THE RESPONSE OF RIFFLES AND POOLS TO CHANGING WATER CONTAMINANTS IN SIXTEEN-MILE CREEK, HALTON, ONTARIO

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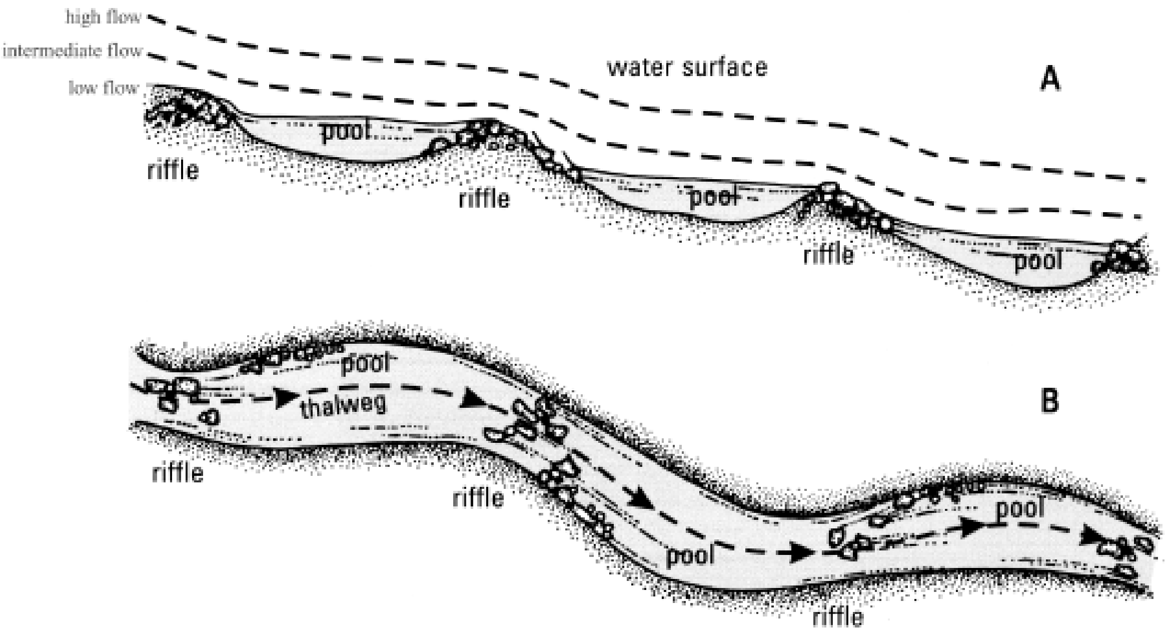
Ashlyne M. Norris



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THE RESPONSE OF RIFFLES AND POOLS TO CHANGING WATER CONTAMINANTS IN SIXTEEN-MILE CREEK, HALTON, ONTARIO

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Ashlyne M. Norris

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Dr. Brian McLaren
Major Advisor

Andrea Dunn
Second Reader

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ABSTRACT

Norris, A.M. 2019. The response of river and pools to changing water contaminants
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Key Words: aquatic ecosystem, contaminants, intolerant, pools, riffles, tolerant.

Increasing water contaminants has been a growing problem in Southern Ontario due to rapid urbanization, agricultural runoff and pollution. Determining how riffles and pools respond to changing contaminants is crucial to understanding effects on species living within those particular habitats. Sites were studied along Sixteen-Mile Creek in Halton, Ontario, to compare water quality and fish occurrence. Electrofishing was used to sample Johnny darter, longnose dace, river chub and rainbow darter as models for tolerant and intolerant species. Elevated sodium chloride had an effect on all species except for the tolerant longnose dace. Meanwhile, lower dissolved oxygen and an increase in phosphorous affected both tolerant and intolerant species. Overall, water contaminants pose a great threat to aquatic ecosystems as they can lower fecundity, decrease activity, impair growth and development and reduce survivability in fish.

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ACKNOWLEDGMENTS

Many hours went into making this thesis successful, and I would like to especially acknowledge Dr. Brian McLaren who has guided me through the thesis process and took time out of his busy schedule to meet with me weekly to discuss my thesis and provide guidance. I would also like to acknowledge the staff at Conservation Halton who generously granted me access to the data used for this thesis. In particular I would like to acknowledge Andria Dunn for being a second reader and providing essential aquatic knowledge in order to complete this thesis, and Kim Funk for continually updating my data throughout the entirety of my thesis.

INTRODUCTION

The region of Halton has been developing at an unprecedented rate, with schools, shopping centers and apartment buildings taking up what was once forested or agricultural land (Faita 2012). There are a number of important rivers, creeks and streams that flow through the Halton area and into Lake Ontario. The morphology of these waterways provides essential habitat to a large variety of vertebrates and invertebrates. Structures within a stream or creek such as pools and riffles are very important as they provide living organisms with ideal habitats, a food source and shelter from predators (CIES 2012).

Sixteen-Mile Creek is a 372-km urban river that flows straight through the town of Milton and Oakville and into Lake Ontario (OCA 2019). The creek itself houses many important fish and benthic invertebrate species, including migratory Pacific salmon (*Oncorhynchus tshawytscha*), brown trout (*Salmo trutta*) and steelhead (*Oncorhynchus mykiss*; CH 2019). The data being analyzed for this thesis was collected within the boundaries of Conservation Halton watershed. It is important to note that small streams are often overlooked or forgotten, but these small urban streams and creeks aid the surrounding city by reducing contamination, easing flash flooding and also improving the esthetics and livability of our busy cities (USGS 2014).

Rainbow and Johnny darters (*Etheostoma caeruleum, E. nigrum*) are small, perch like fish found in freshwater streams and are a member of the family Percidae (Paine 1982). Blacknose dace (*Rhunichthys atratulus*) and river chub (*Nocomis micropogon*) are minnow species that are also found in freshwater stream systems and belong to the family Cyprinidae (Grabarkiewicz and Davis 2008). Rainbow and Johnny darters, along with longnose dace and river chub, will act as models for other species of tolerant and intolerant fish found in the pools and riffles of Sixteen-Mile Creek. The rainbow darter is a suitable model for intolerant riffle species as it is commonly found in cool running freshwater streams (ODNR 2012). They are most common in areas with gravel, rocky or sandy substrates in fast-moving shallow riffles (McNeilly 2014). The rainbow darter is heavily affected by human induced changes such as pollution or sewage drainage and avoid silty waters (Harding 1998). River chub inhabit pools, areas of a stream where the water is at its deepest and the current at its slowest (Holm et al. 2010). Like the rainbow darter, the river chub is also an intolerant species that is greatly affected by water pollution and turbidity (Cravotta et al. 2010). The river chub will serve as an indicator for intolerant species found in pools of Sixteen-Mile creek. The Johnny darter inhabits streams of all sizes and like the river chub, and is found in pools and other slow-moving water habitats (ODNR 2012). The Johnny darter is the most tolerant Percidae species to water pollution and can do very well in moderately turbid water when compared to intolerant species, so it will act as a model for tolerant pool species throughout the study. The longnose dace is also considered to a be a tolerant species that can withstand high water temperatures and a higher degree of pollution than many species (Pirhalla 2004). It commonly inhabits areas of stream where the current is fast and the water is shallow (Grabarkiewicz and Davis 2008), making it a suitable model for tolerant riffle species in Sixteen-Mile creek.

