Water Quality Improvements and Biodiversity Recovery Within the Upper Junction Creek Watershed

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Cover photos

Greater Sudbury Archives https://www.archeion.ca/269

Sudbury.com https://www.sudbury.com/local-news/volunteers-launch-2000-brook-trout-into-junction-creek-8734792

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Executive Summary

This report compiles available information on the past, present and expected future conditions of water quality and biodiversity of the Upper Junction Creek Watershed (UJCW). Junction Creek and its tributaries flow 52 km through the centre of the Sudbury, Ontario, and over the past 60 years this system has been transformed from what once was a severely damaged ecosystem with significant public safety concerns, into a highly valuable natural asset. This literature and data syntheses is designed to aid in management planning for areas where Conservation Sudbury owns property or infrastructure such as flood control structures within the watershed.

1. The Past

The history of the UJCW is marked by decades of industrial and urban environmental degradation as Sudbury grew from a small forestry town into a mining hub. By the 1960s, Sudbury's metal smelting operations had become the largest point source of sulfur dioxide (SO_2) emissions in the world, contaminating the surrounding environment with both sulfur and heavy metals (Ni, Cu, etc.) and severely impacting biodiversity in the region's lakes and streams. The mining impacts combined with the earlier forestry harvest left a large area with a denuded landscape and extreme soil loss that was vulnerable to extreme flooding.

During the early period of urban and industrial development there were several catastrophic floods, particularly in the Flour Mill and Downtown areas, resulting in numerous drownings and significant property damage. By 1965, the region was at a critical juncture. Not only were flooding and industrial runoff severe problems, but inadequate sewage systems were also adding to the contamination problem. Conservation Sudbury, then known as the Nickel District Conservation Authority, was established to address these challenging flood management and water quality issues.

2. Current Situation: A New Era of Restoration

Since the 1960s, significant strides have been made in flood management and environmental restoration across the UJCW. Early flood control efforts by the Nickel District Conservation Authority included the construction of the Frood, Nickeldale, and Maley dams, aimed at controlling stormwater runoff and mitigating flood risks. In the 1970s, the mining industry (INCO, now Vale) built lime treatment plants on Copper Cliff, Nolin, and Garson tributaries to neutralize the incoming acid mine drainage. Around the same time, extensive tree planting began as part of a larger, progressive effort to restore the landscape, spearheaded by INCO, Laurentian University Researchers, and the volunteer-led Vegetation Enhancement Technical Advisory Committee (VETAC), established in 1973. To date this initiative has planted over 2.3 million trees and shrubs within the Upper Junction Creek Watershed, contributing significantly to landscape stabilization and ecological recovery.

Water quality has also improved dramatically over the past 60 years. The massive reductions (> 95%) of acid and metal deposition from area smelters, followed by large investments to address toxic drainage from waste tailings or active mines has resulted in orders-of-magnitude improvements in water chemistry parameters such as pH, copper (Cu), and nickel (Ni). Specific interventions, such as the 2001 diversion of acid mine drainage to mine-owned water treatment plants on the Frood branch of Junction Creek, have also contributed to very positive effects on both the chemistry and biodiversity of the downstream creek.

The most biodiverse and healthiest areas of the watershed are now found in the Maley tributary, a subwatershed area without any history of mining activity. Much of the Conservation Sudbury land holdings (12% of the surface area) are in the Maley subwatershed. The changes in this so called internal "reference area" clearly shows that regional efforts of atmospheric emission reductions and restoration efforts have yielded very positive results, with water quality conditions now approaching Provincial Water Quality Objectives (PWQO). Additionally, this Maley area is enriched by discharges of a groundwater aquifer providing cleaner water, further contributing to the higher biodiversity quality of this portion of the watershed. This area, with further work, has the possibility of someday supporting a reproducing Brook Trout (*Salvelinis fontinalis*) population.

Although there are no pre-disturbance reference sites in the watershed to describe the original biological community, the positive trends in biodiversity recovery in recent decades are very promising. In 1965, only two individual Brook Stickleback (*Culea inconstans*) were recorded near the confluence of the Maley Tributary. Today, the watershed supports over 20 fish species, including the relatively sensitive Blacknose Shiner (*Notropis heterolepis*), and stocked Brook Trout have survived for up to three years post-release. Benthic invertebrate communities have similarly shifted—from domination by highly tolerant midges (Chironomidae) and worms (Oligochaeta) in the 1960s to the reappearance of more sensitive species such as caddisflies (Trichoptera), mayflies (Ephemeroptera), and even stoneflies (Plecoptera), which were first documented near Paquette Street in 2007.

These signs of recovery—diverse, stable communities of fish and benthic invertebrates, alongside water quality improvements—are clear indicators of the benefits and resilience achieved through engineered interventions such as emission controls, liming plants, flood mitigation, drainage diversion, and regreening. These metrics show that these large and expensive environmental investments in UJCW are working. While the UJCW landscape has been significantly altered and is far from its original state—once a meandering creek flowing through old-growth pine forest—our community goal can be to continue to improve the current ecological conditions while focusing on enhancing resilience in preparation for the future.

Community engagement, especially by the award-winning Junction Creek Stewardship Committee (JCSC, formed in 1999), has been extremely effective at both raising public interest in the creek and assisting with the restoration work. The JCSC has supported development of many new walking trails alongside litter clean ups, bug searches with kids, extensive tree planting, management of invasive plant species, installation of erosion control structures for stream bank stabilization, and have conducted water quality and biodiversity surveys. Perhaps the most newsworthy and prominent of their public engagement activities has been the release of Brook Trout (*Salvelinus fontinalis*) over the last 25 years. To date, the public has assisted in the release of over 2000 juvenile Brook Trout (*Salvelinus fontinalis*) in hopes of re-establishing a reproducing population. However, there is currently no solid evidence that a self-sustaining population has been achieved, indicating that further ecological improvements are needed.

3. Future Threats

Despite the progress made, new challenges have emerged that threaten the health of the Upper Junction Creek Watershed. One concern is the rising levels of chloride (Cl) in the water from application of road salt for winter safety, which may have adverse effects on local biota. The introduction of microplastics and a wide variety of anthropogenic chemicals (e.g. PFAS) into the ecosystem poses another growing threat, as their impact on water quality and aquatic life remains largely unknown. There is also some evidence of rising nutrient levels in the Garson area, perhaps from sewage or wastewater lagoons. However, the most important concern is climate change with the likelihood of more extreme events (heat, drought, flooding) and altered seasonal impacts (e.g. precipitation on snow and ice) that are a serious threat to the safe management and use of this system.

4. Conclusion

The UJCW is experiencing remarkable ecological improvements in both water quality and biodiversity. The efforts of the past decades have begun to yield very positive results, but challenges remain. Urbanization and climate change will continue to play a significant role in shaping the future of the watershed. It is essential that we look forward, focusing on strategies to enhance the resilience of the ecosystem rather than simply dwelling on past challenges. The UJCW is an example of a landscape rising from the dust and, with continued commitment to restoration and protection, it has the potential to thrive for generations to come. The body of this report documents the evidence that UJCW is improving but remains a highly modified system. Some general recommendations are provided at the end of the report.

Acknowledgements

This report is a contribution to the partnership agreement recently established between Conservation Sudbury and the Cooperative Freshwater Ecology Unit (CFEU) at Laurentian University, an agreement designed to share information derived from student and faculty projects that can be used to help in the management of conservation lands.

Many thanks to Miranda Virtanen of Junction Creek Stewardship Committee, Bill Keller of Cooperative Freshwater Ecology Unit, Brie Edwards of Ontario Ministry of Environment, Conservation, and Parks, and Jennifer Davidson of Conservation Sudbury for sharing knowledge and documents. Special credit to Cassidy McAuliffe for assembling the fish figure.

Introduction

Junction Creek/Nibi Nikwejiwong is the urban stream that flows through the heart of Greater Sudbury/N'Swakamok. The Upper Junction Creek Watershed (UJCW) has a long history of industrial and urban impacts, beginning with the introduction of logging in the early 1870s[1], followed by the rise of large-scale mining and smelting operations, which would lead to acidification and metal deposition across the landscape[2]. The UJCW also experienced point source industrial pollution from a creosote plant[3], acid mine drainage from waste rock piles at Frood Stobie mine and the massive Copper Cliff tailing and slag piles[2,4], as well as urban wastewater and sanitary sewer inputs[5].

Fortunately, the UJCW also has a long history of restoration and recovery work, including being part of a highly successful and ongoing regreening program in the Sudbury area[2], the continuing reduction of industrial atmospheric pollutants[6], and many initiatives addressing acid mine drainage (e.g. building lime treatment plants, effluent diversion projects) and other pollution sources[43]. This work, and continuing efforts, have allowed impressive strides in ecosystem recovery in the UJCW.

