (2016), Industrial road crossings drive changes in community structure and instream habitat for freshwater fishes in the boreal forest. Freshw Biol, 61: 1-18. https://doi.org/10.1111/fwb.12671

Naiman, R. J., Decamps, H., & McClain, M. E. (2010). Riparia: ecology, conservation, and management of streamside communities. Elsevier.

Nathan, L.R., Smith, A.A., Welsh, A.B., Vokoun, J.C. (2018), Are culvert assessment scores an indicator of Brook Trout Salvelinus fontinalis population fragmentation?, Ecological Indicators, Volume 84. https://doi.org/10.1016/j.ecolind.2017.08.033

National Land Cover Database. 2019 U.S. Geological Survey. Sioux Falls, SD https://www.mrlc.gov

Norman, J.R., Hagler, M.M., Freeman, M.C. and Freeman, B.J. (2009), Application of a Multistate Model to Estimate Culvert Effects on Movement of Small Fishes. Transactions of the American Fisheries Society, 138: 826-838. https://doi.org/10.1577/T08-156.1

North Atlantic Aquatic Connectivity Collaborative (NAACC). (2021). NAACC Search Page. https://naacc.org/naacc_search_crossing.cfm

Ogren, S.A. and Huckins, C.J. (2015), Culvert replacements: improvement of stream biotic integrity?. Restor Ecol, 23: 821-828. https://doi.org/10.1111/rec.12250

Poplar-Jeffers, I.O., Petty, J.T., Anderson, J.T., Kite, S.J., Strager, M.P. and Fortney, R.H. (2009), Culvert Replacement and Stream Habitat Restoration: Implications from Brook Trout Management in an Appalachian Watershed, U.S.A.. Restoration Ecology, 17: 404-413. https://doi.org/10.1111/j.1526-100X.2008.00396.x

Prenosil, E., Koupal, K., Grauf, J., Schoenebeck, C., & Hoback, W. W. (2016). Swimming and jumping ability of 10 Great Plains fish species. Journal of Freshwater Ecology, 31(1), 123-130. https://doi.org/10.1080/02705060.2015.1048539

Price, D., Quinn, T., & Barnard, R. (2010), Fish Passage Effectiveness of Recently Constructed Road Crossing Culverts in the Puget Sound Region of Washington State. North American Journal Of Fisheries Management, 30(5), 1110-1125. https://doi.org/10.1577/m10-004.1

“Pro20 Dissolved Oxygen Meter.” YSI, www.ysi.com/pro20

Reich, P., Lake, P. S., Thomson, J. R., Daniel, T., Johnson, M., Metzeling, L., Boulton, A. J., & Hale, R. (2023). Aquatic invertebrate responses to riparian restoration and flow extremes in three degraded intermittent streams: An eight-year field experiment. *Freshwater Biology*, 68, 325– 339. https://doi.org/10.1111/fwb.14028

Roscoe, D.W. and Hinch, S.G. (2010), Effectiveness monitoring of fish passage facilities: historical trends, geographic patterns and future directions. Fish and Fisheries, 11: 12-33. https://doi.org/10.1111/j.1467-2979.2009.00333.x

"Salt/TDS/Conductivity/TEMP TRACER Pocketester™." LaMotte Company, lamotte.com/salt-tds-temp-tracer-1749

Schaefer, J.F., Marsh-Matthews, E., Spooner, D.E.Gido, K & Matthews, W.J. (2003), Effects of Barriers and Thermal Refugia on Local Movement of the Threatened Leopard Darter, Percina pantherina. Environmental Biology of Fishes 66, 391–400. https://doi.org/10.1023/A:1023906424075

Scoring Road‐Stream Crossings as Part of the North Atlantic Aquatic Connectivity Collaborative (NAACC). (2015) https://streamcontinuity.org/sites/streamcontinuity.org/files/projects/images/Aquatic_Passability_Scoring.pdf.

Strayer, D. (2006). Challenges for freshwater invertebrate conservation. Journal of the North American Benthological Society https://doi.org/10.1899/0887-3593(2006)25[271:CFFIC]2.0.CO;2

Toepfer, C.S., Fisher, W.L. & Haubelt, J.A. (1999), Swimming Performance of the Threatened Leopard Darter in Relation to Road Culverts, Transactions of the American Fisheries Society 128:1, 155-161. https://doi.org/10.1577/1548-8659(1999)128<0155:SPOTTL>2.0.CO;2

Warren, D.R., Roon, D.A., Swartz, A.G., and Bladon, K.D.. (2022), " Loss of Riparian Forests from Wildfire Led to Increased Stream Temperatures in Summer, yet Salmonid Fish Persisted." *Ecosphere*13(9): e4233. https://doi.org/10.1002/ecs2.4233

Warren, M.L., Jr. and Pardew, M.G. (1998), Road Crossings as Barriers to Small-Stream Fish Movement. Transactions of the American Fisheries Society, 127: 637-644. https://doi.org/10.1577/1548-8659(1998)127<0637:RCABTS>2.0.CO;2

Wood, D.M., Welsh, A.B., and Todd Petty, J. (2018), Genetic Assignment of Brook Trout Reveals Rapid Success of Culvert Restoration in Headwater Streams. North Am J Fish Manage, 38: 991-1003. https://doi.org/10.1002/nafm.10185

Vasavada, Navendu. “One-Way ANOVA (Analysis of Variance) with Post-Hoc Tukey HSD (Honestly Significant Difference) Test Calculator for Comparing Multiple Treatments.” (2016), ANOVA with Post-Hoc Tukey HSD Test Calculator with Scheffé, Bonferroni and Holm Multiple Comparison - Input k, the Number of Treatments https://astatsa.com/OneWay_Anova_with_TukeyHSD/