Previous studies (Brabec et. al 2004; Parsons 1996) have examined the importance of pools or riffles and how they are affected by water contaminants, but there is little to no data comparing how each structure interacts together and their response to a change in water contaminants. This study analyzes data collected in Sixteen-Mile Creek, a creek surrounded by urbanization, to study the response of species located in pools and riffles and how they change with varying water contaminants.

This thesis will use data collected with Conservation Halton in 2019, combined with past data collections to determine the response of riffles and pools to changing water contaminants in Sixteen-Mile Creek, using four species of fish as models. The thesis will provide information regarding why the chosen fish species are suitable models and why each water contaminant was chosen to illustrate the effects found in riffles and pools. The response of both riffles and pools compared has yet to be explored. Therefore, the study will concentrate on the effects of each water contaminant and how riffles respond differently or similar to pools. By using models for both riffles and pools the study will expand on how changing water contaminants effects living organisms within creeks and streams. This thesis will look at long-term effects of urbanization and how it is affecting biodiversity of nearby aquatic life. Urbanization has and will continue to impact Sixteen-Mile Creek by changing the levels of water contaminants and will affect pools more than riffles due to pools being slow-moving water and riffles being fast-flowing water. I predict that aquatic organism inhabiting pools will be less affected by the change in water contaminants than those inhabiting riffles.

LITERATURE REVIEW

Urbanization has been around for centuries and takes place all over the planet, but how does this human interaction effect our urban creeks and streams? Urban waterways are very important and are used for water supply, flood mitigation and act as a habitat for a number of vertebrate and invertebrate species. Many studies have been done on the effects of pollution in urban streams, but none have looked at the response of species inhabiting riffles and pools and how their reaction varies with different water pollutants.

BIOLOGY OF RAINBOW DARTER, RIVER CHUB, JOHNNY DARTER AND LONGNOSE DACE

In order to study the reaction of species inhabiting riffles and pools in urban streams a model had to be chosen to represent both tolerant and intolerant species in the two habitats. The rainbow darter and river chub were chosen to represent intolerant species, while the Johnny darter and longnose dace were chosen to represent tolerant species. The rainbow and Johnny darter are both small fishes belonging to the perch family (Percidae) and are tiny relatives to the walleye. Longnose dace and river chub are in the Cyprinidae, family along with other minnow species and carp.

Rainbow darters commonly live for 2-3 years and typically grow to 55-60 mm weighing less than 3 g (Paulsan et al. 2002). They prey mostly on a variety of benthic invertebrates including midge, caddisfly, mayfly and stonefly larvae, along with water mites, snails and young crayfish. Predators of the rainbow darter include young burbot, stonecats, smallmouth bass and fish-eating birds such as great blue herons. Rainbow darters spawn during the spring in clean, rocky riffles from March to June. The rainbow darter will represent riffles as it has adapted to fast-flowing streams seeking habitat in riffled areas throughout the waterway (Tonnis 2006). It is sensitive to habitat degradation and is widely used as a representative of stream condition. Researchers in the past have used the rainbow darter as a biological indicator because they cannot tolerate most forms of pollution (Paulson 2002; Tonnis 2006). Because the rainbow darter has such a low tolerance for mucky water and human-induced changes including pollution or sewer drainage, there is potential for its abundance to be largely impacted by these habitat changes (Harding 1998). Therefore, the rainbow darter will serve as a model for other aquatic fish species inhabiting riffles.

River chub spawn in April and May when the male builds a nest of stones up to 100cm in diameter and 33cm in height (Holm et al. 2010). They feed primarily on small aquatic insects, crustaceans, algae and plant material. The river chub prefers to inhabit pools where the water is cool, and the substrate is rocky. They are considered an intolerant species that cannot tolerate pollution or turbidity and require a minimum pH of 6.0 (Cravotta et al. 2010). The river chub is commonly used as an indicator species as it inhabits high quality streams and is not able to tolerate poor water conditions (Grabarkiewicz and Davis 2008). Like the rainbow darter it will likely be affected by changes in water quality and high levels of turbidity. As it is commonly found in pools of rivers and streams it will serve as a model for intolerant species inhabiting pools in Sixteen-Mile Creek.

The Johnny darter has a lifespan of 3-4 years, spawns in the springtime between the months of May-June, and tends to feed primarily of chironomid larvae (ODNR). It is the most widespread member of its genus from Hudson Bay drainages to the Appalachian Mountains (Propst 1989). Its widespread occurrence can be attributed to its broad environmental tolerances that have allowed it to inhabit areas with some organic and inorganic pollution. The Johnny darter prefers slow moving sandy silty, gravelly, pools of creeks and small to medium rivers and the sandy shores of lakes (ODNR). The Johnny darter's preference for pools found in creeks and streams in addition to its ability to tolerate levels of turbidity and pollution will allow it to serve as a model for tolerant aquatic fish species inhabiting pools.

Longnose dace can reach about 100 mm in length and are found along the southern border of Canada extending from Manitoba to the Atlantic Ocean and south to the United States (Robert and Burkhead 1994). They eat primarily aquatic invertebrates, including chironomids and other nymphs and larvae (Trial et. al 1983). The longnose dace prefers to inhabit swift shallow riffles of streams where the water is cool to warm, and the current is moderate to strong (Grabarkiewicz and Davis 2008). The species is able to withstand a high water temperature, and to tolerate pollution, habitat alteration and disturbed habitats; therefore, it has been declared as a tolerant species by many researchers (Lyons 1992, Barbour et al. 1999, Pirhalla 2004, Grabarkiewicz and Davis 2008). The longnose dace will be a suitable model for tolerant species inhabiting riffles in Sixteen-Mile Creek.