Water quality and biodiversity of the UJCW have been assessed in numerous studies since at least the 1960s, with fish and benthic macroinvertebrates commonly used as indicators of environmental health. This report brings together years of studies and assessments focused on the UJCW, illustrating the changes in water quality and biodiversity that have occurred in the watershed over time.

Study Area

The UJCW is part of the City of Greater Sudbury in northern Ontario. The city is located within the area encompassed by the Robinson Huron Treaty of 1850 and within the traditional homelands of Atikameksheng Anishinabek and Wahnapitae First Nation. It is situated on the Canadian Shield but exhibits a unique topography because of the Sudbury Basin, an impact crater created 1.85 B years ago and responsible for Sudbury's rich copper and nickel ore deposits[7]. The present-day topography is characterized by numerous rock outcrops and narrow valleys that are the result of heavy scouring during the Wisconsin glaciation. Forests in the Sudbury area are a mix of coniferous and deciduous trees as the Great Lakes St. Lawrence Forest Region transitions to Boreal Forest[8]. The city is also home to 330 lakes, as well as an abundance of ponds, wetlands, creeks, and rivers[9].

Junction Creek is the central urban stream in Greater Sudbury, flowing for a total length of 52 km[10]. From its headwater near the South Mine in Garson to the outlet into McCharles Lake, the total area of the Junction Creek Watershed is approximately 320km[2, 10]. The focus of this report is on the upper portion of the watershed (the Upper Junction Creek Watershed, or UJCW) beginning at the headwater and ending at the outlet into Kelly Lake (Figure 1).

Junction Creek flows through many parts of the city, as well as through the provincially significant Ponderosa Wetland, and under the downtown core, before draining into Kelly Lake which denotes the end of the upper section of the creek. The UJCW also includes the Maley, Frood, Nolin, and Copper Cliff tributaries, each flowing into the main branch of the creek. As the Maley tributary is considered the least impacted by urban or industrial effects, it is often used as a reference condition for the creek. A portion of land (see Table 1) in the UJCW is protected land managed by Conservation Sudbury (Figure 1), including a substantial portion in the Maley watershed. The UJCW also includes several dams for both flood control and industrial waste management[2].

*Table 1 - Total subwatershed area, area owned by Conservation Sudbury (CS), area of parklands owned by the City of Greater Sudbury (CGS), as well as total area limed, number of trees planted, and number of understory transplants from the municipal regreening program for each subwatershed in Upper Junction Creek. *The diversion of AMD from the Frood subwatershed in 2001 decreased the effective size of the watershed from 1000.8 ha.*

Subwatershed	CS Land (ha)	CGS Lands (ha)	Total Land (ha)	% Protected	Area Limed (ha)	Trees Planted	Understory Transplants
Maley	381.8	27.0	3190.3	12.8	832.1	504794	23
Garson	6.5	48.8	912.9	6.1	2.8	191279	46
Frood	50.4	21.5	752.4*	9.6	176.3	361018	67
Nolin	0	61.4	2465.2	2.5	1128.9	886450	145
Copper Cliff	0	12.2	2080.9	0.6	325.2	222437	14
Main Branch	80.2	109.9	2363.9	8.0	315.5	37540	51
Total	518.9	280.8	12022.0	6.7	2780.8	2293851	346

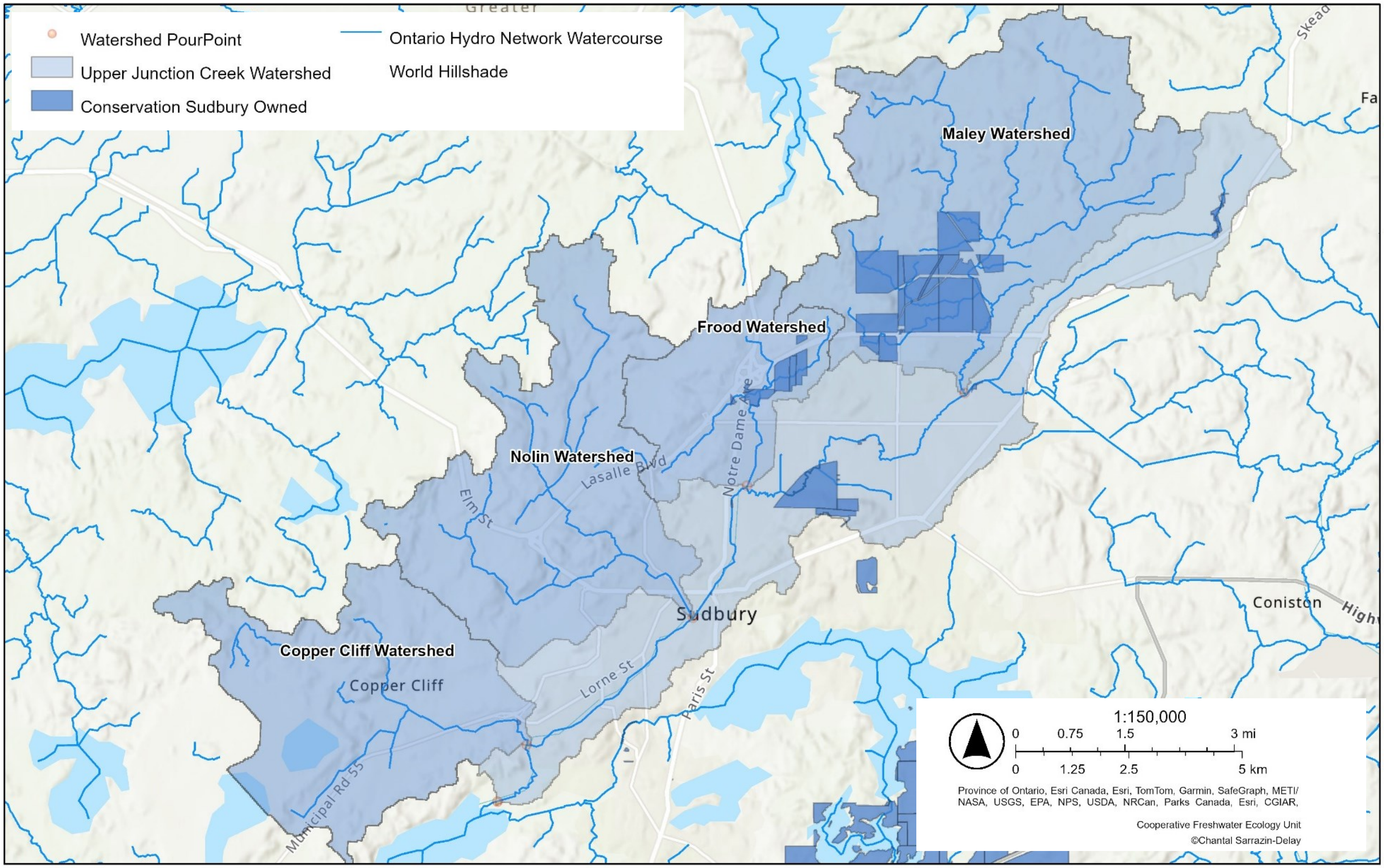

Figure 1 – Upper Junction Creek watershed with its four tributary watersheds in blue (source: Ontario Watershed Information Tool) along with Conservation Sudbury protected land in darker blue. Note that these watershed boundaries do not account for all water control features on Vale property (e.g., Frood watershed underground diversion to Copper Cliff).

The History of Sudbury and the Upper Junction Creek Watershed

Sudbury and its local watershed areas are among the most environmentally impacted areas in the world[8,6]. Forest fires, logging, and metal smelting created enormous impacts on the terrestrial and aquatic ecosystems[11,12,13,14], destroying the landscape that was home to Indigenous communities for millennia. When European colonists arrived, the area was dominated by Red (*Pinus resinosa*) and White Pine (*Pinus strobus*), with some hardwoods such as Sugar Maple (*Acer saccharum*) and Yellow Birch (*Betula alleghaniensis*) in the southern sections[14]. These early European colonists gave Sudbury the name Ste. Anne of the Pines as a reflection of what Sudbury looked like before extensive lumbering began in the early 1870s[1]. The lumber industry continued to be widespread in Sudbury until as late as 1927, when mining then rose to dominance in the area[14].

Sudbury's metal mining operations began in the late 1800s[15]. The first official report of vegetation damage was published in 1945 after government representatives met to discuss the problem of sulfur dioxide (SO_2) damage in the surrounding forests[14]. Smelting emissions peaked in the 1960s when Sudbury smelters represented the largest point source of sulfur pollution in the world, with annual emissions exceeding 2 million tons of SO_2 per year[15]. Gorham and Gordon[11,12] were the first scientists to publish journal articles describing the damage. They described the extensive vegetation damage but focused on impacts to ponds and wetlands. Peatland communities within 30km of the smelters were particularly heavily impacted by airborne pollutants, with levels of copper (Cu) and nickel (Ni) in the mosses increasing with the proximity of the smelters[16]. Sphagnum mosses and lichens proved highly sensitive with an extensive lichen and sphagnum moss desert extending out from the smelters[17].