Overall, the rainbow darter and river chub, as with the Johnny darter and longnose dace, are two species that occupy two different habitats, one riffles, and one pools. This difference will allow for a comparison between the response of intolerant and tolerant species inhabiting pools and riffles and how they react to changing water contaminants.

STREAM DYNAMICS: RIFFLE AND POOL CLASSIFICATION

Streams are important ecosystems that provide habitat or a natural environment for many diverse aquatic organisms and plants. Every stream has a distinctive anatomy, comprised of a series of riffles, runs and pools (CIES 2012). A riffle is characterized by an area of stream with shallow depths, where fast, turbulent water is present. They are short, shallow segments of the stream where flow is agitated by rocks (Cave 1998). The rocky, cobble bottom provides a variety of organisms with protection from prey, food deposition and shelter (CIES 2012). Not all organisms can inhabit the fast-flowing water found in riffles, only organisms that cling well, such as caddisflies (Trichoptera), stoneflies (Plecoptera), net-winged midges (Blephariceridae), and strong swimming fish such as dace (Cyprinidae), sculpins (Cottidae) and rainbow darters (Cave 1998). Riffles have a high dissolved oxygen (DO) concentration due to turbulence and stream flow; water with high and relatively stable levels of DO is typically considered to support a healthy ecosystem and greater biodiversity (CIES 2012).

Pools are an area of stream characterized by deep depths and slow current. They are typically created by the vertical force of water falling down over logs or boulders (Thompson 2018). Pools offer deeper water habitat during periods of low flow, as well as protection from predators and shelter. Aquatic organisms already inhabiting pools do not have to relocate to another area of stream if the water level begins to lower. Due to the slow flow of water, organic debris settles out, provides a food source for organisms; pools, therefore, can be classified as depositional habitats (Frissell 1986).

Riffle and pool communities illustrate distinct and significant differences when looking at species abundance patterns. Fish communities found in riffles vary largely when compared to communities found in pools, both communities also respond to environmental gradients in different ways (Taylor 2000). Pool communities have a higher species diversity when compared to a riffle community due to more space, food and slower flowing water (Thompson 2004).

EFFECTS OF URBAN POLLUTION ON WATER QUALITY

Every year urban landscapes replace agricultural and forested areas, leading to significant hydrologic and water quality impacts (Waller and William 1986). The urban land surface is covered by buildings and pavement, which does not permit rain and snowmelt to soak into the ground. Instead, storm drains carry urban runoff directly to the streams, creeks and rivers nearby. The storm water runoff carries a variety of pollutants including, oil, dirt, road salts, chemicals, lawn fertilizer and many more (EPA 2003). Surface runoff and combined sewage are significant pollution sources in Canada (Waller and William 1986).

When large amounts of rain or snow melt occur, the runoff gathers in unnaturally large amounts resulting in speed and erosional power as it travels underground (EPA 2003). When the runoff reaches streams, its excessive volume can blast out stream banks, damaging vegetation, wiping out aquatic habitat and carrying sediment loads from construction sites and eroded streambanks. Urban runoff carries toxins that can result in a shift of natural chemicals in a stream, sediment loads that increase turbidity, and higher water temperatures from roof tops and roads. Deposited solids have the ability to smother aquatic bottom life, including fish eggs and larvae; in large quantities sediments may even fill reservoir storage (Walter and William 1986). Resuspension of sediment during storm periods could result in serious short-term effects for fish or for downstream dissolved oxygen levels. Runoff containing fertilizers can lead to high levels of phosphorus and nitrogen, which result in unnatural nutrient enrichments leading to an increase in bacteria, fungi, phytoplankton, zooplankton and shifts of algae populations toward less desirable types such as blue-greens (Walter and William 1986). It can also increase dissolved organic substances, which lead to an increase in pH and pH fluctuations, and chronic oxygen depletion at the sediment-water interface, resulting in a release of dissolved and gaseous products of anaerobic decomposition of algal material and solubilization of metals.

The result of these water quality changes has the ability to lead to increased turbidity, harm vertebrate and invertebrate species, kill native vegetation, foul drinking water supplies, and ruin the aesthetics of urban life (EPA 2003). In an urban creek located in Washington, it was found that development resulted in a reconstructing of the fish community (Scott et al. 1986). Environmental perturbations, including increased nutrient loading, habitat alteration and degradation of the intragravel environment had a great impact on Coho salmon (*Oncorhynchus kisutch*) and non-salmonid fish species.

EFFECTS OF POLLUTANTS ON FRESHWATER FISH

When large quantities of pollutants are released into waterways there may be an immediate impact resulting in large-scale sudden mortalities, whereas lower levels of discharge may result in an accumulation of the pollutants in the aquatic ecosystem (Austin 2010). When pollutants are accumulated over time, the effects on aquatic life are different; some fish may suffer from immunosuppression, reduced metabolism, suppressed reproduction and damage to the gills and epethelia. There are many types of pollutants being released into urban waterways proven to impact aquatic life, including a change in heavy metals, chloride, pH, turbidity, temperature and suspended solids (Authman 2015; Chapman 2014).

Heavy metal pollution is a result of direst atmospheric deposition, geologic weathering, and discharge through agricultural, municipal, residential or industrial waste products (Authman et al. 2015). Mercury, cadmium, copper, lead and zinc are the most important heavy metal pollutants that affect the aquatic environment, accumulating in tissues and poisoning fish. Research has shown heavy metals and organic xenobiotcs affect the morphology of the gill epithelium of fish, which serves a multitude of vital functions including gas exchange, ionic regulation, acid-base balance, and nitrogenous waste excretion (Evans 1987). Heavy metals can also influence the vital operations and reproduction of fish, weaken the immune system and induce pathological changes (Authman et. al 2015).

An increase in fine sediments from anthropogenic development can increase turbidity and suspended solid levels within streams (Chapman et. al 2014). It was shown through meta-analysis that increased sediment in lotic environments had an effect on both tolerant and intolerant freshwater fish species. Negative effects occurred for spawning success, feeding behaviour and species richness. High turbidity levels can also make it difficult for fish to see and catch prey, bury and kill eggs laid on the bottom of rivers; in high quantities, suspended sediment can clog the gills of fish, killing them directly (GNT 2016).

Fish are cold-blooded animals, adapting their temperature to their surroundings, making water temperature one of the most important physical factors affecting fish growth and production (Viadero 2005). Depending on a fish's tolerance for a particular temperature range, it can be classified as a cold, cool or warm water species. Fish survival is bound by an upper and lower temperature, between which an optimum temperature for growth exists. When temperature varies outside optimum range, it leads to decreased tolerance to changes in water quality constituents and a decrease in immunological response. Pollution and water runoff from paved surfaces can increase water temperature, resulting in decreased growth and productivity in fish, and in some cases mortalities, depending on the magnitude of deviation from the optimum temperature.

Agricultural runoff and urban garden fertilizer have beneficial effects for crops and plants, but their runoff can cause an overabundance of phosphorous and nitrogen entering lakes and streams, leading to excessive nutrient abundance (Litke 1999). Phosphorous is a nutrient that is relatively low in natural water systems (MPCA 2008). In the 1960s, scientists discovered that human activities lead to a large increase in phosphorous levels, which lead to the excessive growth of algae and degrade water quality. Too many nutrients in streams and lakes can cause excessive amounts of algae, leading to dissolved oxygen depletion and pollution in waterways.

The primary agent in road salts is sodium chloride, which makes its way into the natural environment through soil, groundwater, surface water and storm drains. There is no natural process to break down chlorides or remove them from the environment, so chloride discharge remains in solution and does not leave a watershed until washed downstream (Nagpal 2003). Sodium chloride in water can result in a higher density and contaminated water will settle at the deepest part of a pool. This can lead to the bottom layer of the pool becoming void of oxygen and unable to support aquatic life. High levels of chloride in surface waters can disrupt osmoregulation in aquatic organisms leading to impaired survival, growth and reproduction (Nagpal 2003). It can also place salinity stress on sensitive aquatic species, impact species diversity, and inhibit nutrients and dissolved oxygen from enriching the ecosystem.

MATERIALS AND METHODS

MATERIALS:

Site Selection and Fish Sampling

Backpack Electro-fishing (Toronto Regional Conservation Authority, 2018)

Rainbow and Johnny darters along with many other fish species were collected from 20 sites along Sixteen-Mile Creek from June to August 2019. The sampling extends back to the 1950s, when similar methods were used. The rainbow and Johnny darters were not present at all sites, but one of each species was found at all 20 sites. At a number of sites in 2019, the rainbow darter, along with a number of other species, was found to have black spot disease. Fish were sampled using a backpack electrofisher, anode pole, dip net and bucket. The fish were then measured on a board and spring scale. Prior to sampling the site, the Ontario Stream Assessment Protocol (OSAP) was done to identify the site location and physical habitat, which includes the geomorphology, hydrology and water temperature (Stanfield 2010). A measuring tape was used to determine the length and width of the site, a cover ring was used to guide the selection of substrate, along with a metre stick to determine hydraulic head. On the stream bank, a profiling tool was used to determine slope and a bank vegetation grid was used to determine abundance of rooted vegetation. A GPS unit was used to record the UTMs of the site. Data sheets were also used throughout the process to record all the data collected regarding the sampling sites.

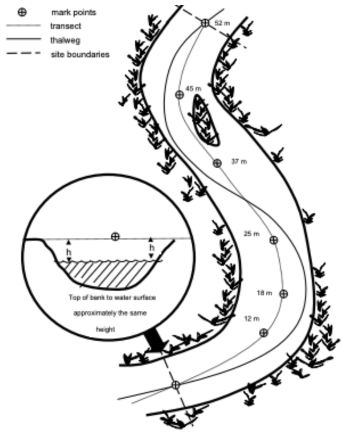
Water Quality Sampling

Water samples were taken each month for eight months of the year (April to November) at five sites within Sixteen-Mile creek. Samples were taken when no rain had occurred for at least a 48-hour period, and four samples were taken within 48-hours of a 2mm or greater rain event. Five jars were used to collect the water and samples were sent to the Ontario Ministry of Enviornment, Conservation and Parks (MECP) for laboratory analysis. The water quality data dates back to the 1960s with similar methods followed since.

METHODS

Site Selection

Study sites were chosen following the OSAP protocol. Each site began and ended at a crossover. Every site also had at least one riffle-pool sequence. Once a site was determined, the length was measured by chaining up the center of the stream with a tape measurer (Stanfield 2010). Once the length was determined, UTM coordinates were taken and a map was drawn to highlight the start and finish of each site. Around 10 transects were then set up throughout the length of the sites, perpendicular to the general direction of the flow. A measuring tape was placed to determine the active channel width and guide the placement of 2-6 points which were used to measure stream characteristics. The number of transects and points was determined based on the minimum stream width of the site, with smaller streams having more transects and fewer



Site Boundaries and Length Determination (Stanfield 2010) points per transect. At each point, the substrate was classified by randomly selecting a piece of the stream bottom; if it was larger than sand, the width of the sample was measured and it was described as flat, round, or undercut. Aquatic vegetation was also recorded. The hydraulic head and depth were then taken at each point. On both sides of the bank where the stream width was estimated, bank angle, bank composition, riparian vegetation and canopy cover were measured.

All twenty sites were eventually located in Sixteen-Mile Creek. The Sixteen-Mile Creek watershed is the largest of all of Conservation Halton's watersheds, with a landbase that extends 372 kilometres in size and flows into Lake Ontario (d'Entremont 2018). The creek mainly flows through the town of Milton and Oakville, and the watershed extends to the edge of Mississauga, Georgetown and Campbelleville. Milton was the fastest growing municipality in Canada between 2001 and 2011, seeing a 71.4% increase in population from 2001-2006 and another 56.5% increase from 2006-2011 (GC 2016). Oakville at its 2016 census population of 193,832 was named one of Ontario's largest towns and one of the most densely populated areas of Canada. Both the towns of Milton and Oakville have succumbed to large developmental projects and vast amounts of urbanization.

Fish Sampling

At each site a backpack electro fisher was used following the single-pass method by three people, a fisher and two netters (Standfield 2010). At each site the total surface area of the site was sampled, including under logs and banks, and in deep pools and rapids. After the sampling was completed all the fish were separated by species into buckets of water. The number of each species collected was recorded along with bulk weight and the longest and shortest fish from each species. Data for each site also included the stream name and code, substrate, riparian and aquatic vegetation, location, weather and effort. Each site was sampled relatively close to the date of previous years.

Analysis

Data was received from Conservation Halton and then sorted into various spreadsheets based on water quality parameter, site and fish species. There were hundreds of thousands of data entries to sort through and separate by year and site. Once everything was organized graphs were created to compare fish species and their population responses to water quality parameters. Number of individuals caught was converted to a percentage of total catch in order to compare and combine data across multiple sites. A linear regression was fit to the data and the associated R^2 value was calculated if the regression was significant.