Government control orders and regulations finally came into effect in the late 1960s and early 1970s to reduce pollution[18]. A major reduction (approx. 50%) in pollution occurred in 1972, with the closing of the Coniston smelter and the construction of the 381m Superstack that dispersed the sulfur dioxide away from Sudbury[15]. These government-imposed regulations of the day and those that continued to force change drove the innovation of new technology (e.g. electrostatic precipitators, gas scrubbers, pre-sorting of ore of different quality, etc.) that would ultimately result in the significant reductions (>95%) of smelter emissions of SO_2 and metallic dust we see today[19,6]. Reducing the release of these gases and metal particles, coupled with a strong science-based municipal regreening program, kick-started a remarkable chemical and biological recovery across the Sudbury region[15] (Figure 2), including the Junction Creek watershed.

Figure 2 – 45 years of Sudbury, Canada's landscape restoration, then and now (1978-2022)

The History of Upper Junction Creek

Historically, prior to the deforestation and rapid urbanization leading into the 1960s, Junction Creek was a shallow, meandering stream surrounded by pine forest (Figure 3). As the city developed, many historical records indicate that, during snowmelt or heavy rain events, the Downtown and Flour Mill areas of the City were subjected to numerous floods as Junction Creek overflowed its banks, often with costly and very tragic results (Figure 4). Over 20 deaths have occurred in the past century due to drowning[20] in Junction Creek, often related to these high flow events.

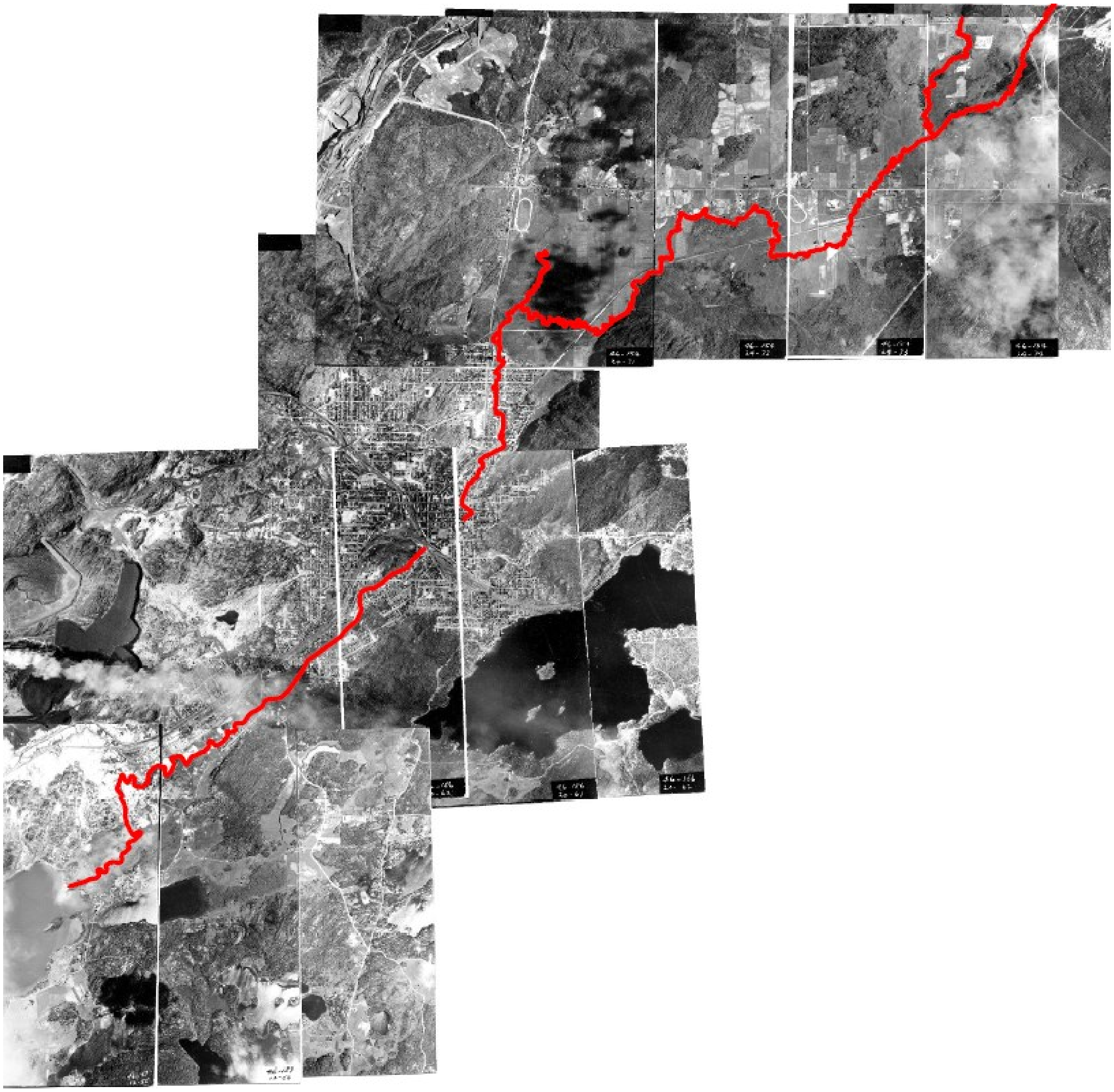

Figure 3 – The earliest freely available historic aerial photos (1946) with Junction Creek delineated [21,22]

Figure 4 – Spring flooding on Dell Street in the Flour Mill area of Sudbury, April 2, 1942. The barren hills seen in the background illustrate the lack of vegetation in the city at that time. Image from City of Greater Sudbury Archives https://www.archeion.ca/269-17

The city first attempted to mitigate flooding impacts by enclosing parts of Junction Creek and its tributary Nolin Creek in a large box culvert to protect the Downtown, with the work beginning in the 1930s and continuing for several decades (Figure 5). The downtown box culvert encloses 1775 m of Junction and Nolin Creeks in a concrete structure that increases in size from 5.8 m x 3.6 m on the upstream side to 9.7 m x 5.5 m as it continues downstream.

Figure 5 – The construction of box culverts in Downtown Sudbury, 1939. Photo from Conservation Sudbury.

In addition to the box culvert, portions of Junction Creek were straightened and deepened for both development and flood resilience reasons. To further address the flooding problem, several dams were built during the 1970s. The Frood, Maley, and Nickeldale dams were built and operated by Conservation Sudbury while the Clarabelle dam was built and operated by Vale (then INCO Ltd.). The Maley, Nickeldale, Frood, and Clarabelle dams are storage reservoirs that capture large volumes of runoff water during events like heavy rainstorms and release it at a much slower rate to minimize downstream flooding[23]. At present, a re-profiling of Junction Creek that runs along Notre Dame Avenue is slated for 2025-2027 to reduce flood risk to the Flour Mill neighbourhood of the City.

In addition to the risk to the citizens, Junction Creek was also a poisonous stream that eliminated much of the possibility of having healthy aquatic ecosystems that would support fish and other biota flowing through the city. A 1965 biological survey of Sudbury's streams and lakes found Junction Creek and its major tributaries to be heavily polluted by both sanitary and mining waste, leading to heavy organic enrichment and enormous concentrations of acid and toxic heavy metals[5]. Fortunately, improvements in wastewater treatment, such as the construction of the Sudbury Wastewater Treatment Plant in the early 1970s[24], and industrial actions, such as the acid mine drainage diversion project that eliminated acidic, metal contaminated runoff water from entering the Frood tributary[4], have allowed for much improved conditions in the UJCW. Remediation projects, such as the removal of contaminated sediment from a historic creosote facility, have also improved areas of the UJCW[3].

Climate projections for the region of Sudbury

Climate change is expected to result in significant environmental shifts across the Sudbury region, with the most noticeable change being a rise in temperatures (Figure 6). Under the high-carbon scenario (RCP8.5), the average summer temperature is projected to increase from a historical mean of 17.6°C, to 19.7°C between 2021 and 2050 (a rise of 2.1°C), and to 22°C between 2051 and 2080 (a rise of 4.4°C) (Figure 7)[25]. This warming trend will lead to more frequent and prolonged heatwaves, with the number of heatwaves projected to increase from 0.6 to 4.6 events annually (2051-2080)[25]. The number of very hot days in a year (temperatures 30°C or above) is also expected to rise substantially, from 5.5 days historically to 16 days per year in 2021-2050 and 31.6 days in 2051-2080 (Figure 6, Figure 7).[25]

These temperature changes will exacerbate the occurrence of drier summers, contributing to lower water levels. This in turn can result in increased acid and metal releases into water bodies[26]. Warmer water temperatures will also impact fish and other aquatic life, with cool and coldwater fish, like Brook Trout (*Salvelinus fontinalis*), being pushed out of areas as temperatures rise.

Additionally, warmer spring temperatures in the region can lead to faster spring melts, which will increase the likelihood of spring flooding. Flooding related to spring melt is a historic and ongoing problem for several neighbourhoods in the Junction Creek watershed[27][28] and may be intensified by this increase in spring temperatures.

RCP 8.5: High Carbon climate future
GHG emissions continue to increase at current rates

Variable	Period	1976-2005	2021-2050			2051-2080		
		Mean	Low	Mean	High	Low	Mean	High
Precipitation (mm)	annual	853	747	909	1079	778	943	1128
Precipitation (mm)	spring	191	142	209	291	149	225	314
Precipitation (mm)	summer	217	139	219	309	140	215	301
Precipitation (mm)	fall	258	188	276	370	189	280	380
Precipitation (mm)	winter	187	145	205	268	156	222	291
Mean Temperature (°C)	annual	4.2	5	6.5	8	7.1	8.8	10.8
Mean Temperature (°C)	spring	3.2	2.6	5.2	8.2	4.6	7.4	10.9
Mean Temperature (°C)	summer	17.6	18.3	19.7	21.4	20.2	22	23.9
Mean Temperature (°C)	fall	6.5	7	8.7	10.4	8.8	10.7	12.5
Mean Temperature (°C)	winter	-10.6	-11.1	-8.1	-5	-8.3	-5.2	-2
Tropical Nights	annual	1	1	5	11	5	16	30
Very hot days (+30°C)	annual	6	5	17	31	17	37	59
Very cold days (-30°C)	annual	6	0	2	5	0	0	2
Date of Last Spring Frost	annual	May 14	April 13	May 3	May 19	April 2	April 23	May 10
Date of First Fall Frost	annual	Sep. 28	Sep. 26	Oct. 13	Oct. 30	Oct. 7	Oct. 24	Nov. 12
Frost-Free Season (days)	annual	134	135	160	189	155	181	214

Figure 6 – Climate projections for the Sudbury region from the Climate Atlas of Canada (www.climateatlas.ca)

Changes in precipitation patterns are also anticipated with climate change, with the spring, fall, and winter seasons expected to have increased precipitation in both 2021-2050 (9%, 7%, 10% respectively) and 2021-2080 (18%, 8%, and 19% respectively) (Figure 6, Figure 7), while summer rainfall shows little change (+1% 2021-2050, -1% 2051-2080)[25]. Increasing winter precipitation, along with warmer average winter temperatures (+5.4°C in 2051-2080)[25] will likely lead to more occurrences of rain on frozen ground, which can lead to flooding, especially in low-lying areas. Extreme rain events are also expected to become more frequent, with the number of days per year receiving 20mm of rain or more increasing from 5.3 days historically to 7.4 days between 2051 and 2080 (Figure 7)[25].

The combination of warmer temperatures, altered precipitation patterns, and more intense rainfall events will lead to increased water runoff over land. This runoff will carry pollutants such as microplastics, oils, gases, and metals, as well as hot water from impervious surfaces, into Sudbury's lakes, streams, and rivers. Erosion and sedimentation will also intensify, which could hinder fish spawning and degrade refugia for benthic invertebrates.

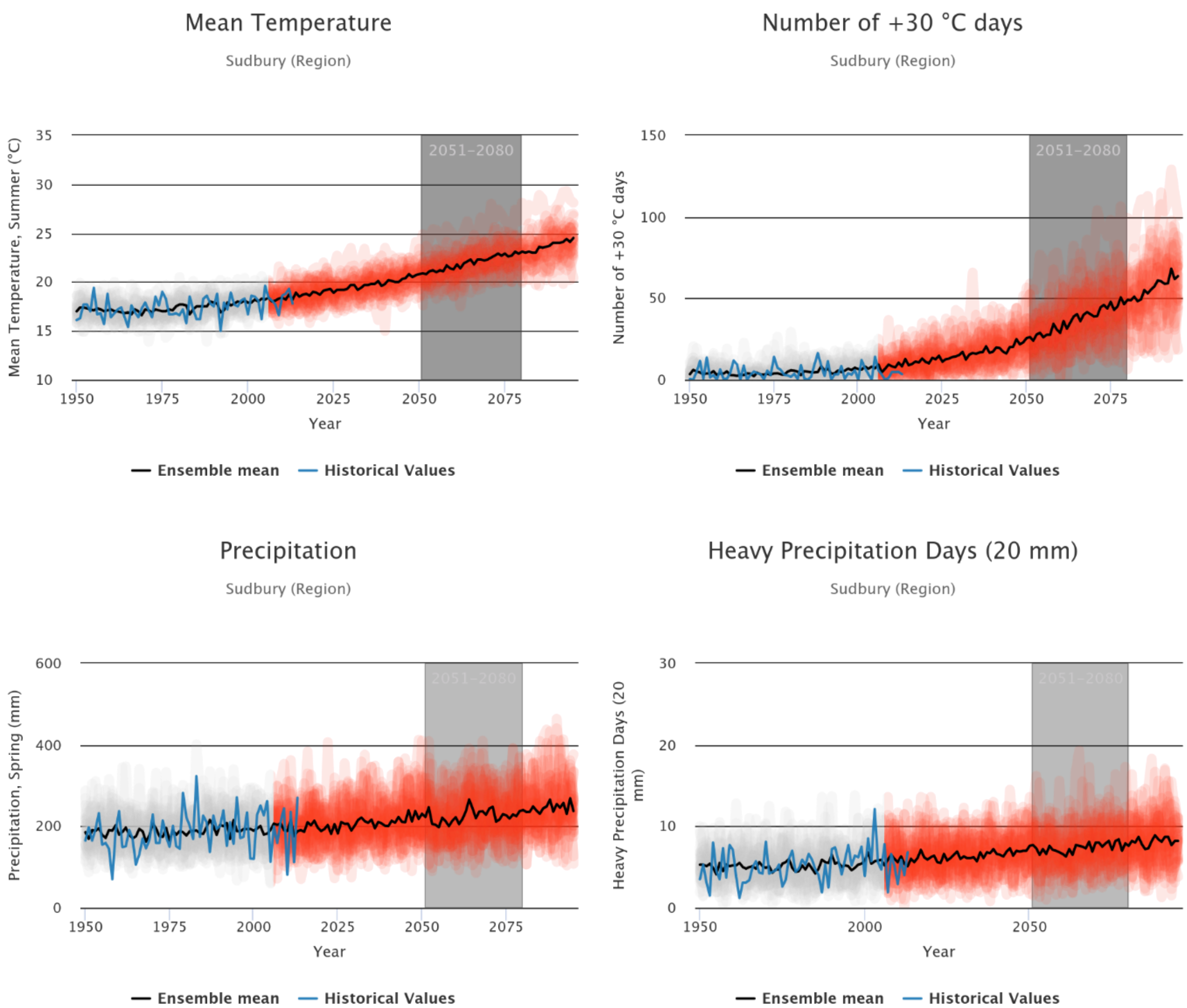

Figure 7 – Temperature and precipitation projections for the Sudbury region from Climate Atlas of Canada (www.climateatlas.ca). Top row: increase in summer mean temperature (from 17.6 to 22°C) and increasing days above 30°C (from 5.5 to 37). Bottom row: mean spring precipitation increases 18%, and more days (5.3 days to 7.4 days) of heavy rain (20mm or more) are projected.

As communities face greater challenges with flooding, shoreline damage could become more prevalent and existing environmental and infrastructure issues are liable to become exacerbated. These impacts highlight the urgent need for ongoing adaptive strategies to mitigate climate-related risks in the Sudbury region.

Adaptation can include (Figure 8):

- Keeping wetlands and natural spaces in the community, or creating spaces like rain gardens
- Keeping/restoring natural conditions
- Monitoring water quality and water levels
- Maintaining good community drainage and planning projects with floodplains in mind
- Preventing pollutants from entering waterways and limiting shoreline erosion with riparian vegetation
- Ensuring wastewater lagoons can handle heavy rain and upgrading if needed

Figure 8 – Watershed Climate Adaptation Quick Guide by Up North on Climate listing typical climate impacts on watersheds in northern Ontario and potential adaptation options[29].

Previous Studies of Water Quality and Biodiversity

Water quality and biodiversity have been assessed in Upper Junction Creek intermittently since at least the 1960s. Water quality has been analysed at various stations within the context of biodiversity studies but also as a long-term monitoring project. Biodiversity studies in the creek have included fish, benthic macroinvertebrates, and to a lesser extent macrophytes. Although not presented here, watershed studies have also included riparian vegetation and thermal studies. Here, we focus on trends in water quality, fish communities, and benthic invertebrates as evidence that Upper Junction Creek has turned the corner on a dark past and is showing remarkable indications of recovery.