RESULTS

A downward trend is observed for the rainbow darter catches with increases in sodium chloride concentration, while there is no similar trend for longnose dace (Figure 1). The rainbow darter population appears more sensitive to chloride levels in the riffles. The same trend occurs for both the Johnny darter and river chub, located in pool habitats; the downward trend for the Johnny darter is the singular significant effect among the analyses (Figure 2). When phosphorus levels were higher, the intolerant rainbow darter trended downward in the catch as it did for chlorides, while the tolerant longnose dace trended slightly upward (Figure 3). The same upward trend occurred for the tolerant Johnny darter in the pool habitat (Figure 4). When dissolved oxygen levels were higher in the riffles, rainbow darter catch was also higher, while the more tolerant longnose dace populations appeared relatively unchanged (Figure 5). The unchanged situation was similar for the pool-dwelling Johnny darter and longnose dace (Figure 6).

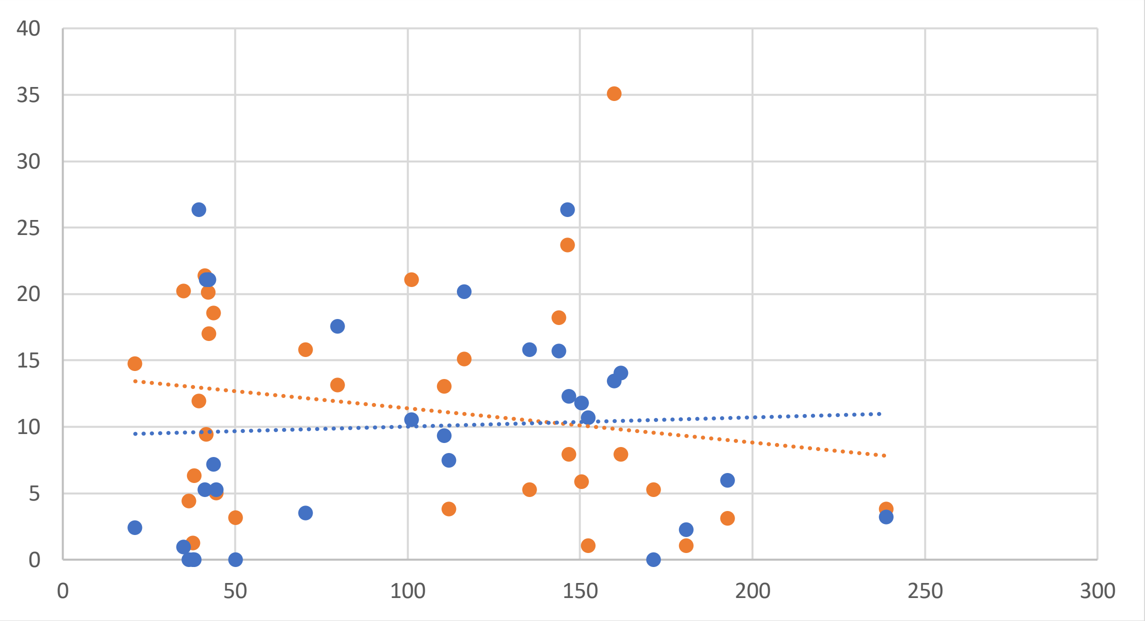


Figure 1. Longnose dace (blue) and rainbow darter (orange) percent of catch over time across various sites in Sixteen-Mile Creek graphed against chloride levels.

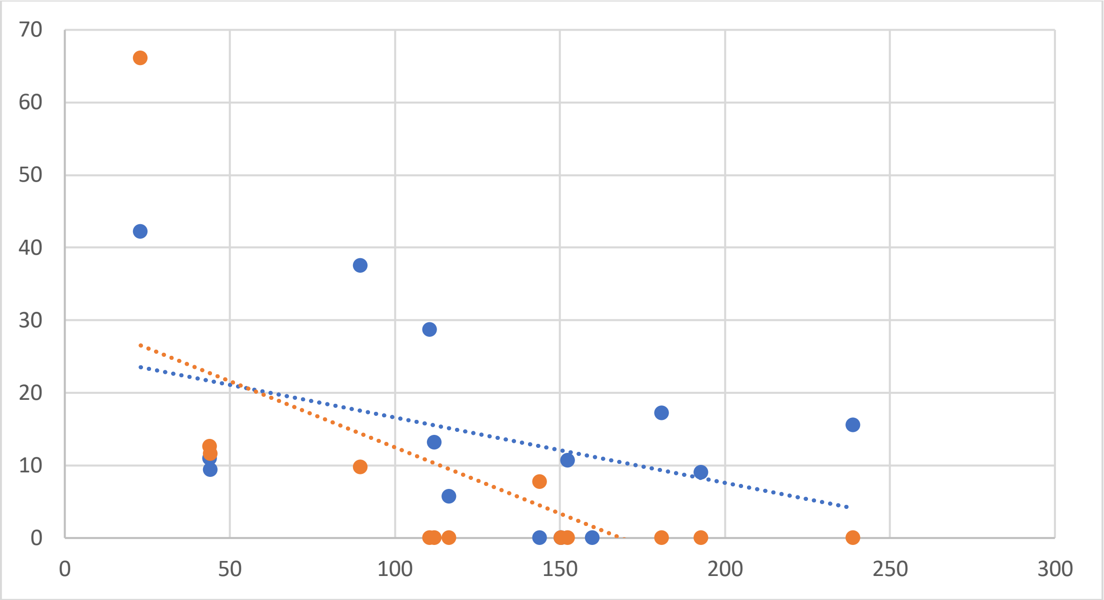


Figure 2. Johnny darter (orange) and river chub (blue) percent of catch over time across various sites in Sixteen-Mile Creek graphed against chloride levels. The relationship for Johnny darter has $R_2 = 0.40$.

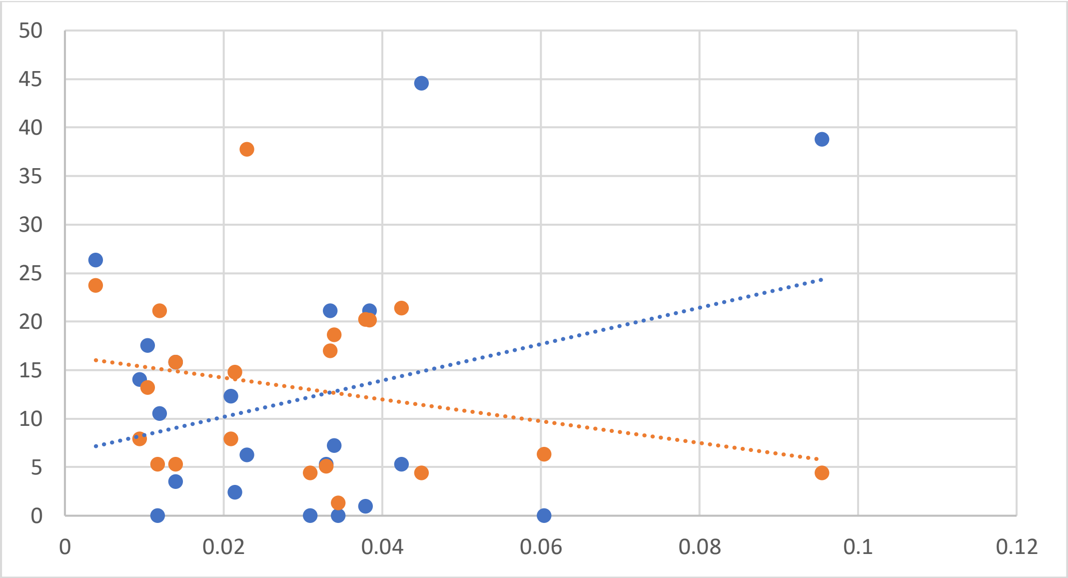


Figure 3. Longnose dace (blue) and rainbow darter (orange) percent of catch over time across various sites in Sixteen-mile Creek graphed against phosphorus levels.

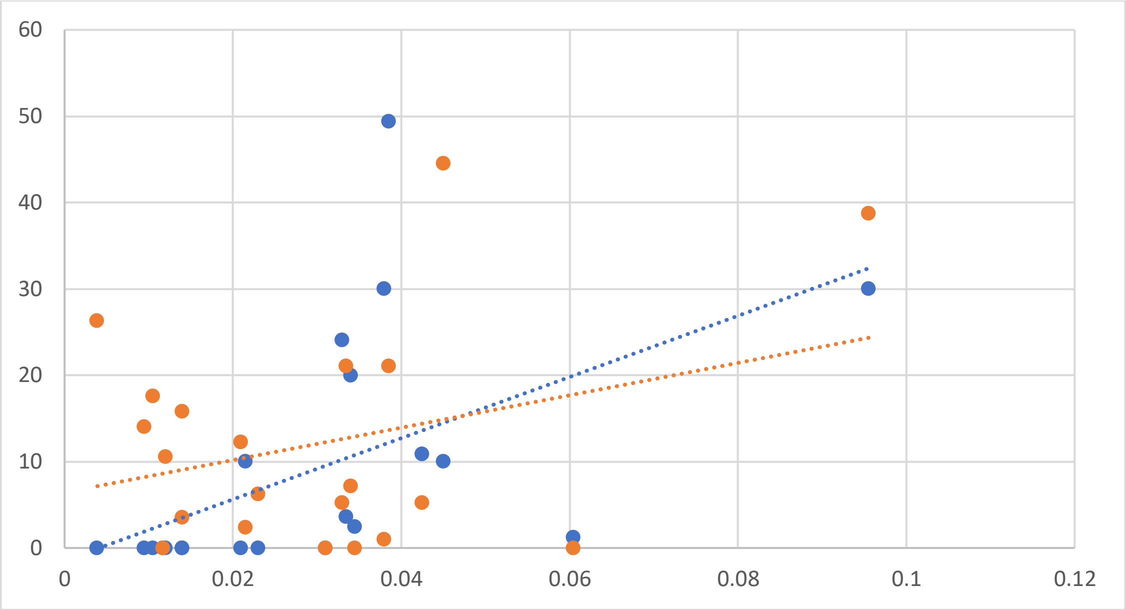


Figure 4. Johnny darter (blue) and longnose dace (orange) percent of catch over time across various sites in Sixteen-mile Creek graphed against phosphorus levels.

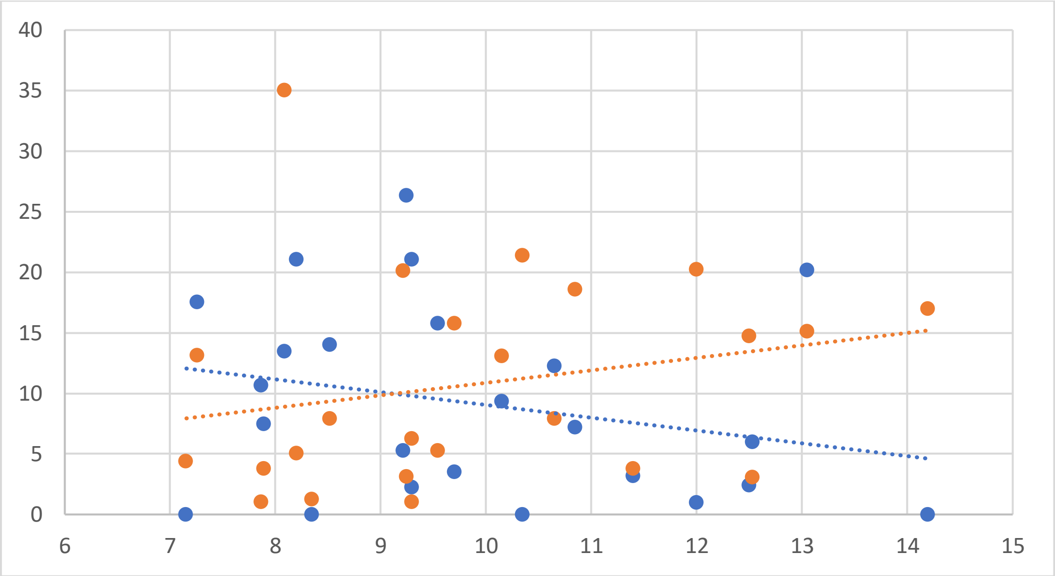


Figure 5. Longnose dace (blue) and rainbow darter (orange) percent of catch over time across various sites in Sixteen-Mile Creek graphed against dissolved oxygen levels.