Water Quality Assessment

Water chemistry data across the UJCW were sourced from provincial and local monitoring programs, data reports, and academic theses. Together, these sources span over 60 years of monitoring and include 4,616 water sampling events from 134 sampling stations, representing around 65 discrete sampling locations (Figure 9). Some locations overlap between studies, and in some cases, the exact location of sampling is unknown. A brief summary of the 8 data sources is provided below.

1960-1965 – Ontario Water Resources Commission (n = 59)

The earliest water chemistry data for Upper Junction Creek were collected at 28 sites across the watershed in the early 1960s by the Ontario Water Resources Commission[30,31]. A total of 28 sites were sampled across the watershed, including 3 sites in the Garson headwaters, 4 in Frood, 2 in Nolin, 5 in Copper Cliff, and 14 along the main branch of the creek. Depending on the site, 1-7 water quality parameters were measured including pH, copper, nickel, iron, alkalinity, calcium, and sulfate.

1968-1996 – Provincial Water Quality Monitoring Network (n = 2042)

The largest historical source of water chemistry data is from the Provincial Water Quality Monitoring Network (PWQMN), administered by the Ontario Ministry of the Environment, Conservation and Parks. Data were collected from 23 sites over different periods between 1968 and 1996, depending on site[32]. This includes 2 sites in the Garson headwaters, 6 in Frood, 4 in Nolin, 4 in Copper Cliff, and 7 along the main branch of the creek. Sixteen water quality parameters were measured including water temperature, conductivity, aluminum, alkalinity, arsenic, calcium, cadmium, chloride, copper, iron, hardness, manganese, nickel, lead, pH, sulfate, and zinc.

1972 – Keller Report (n = 33)

In 1975, a data summary report was produced by Bill Keller of the Ontario Ministry of the Environment outlining water quality data from 1972 at 19 sites across Upper Junction Creek[33]. This included 5 sites in the Garson headwaters, 3 in Frood, 2 in Maley, 2 in Nolin, 1 in Copper Cliff, and 6 along the main branch of the creek. Twelve water quality parameters were measured including temperature, conductivity, calcium, cadmium, copper, iron, nickel, nitrate, phosphorous, pH, sulfate, and zinc.

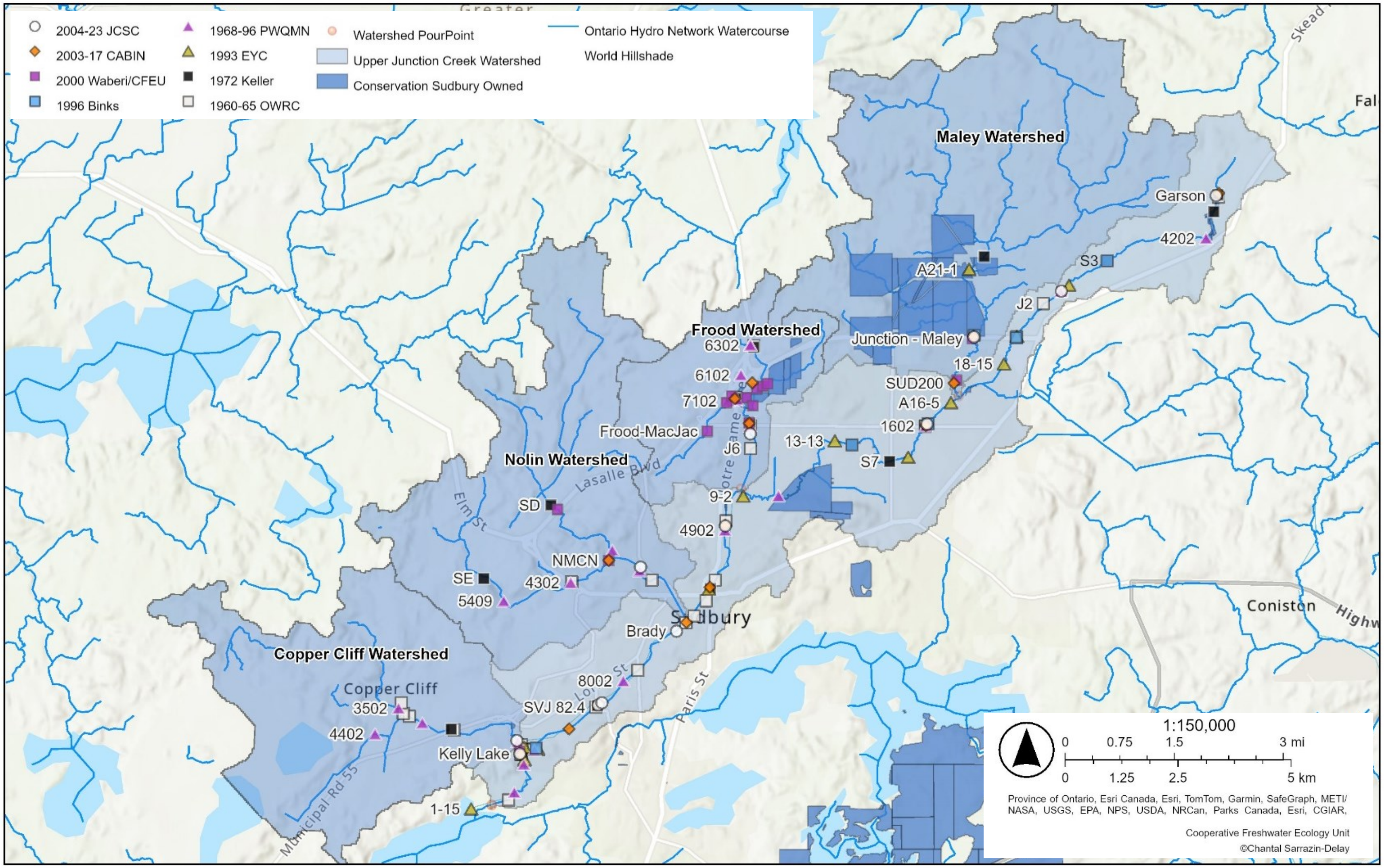

Figure 9 – Map of all water sampling sites from 1960 to 2024 sourced from provincial and local monitoring programs, data reports, and theses.

1993 – Environmental Youth Corps Assessment (n = 14)

In 1993, the Environmental Youth Corps conducted a water quality survey at 14 sites in Upper Junction Creek[34]. This included 3 sites in the Garson headwaters, 1 in Maley, and 10 along the main branch of the creek. Thirteen water quality parameters were measured including conductivity, aluminum, alkalinity, calcium, chloride, copper, iron, manganese, nickel, lead, pH, sulfate, and zinc.

1996 – Binks and Donato Undergraduate Thesis (n = 12)

In 1996, 6 sites in Upper Junction Creek originally surveyed by the Ministry of the Environment in 1972 were resurveyed as part of an undergraduate thesis at Laurentian University[35]. This included 2 sites in the Garson headwaters, 1 in Maley, and 3 along the main branch of the creek. Twelve water quality parameters were measured including conductivity, calcium, cadmium, copper, iron, nickel, nitrate, phosphorous, pH, sulfate, and zinc. Other parameters not discussed here were also measured.

1996-2003 – Cooperative Freshwater Ecology Unit Data (n = 190)

Between 1996 and 2003, the Cooperative Freshwater Ecology Unit (CFEU) collected water quality data from 14 sites in Upper Junction Creek. This sampling was primarily targeted at the Frood subwatershed[36] (9 sites) but also included 2 sites in Nolin, 2 in Maley, and 1 along the main branch of the creek near Kelly Lake. Measured parameters include conductivity, aluminum, alkalinity, calcium, chloride, copper, iron, manganese, nickel, nitrate, phosphorus, pH, sulfate, and zinc.

2003-2017 – Canadian Aquatic Biomonitoring Network (n = 92)

Water chemistry data collected by the CFEU, including the Ministry of the Environment and Laurentian University, were available for 13 sites. This included 1 site in the Garson headwaters, 1 in Maley, 4 in Frood, 1 in Nolin, and 6 along the main branch of the creek (CFEU unpublished data). Between 3 and 15 water quality parameters were measured depending on sampling event, including temperature, conductivity, aluminum, alkalinity, arsenic, calcium, cadmium, chloride, copper, iron, hardness, manganese, nickel, nitrate, phosphorous, pH, selenium, sulfate, and zinc.

2004-2023 – Junction Creek Stewardship Committee Water Quality Monitoring (n = 2174)

Nearly continuous data were available from the Junction Creek Stewardship Committee water quality monitoring program for 8 sites over the period 2004-2023. Additional sites were added in 2007 (2 in Garson) as well as in 2021 (1 in Nolin and 1 in Copper Cliff), bringing the total to 12 sites: 3 in the Garson headwaters, 1 in Maley, 1 in Frood, 1 in Nolin, 1 in Copper Cliff, and 6 along the main branch of the creek. Samples are collected monthly following the PWQMN protocol for stream water quality monitoring and are analyzed at the Vale (formerly INCO) lab in Sudbury[37]. Over 20 water quality parameters were measured including water temperature, conductivity, aluminum, alkalinity, arsenic, calcium, cadmium, chloride, copper, iron, hardness, manganese, nickel, nitrate, phosphorus, lead, pH, selenium, sulfate, and zinc. Quality assurance and control protocols (QAQC) for the generation of these data were critically reviewed and deemed to be satisfactory. Other datasets provided limited QAQC data or protocols.