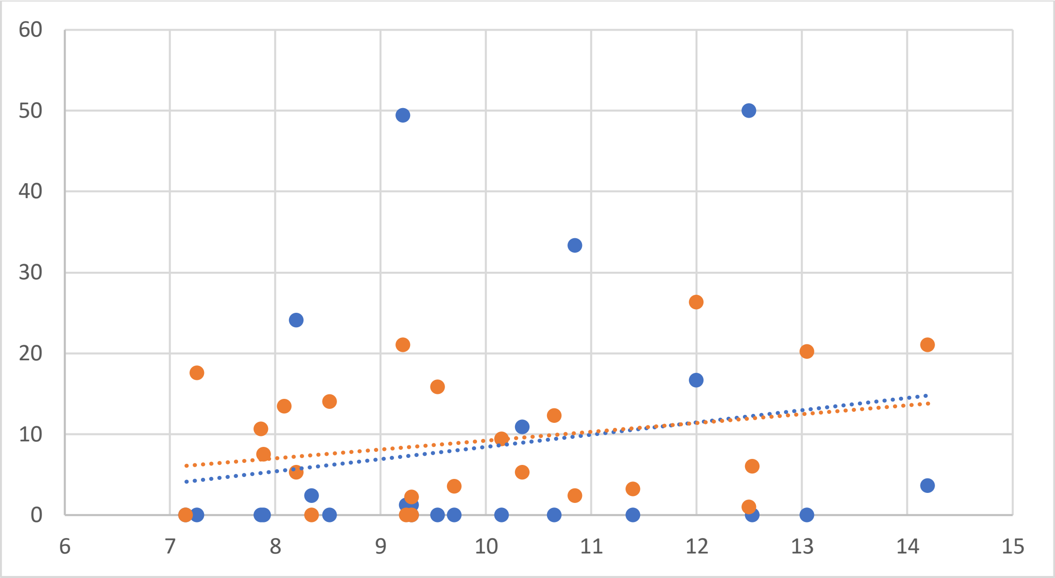


Figure 6. Johnny darter (blue) and longnose dace (orange) percent of catch over time across various sites in Sixteen-Mile Creek graphed against dissolved oxygen levels.

DISCUSSION

Urban populations pollute waterways by introducing a variety of chemicals and nutrients that can have negative impacts on aquatic life (Austin 2010). Chloride and phosphorus play a large role in altering an aquatic ecosystem; chloride affected three of four species in both habitats in this study, while most affected by phosphorus were the riffle habitats and the intolerant rainbow darter. Chloride often makes its way into rivers and streams through the use of road salts in the wintertime (Environment Canada 2011). Increased levels of chloride have been linked to reducing the vertical mixing of surface waters by changing the density gradient in lakes and pools. It has been recorded that this phenomenon can cause deep layers of water to become oxygen depleted. For example, a study found that high chloride levels can cause lakes to have a surface layer dissolved oxygen level of 10 mg/L or higher, while the deepest level may only have 1 mg/L or lower of dissolved oxygen (Lampert et al. 1997). Major phosphorus sources entering waterways are agricultural runoff and sewage effluents, which can cause eutrophication (Jarvie et al. 2006). It has been found that phosphorus loadings in Lake Erie have led to the presence of harmful algae blooms and zones of low oxygen, threatening the aquatic ecosystem (Environment Canada 2018). Large algae blooms that lead to lowered oxygen levels can affect fish population, especially species that require higher levels of oxygen, reduce mollusk populations and alter essential fish communities. Large algae blooms have also been found to reduce water clarity, lowering the success of predators who rely on light to catch prey, and raises pH levels during the day (Chislock et al. 2013). In Sixteen-mile Creek, there was no observable effect of high phosphorus loading on the tolerant species in either riffle or pool habitat.

It is believed that out of the many changes the aquatic ecosystem is facing, the reduction of dissolved oxygen is the most important (Doudoroff and Shumway 1970). In Sixteen-mile creek it was the intolerant rainbow darter in the riffle habitat that was most affected by changes to dissolved oxygen, while the tolerant species remained relatively unchanged with the fluctuations in dissolved oxygen. Low levels of dissolved oxygen lead to reduced fecundity, hatching delays of eggs, impaired growth development, depressed activity, and lethality at very low levels. Overall, it may be that the fast-flowing water found in riffle habitats in Sixteen-Mile Creek provide relief from water pollution, whereas pool habitats accumulate pollution, leading to both intolerant and tolerant pool species being more affected than tolerant riffle species.

CONCLUSION

Human caused pollution has been contaminating waterways all around the world (Duda 1993). The region of Halton in particular has seen a large rise in population over the decade leading to the destruction of many of their natural lands (Faita 2012). There are many threats that pose a risk to contaminating waterways such as agriculture and storm drain runoff, garden fertilizer and many more. In order to determine the effects of water pollution on freshwater fishes inhabiting riffle and pool habitats in Sixteen-Mile Creek model species were chosen. The rainbow and Johnny darter appear to be must affected by pollution, while longnose dace populations appeared least affected.

LITERATURE CITED

Austin, B. 2010. The effects of pollution on fish health. Journal of Applied Microbiology 1(85):234-242.

Authman, M., Zaki, M., Khailif, E., and Abbas, H. 2015. Use of fish as bio-indicator of the effects of heavy metals pollution. Journal of Aquaculture 4(6): 254-261.

Brabec, K., Zahradkova, S., Paril, P., Nemejcova, D., Kokes, J., and Jarkovsky, J. 2004. Assessment of organic pollution effect considering differences between lotic and lentic stream habitat. Integrated Assessment of Running Waters in Europe, 56(175):331-346.

Cary Institute of Ecosystem Studies. 2012. Water Life: Riffles and Pools. https://www.caryinstitute.org/sites/default/files/public/downloads/lesson-plans/water_life_riffle_and_pool_background.pdf

Cave, C. 1998. Stream Biology. School of Fisheries, University of Washington. http://www.lakesuperiorstreams.org/understanding/riffle_run_pool.htm

Chapman, J., Proulx, C., Veilleaux, M., Levert, C., Bliss, S., Andre, M., Lapointe, N., and Cooke, S. 2014. Clear as mud: A meta-analysis on the effects of sedimentation on freshwater fish and the effectiveness of sediment-control measures. Water Research 1(56):190-202.

Chrislock, M., Doster, E., Zitomer, R., and Wilson, A. 2013. Eutrophication: Causes, consequences, and controls in aquatic ecosystems. Nature Education Knowledge 4(4):10.

Conservation Halton. 2019. https://www.conservationhalton.ca/where-to-fish

d'Entremont, D. 2018. Sixteen Mile creek: Heart of the Halton Region. Oakvillegreen Conservation Association. https://oakvillegreen.org/discover-your-creek/sixteen-mile-creek-heart-of-the-halton-region/

Cravotta, C., Brightbill, R. and Langland, M. 2010. Stream Water Quality Trends Coinciding with the Return of Fish. Mine Water and the Environment. 29(3): 176-199.