Subwatershed-Scale Changes in Water Chemistry Over 60 Years

To maximize the use of historic water chemistry data, sampling locations within each subwatershed (Garson Headwaters, Maley, Frood, Nolin, and the Main Branch) were pooled for comparison. While this approach may obscure trends at individual sites due to the heterogenous nature of anthropogenic impacts, even within individual subwatersheds, it enables broad comparisons of water chemistry across the UJCW over the past 60+ years.

Overall, concentrations of most mining-associated metals (e.g., Cu, Ni) have markedly decreased across Upper Junction Creek and its subwatersheds since the 1960s (Figure 10). These improvements are particularly pronounced across the more impacted Frood and Nolin subwatersheds. For example, the maximum nickel (Ni) concentration often exceeded 30,000 µg/L at these sites—approximately 1200 times greater than the Provincial Water Quality Objective (PWQO) for nickel. In the 1980s, the average concentrations of nickel at these two sites were 16,820 ± 17900 and 3670 ± 9270 µg/L, respectively, but by the 2020s concentrations have dropped to 180 ± 90 and 240 ± 100 µg/L, respectively. This massive reduction represents the combined impacts of good management through emissions reductions, water treatment, and landscape reclamation. Although historic data are limited, the less impacted Maley subwatershed has undergone minimal changes over time with nickel decreasing from 160 ± 60 µg/L in the 1970s to 60 ± 20 µg/L in the 2020s. With these historic decreases, the concentrations of nickel and most other metals are now approaching provincial and national water quality objectives but remain elevated, especially in the most impacted sites.

In addition to decreased concentrations of metals, there have been marked improvements in the pH of the drainage water (Figure 10). In the 1960s, both the Frood and Nolin subwatersheds were highly acidified (pH = 4.3 ± 1.2 and 4.5 ± 1.5, respectively). By the 1980s pH had risen slightly (pH = 5.4 ± 1.2 and 8.6 ± 2.6, respectively), but was highly variable, with pH as high as 12.4 being recorded in the Nolin subwatershed, likely a result of overcompensation for acidity at the Inco (now Vale) liming plant. The historic record in Garson, Maley, and the Main Branch do not show this pattern of extreme low or high pH. Since the 2000s, pH across Upper Junction Creek has stabilized between 6.5 and 9—conditions suitable for most aquatic life—thanks to decades of emissions reductions, runoff control, and landscape regreening.

Despite these impressive improvements, there are some concerning changes. Notably, chloride concentrations across most subwatersheds are trending upwards (Figure 10), most likely driven by runoff of de-icing salts applied to roads and parking lots. The 2020-2023 average chloride (Cl) concentration exceeded the Canadian Water Quality Guidelines (120 mg/L) at Garson (205.78 ± 61.71 mg/L), Frood (257.72 ± 223.04 mg/L), Copper Cliff (159.29 ± 87.72 mg/L), and in the Main Branch upstream and downstream of Frood (128.01 ± 156.38 and 160.61 ± 123.59 mg/L, respectively). Importantly, there is evidence of deleterious impacts of chloride to sensitive taxa well below 120 mg/L of Cl[38] . In contrast, the Maley subwatershed (20.80 ± 34.50 mg/L), with minimal development compared to the rest of the watershed, provides an important source of low chloride water that dilutes inputs from more developed subwatersheds. This highlights the importance of protecting sources of clean water, including the 382 hectares of land in the Maley subwatershed owned by Conservation Sudbury, representing around 12% of the subwatershed (Table 1).

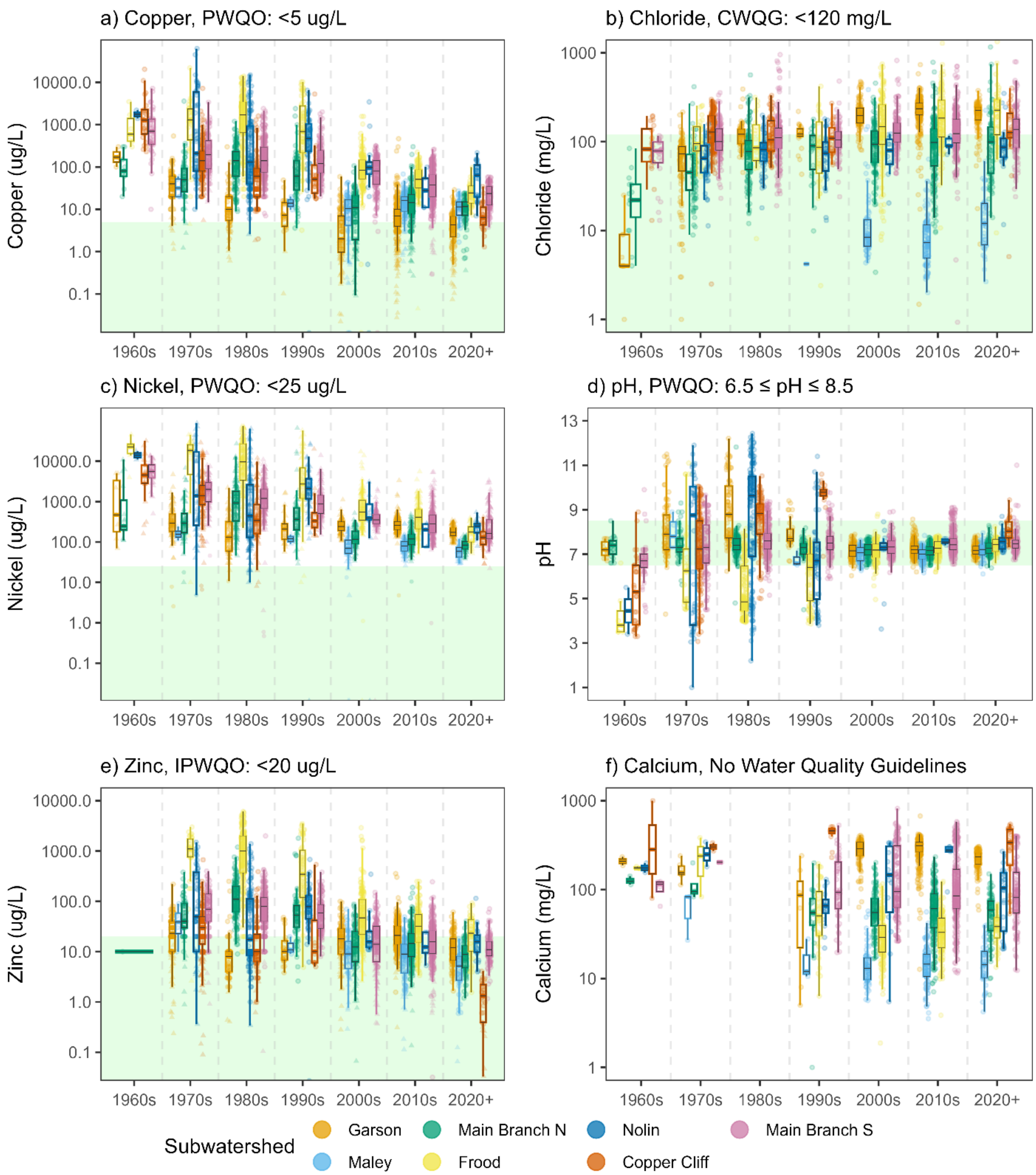

Figure 10 – Changes in pH along with copper, nickel, zinc, chloride and sulfate concentrations in 7 subwatersheds of Upper Junction Creek since the 1960s. Data are pooled for the time periods 1960-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2009, 2010-2019, and 2020-2023. For parameters where a Provincial Water Quality Objective (PWQO), Interim Provincial Water Quality Objective (IPQWO) or Canadian Water Quality Guideline (CWQG) exist, a green background indicates good water quality according to the most stringent guideline and no background indicates undesirable water quality. Points below their respective detection limits are shown as triangles.

Site-Scale Trends in Water Chemistry Over 20 Years

Seasonal Mann-Kendall tests[39] were used to assess for monotonic increases or decreases in individual water chemistry parameters at 8 JCSC monitoring sites where 17-20 years of monthly water chemistry data are available (Figure 11). Over this period there were significant decreases in metals at most sites. Although most metals declined relatively consistently across the watershed, some have had more variable trends. Cadmium and arsenic have both significantly decreased at sites downstream of the Frood subwatershed, but upstream at Maley and Garson have had insignificant increases and decreases. Other metals including iron, aluminum, and manganese have increased significantly across many sites except near the townsite of Garson or near Testmark where opposite trends are seen. Metals historically deposited on the landscape can be transported into waterways by precipitation and runoff. These releases can be exacerbated by drought events, which tend to cause acidification and renewed mobility of metals. A recent master's thesis at Laurentian University investigated the potential for drought induced metal(loid) release in sediments from the Frood and Maley subwatersheds. They found that although there were some impacts of drought, land reclamation and associated liming appears to have significantly reduced the potential for release of metal(loid)s into Junction Creek, making the system more resilient against future climate related impacts[40].

Beyond metals there have also been other changes in water chemistry since the early 2000s. Notably there have been significant decreases in nitrate and phosphorus concentrations at all sites, potentially a result of increased biological uptake of nutrients with regreening activities or reductions in fertilizer use across the subwatershed (Figure 11). Calcium and hardness also decreased at most sites, though this was only significant in the Garson subwatershed. In contrast to other sites, calcium and hardness have actually increased at Maley since 2003 – this may be due to upstream activities and construction of the Maley extension. Both chloride and conductivity showed mixed, generally insignificant, trends across the watershed. This is likely because they have been elevated by road salt and urban inputs long before the monitoring period began (2004-2007), as seen in data from historical monitoring programs above.

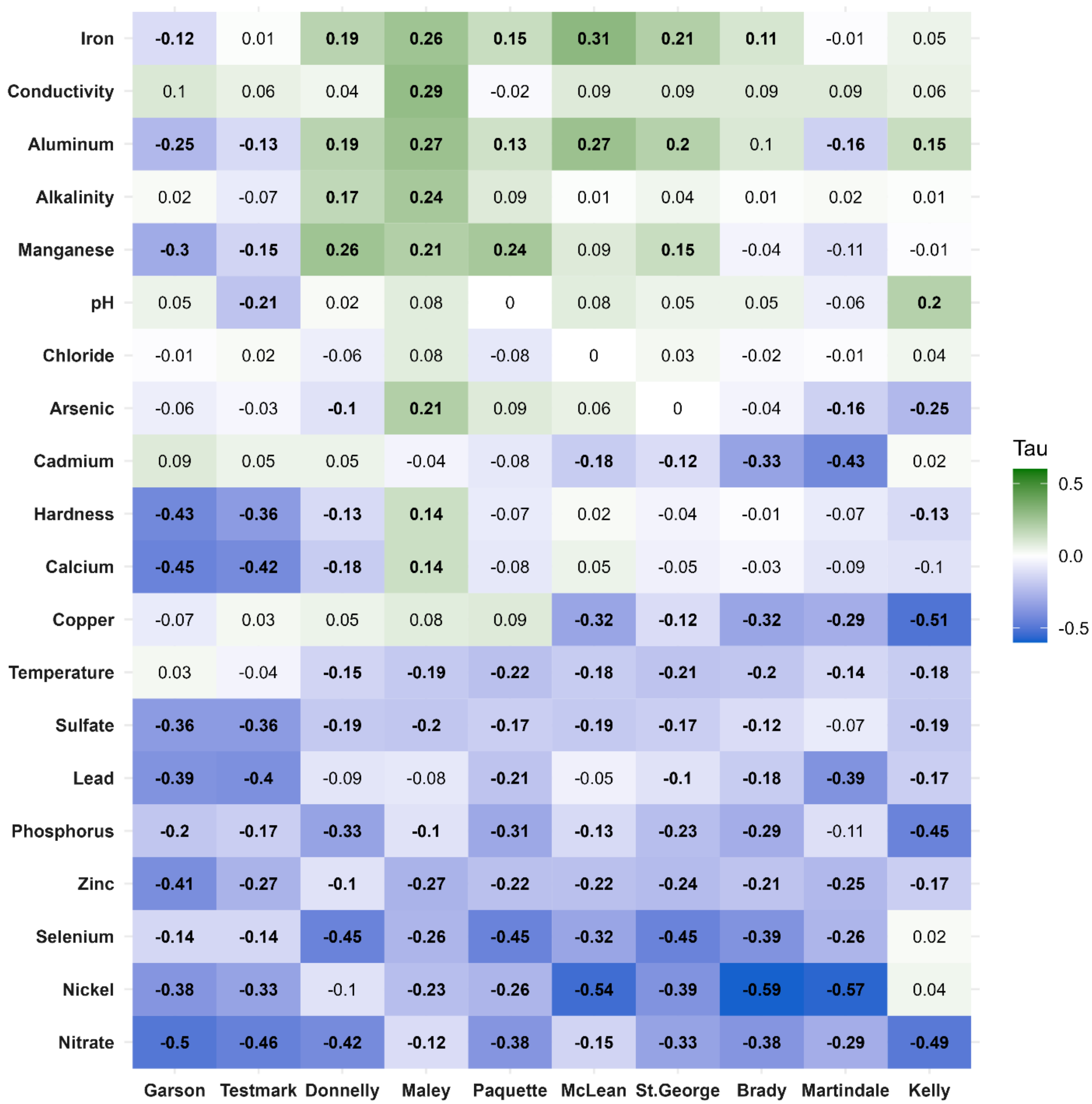

Figure 11 – Seasonal Mann-Kendall Tau (Hirsch et al. 1982) values for 20 water quality parameters across 8 sites in Junction Creek over the JCSC monitoring program (2007-2023 at Garson and Testmark, 2004-2023 at other sites). Negative values (blue) indicate a decrease over time and positive values (green) indicate an increase over time; 0 indicates no change over time. Larger values represent a greater magnitude of change. Significant trends (p<0.05) are bolded.

Fish Community Assessment

Fish sampling was conducted in the main branch of Upper Junction Creek (from the headwaters in Garson to Kelly Lake) in 1965, 1993, 2004, 2008, 2017, 2019, and 2024 (Figure 12). The Maley (1993, 2004, 2008, 2017, 2019, 2022, 2024), Frood (1965, 2004, 2008, 2017), and Nolin (1965, 2004, 2008, 2017, 2022) tributaries of Junction Creek have also been sampled. Data from across Upper Junction Creek were sourced from provincial and local monitoring programs, data reports, and theses. This included 189 reaches/sample sites. A brief summary of the 10 data sources is provided below.

1965 – Ontario Water Resources Commission

In June 1965, the Ontario Water Resources Commission (OWRC), conducted fish and benthic invertebrates sampling at various locations in Junction Creek[30] to characterize the aquatic communities affected by mining and sanitary wastewater. At the time, industrial development consisted of 12 underground mines, 2 major open pit mines, 6 copper-nickel mills, 3 smelters, 1 copper refinery, 3 iron-ore mills, and 2 sulfuric acid-sulfur dioxide plants. Also, sanitary wastewater was being generated by approximately 78,000 people, with much of it entering the Junction Creek stream system. Invertebrates and fish sampling was conducted at 18 stations on Junction Creek and its tributaries, 15 of which are of Upper Junction Creek.

Seine netting was performed at 10 sites on the main branch of Upper Junction Creek, 3 sites on the Frood tributary, and 2 sites on Nolin Creek. Only **1 species of fish**, Brook Stickleback (*Culaea inconstans*), was found and only in the upper reaches, at sites J2 (near Donnely Drive in Garson) and J3 (near the intersection of Lasalle and Paquette Street in New Sudbury) in reach 4 & 6. The authors stated that since seine netting was easily accomplished at most sites, the lack of fish collected likely indicated that fish were not present at the other sites sampled.

1993 – Environmental Youth Corp Assessment

The main stem of Upper Junction Creek (upstream of Kelly Lake), as well as the Maley tributary, were surveyed for fish in the summer of 1993 as part of an Environmental Youth Corp project (Sein, 1993). Fish were captured using a variety of gear types, including minnow traps, seine nets, gill nets, hoop nets, and angling gear.

In total, **12 fish species** were found during the study, with Creek Chub (*Semotilus atromaculatus*) making up 54% of the total catch. The richest and most abundant fish community was found in and around the Ponderosa area near Notre Dame and near the Maley tributary. Fish communities in the upper portion of the creek (before it flows underground at Elm Street and received input from Nolin Creek) had a species composition that R. Sein described as "common to northern Ontario streams". However, very few fish were found downstream of where the creek re-emerges at Riverside Drive, with no fish at all being found for approximately 3km after heavily contaminated water from Nolin Creek entered Junction Creek in the underground portion. The fish community of Junction Creek continued to be depressed from Riverside Drive to Kelly Lake, with only two species (Fathead Minnow (*Pimephales promelas*) and Brook Stickleback (*Culaea inconstans*)) being found in any number.