Doudoroff, P., and Shumway, D. 1970. Dissolved Oxygen requirements of Freshwater Fishes. Department of Fisheries and Wildlife, Oregon State University. Corvallis, Oregon, U.S.A. 286pp.

Duda, A. 1993. Addressing Nonpoint Sources of Water Pollution Must Become an International Priority. Water Science Technology. 28(3-5):1-11.

Environment and Climate Change Canada. 2018. Canada-Ontario Lake Erie action plan. Ottawa. Unpublished report.

Evans, D. 1987. The fish gill: site of action and model for toxic effects of environmental pollutants. Environmental Health Perspectives, 1(71):47-58.

Faita, V. 2012. Urbanization of the Green Belt in the Halton Region. Ryerson University. Unpublished report.

Frissell, C., Liss, W., Warren, C., and Hurley, M. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management, 10(2):199-214.

Government of New Hampshire. 2017. Environmental, health and economic impacts of road salts. Department of Environmental Services.

Government of Nunavut, 2016. Turbidity. https://www.enr.gov.nt.ca/sites/enr/files/turbidity.pdf

Grabarkiewicz, J. and Davis, W. 2008. An Introduction to Freshwater Fishes as Biological Indicators. U.S Environmental Protection Agency. Office of Environmental information.

Harding, J., Burky, A., and Way, C. 1998. Habitat preferences of the Rainbow Darter, *Etheostoma caeruleum*, with regard to microhabitat velocity shelters. Copeia (4):988-997.

Holm, E., Mandrak, N. and Burridge, M. 2010. The ROM Field Guide to freshwater fishes of Ontario. Royal Ontario Museum. Friesens Printers. Altona, Manitoba. 462 pp.

Jarvie, H., Neal, C., and Withers, P. 2006. Sewage-effluent phosphorus: A greater risk to river eutrophication than agricultural phosphorus? Science of The Total Environment. 360(1-3):246-253.

Jenkins, Robert E., and Noel M. Burkhead. Freshwater fishes of Virginia. 1994. American Fisheries Society. 1079pp.

Lampert, W., and Sommer, U. 1997. Limnoecology: The Ecology of Lakes and Streams. Oxford University Press, Science. 382pp.

Litke, D. 1999. Review of Phosphorus Control Measure in the United States and Their Effects on Water Quality. United States Geological Survey. Water-Resources Investigations Report 99-4007. Denver, Colorado.

McNielly, K. 2014. *Etheostoma carruleu.* Animal Diversity Web, University of Michigan. https://animaldiversity.org/accounts/Etheostoma_caeruleum/

Minnesota Pollution Control Agency. 2008. Nutrients: Phosphorus, Nitrogen Sources, Impact on Water Quality. https://www.pca.state.mn.us/sites/default/files/wq-iw3-22.pdf

Nagpal, N., Levy, D and MacDonald D. 2003. Ambient water quality guidelines for chloride. Government of British Columbia, Ministry of Water, Land and Air Protection. https://pdfs.semanticscholar.org/55f6/e21efd43d480cce240752cf5e06197f63203.Pdf

National Oceanic and Atmospheric Administration. What is eutrophication? U.S Department of Commerce. https://oceanservice.noaa.gov/facts/eutrophication.html

Oakvillegreen Conservation Association. 2019. Sixteen Mile Creek: Heart of the Halton Region. https://oakvillegreen.org/discover-your-creek/sixteen-mile-creek-heart-of-the-halton-region/

Ohio Department of Natural Resources: Division of Wildlife (ODNR). 2012. http://wildlife.ohiodnr.gov/species-and-habitats/species-guide-index/fish/rainbow-darter

Ohio Department of Natural Resources: Division of Wildlife (ODNR). 2012. http://wildlife.ohiodnr.gov/species-and-habitats/species-guide-index/fish/johnny-darter

Paine, C., Dodson, J., and Power, G. 1982. Habitat and food resource portioning among four species of darters (Percidae: *Etheostoma*) in a southern Ontario stream. Canadian Journal of Zoology. 60(7):1635-1641.

Parsons, M. and Norris, R. 1996. The effect of habitat-specific sampling on biological assessment of water quality using predictive models. Freshwater Biology, 2(36)419-434.

Paulsan, N., and Hatch, J. 2002. Rainbow darter *Etheostoma caeruleum* Storer, 1845. Minnesota Department of Natural Resources' MinnAqua Aquatic Program. http://academics.cehd.umn.edu/hatch/research/fish/fishes/rainbow_darter.html

Propst, D., and Carlson, C. Life history notes and distribution of the Johnny darter, Etheostoma nigrum (Percidae), in Colorado. The Southwestern Naturalist. 34(2):210-259.

Scott, J., Steward, C., Stober, Q. 1986. Effects of urban development on fish population dynamics in Kelsey Creek, Washington. Transactions of the American Fisheries Society, 115(4):555-567.

Stanfield, L. 2010. Ontario Stream Assessment Protocol. Version 8.0. Fisheries Policy Section. Ontario Ministry of Natural Resources. Peterborough, Ontario. 376pp.

Statistics Canada. 2016. Population and dwelling count highlight tables, 2016 census. Government of Canada.

Taylor, C. 2000. A large-scale comparative analysis of riffle and pool fish communities in an upland stream system. Environmental Biology of Fishes, 58(1):89-95

Thompson, D. 2018. Pool-Riffle Sequences. Reference Module in Earth Systems and Environmental Sciences. 264 pp.

Thompson, L. 2004. Fish habitat in freshwater streams. University of California: Division of Agriculture and Natural Resources. Publication 8112. https://www.researchgate.net/publication/237385944_Fish_Habitat_in_Freshwater_Streams

Tonnis, B. 2006. Microsatellite DNA markers for the rainbow darter, *Etheostoma caeruleum* (Percidae), and their potential utility for other darter species. Molecular Ecology Notes 6(1):230-232.

Unites States Environmental Protection Agency (EPA). 2003. Protecting water quality from urban runoff. EPA 841-F-93-003. https://www3.epa.gov/npdes/pubs/nps_urban-facts_final.pdf

United States Geological Survey (USGS). 2014. Urban land use and water quality. https://www.usgs.gov/mission-areas/water-resources/science/urban-land-use-and-water-quality?qt-science_center_objects=0#qt-science_center_objects viewed 09/26/2019

Winter, J.D and Duthie, H.C. 1998. Effects of urbanization on water quality, periphyton and invertebrate communities in a southern Ontario stream. Canadian Water Resources Journal 23(3):245-257.