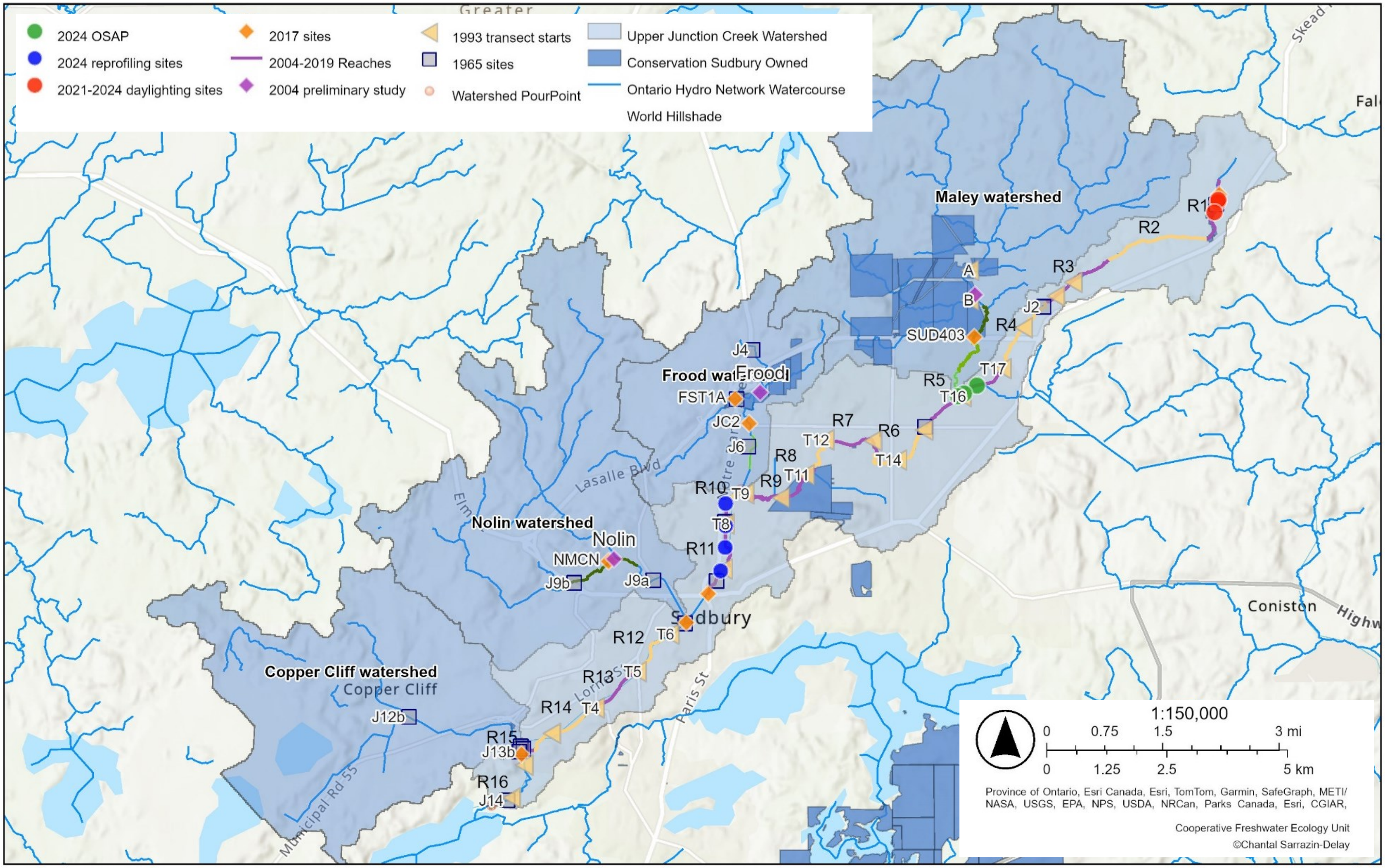

Figure 12 – Map of fish sampling sites from 1965 to 2024. Contemporary sampling reaches (2004, 2008, 2019, 2022) on the main branch are indicated as purple and yellow lines labelled with "R" and reach numbers 1-16 ordered upstream from Kelly Lake. Sites sampled in 1965 are indicated as squares labelled with "J" and site numbers 1-14. The starting point of 1993 sampling transects are indicated as triangles labelled with "T" and transect numbers 1-20. Preliminary tributary study sites (2004) and sites in 2017 are indicated as purple and orange diamonds respectively labelled with their site names/codes. Sites for daylighted area in Reach 1, reprofiling in Reach 11, and Twin Forks OSAP training are indicated as red, blue and green circles respectively. For comparison, fish captured in all locations were assigned to the corresponding contemporary reach. Contemporary sampling reaches in Junction Creek tributaries are shown as green lines (2004 light green, 2022 dark green). The starting point of transects of 1993 sampling on the Maley tributary are indicated as triangles labelled A or B.

2004 – Fish Community Assessment by CFEU

In 2004, an assessment of the fish community in Upper Junction Creek (north of Kelly Lake) and select tributaries was conducted by the Cooperative Freshwater Ecology Unit (CFEU)[42].

Fish were collected largely via electrofishing and minnow traps, with habitat and water chemistry data also collected. The assessment found **14 species of fish** in the Upper Junction Creek main stem (excluding tributaries), with most of the sampled reaches hosting a wide variety of species. Overall, the fish community in 2004 showed noticeable improvement over 1993[34] in both species richness (the number of species found) and abundance (number of fish found) exceeding previous values. Also, fish were found in previously barren areas downstream of Brady Street to Kelly Lake Road. Two Brook Trout (*Salvelinus fontinalis*) from an earlier fish stocking project were also found in the 2004 assessment.

Figure 13 – 1 of 2 Brook Trout (Salvelinus fontinalis) found in Junction Creek during the 2004 fish survey[42].

Electrofishing of the lower section of the once barren Frood tributary (McLean Park to downstream of Mae Street) found 7 fish species, including species like Fathead Minnow (*Pimephales promelas*) that are relatively sensitive to environmental conditions.

Preliminary sampling in tributaries with minnow traps and gill nets yielded 14 species above the Maley dam, Brook Stickleback (*Culaea inconstans*) above the Nickeldale dam, and no fish in Nolin in the Little Britain area or in Copper Cliff above the dam near Highway 17. These were presence data presented as “x” in Table 2.

2008 – Junction Creek Stewardship Committee & CFEU

In 2008, a fish survey was conducted by JCSC, in collaboration with the Cooperative Freshwater Ecology Unit, in the main branch of Upper Junction Creek[43]. The study design was based on the assessment completed in 2004 that had found Junction Creek was showing good evidence of recovery, but that further restoration work was needed.

Figure 14 – Electrofishing as part of the 2008 Fish Community Assessment of Junction Creek[43].

A total of **16 species of fish** were captured with Creek Chub (*Semotilus atromaculatus*) as the most common species and Brook Stickleback (*Culaea inconstans*) being the most widely distributed. The Maley tributary had the greatest species richness, with 15 species. Within the mainstem, Reach 5, the Twin Forks playground area, had the greatest species richness with 13 species detected including Brook Trout (*Salvelinus fontinalis*), which were only detected at this specific location.

Compared to earlier studies, there was increasing species richness and evenness of species in Junction Creek. Sixty-two percent of the reaches in the main stem had an increase in species richness. The section of the creek between Martindale Road and Kelly Lake Road where several tons of creosote was removed in 2007 (Reach 14) showed the greatest improvement. A total of 10 species of fish were found in this section compared to only one individual Brook Stickleback (*Culaea inconstans*) found in 2004.

2017 – Ministry of the Environment, Conservation and Parks

In 2017, 8 sites in the Upper Junction Creek watershed that are part of the Freshwater Invertebrate Research Network of Northern Ontario managed by the MECP were sampled by electrofishing. This study sampled fewer and more discreet sites of shorter length than sampling in 2004 and 2008 with the result that fewer **species (13)** were detected compared to those assessments. However, one new species, the Bluntnose Minnow (*Pimephales notatus*), was detected at a site in the Maley tributary (SUD403). This site had the most diverse fish community with all 13 species found. Sites in the Frood tributary only had 2 species each. At the site in Nolin Creek (NMCN near Beatty Park), 3 species were detected (Creek Chub (*Semotilus atromaculatus*), Iowa Darter (*Etheostoma exile*), and Pearl Dace (*Margariscus nachtriebi*)) marking the first time fish were found in this area, with no fish being detected in earlier sampling events (1965, 2004, 2008).

2019 – Junction Creek Stewardship Committee

In 2019, Junction Creek Stewardship Committee sampled the main branch of Upper Junction Creek[44] with electrofishing and minnow traps. Due to deeper water levels that year, more sites were sampled with minnow traps rather than electrofishing compared to the 2008 assessment, which may have influenced results. **17 species** were found in 2019, more species than in past creek assessments, including two new species, the Pumpkinseed (*Lepomis gibbosus*) and the relatively sensitive Logperch (*Percina caprodes*).

Again, the reach that includes the confluence with the Maley tributary had the highest species richness. When comparing the 2004, 2008, and 2019 assessments, Junction Creek was showing a steady increase in sensitive fish species over time. Comparisons of species richness between 2008 and 2019 suggest that about half of study areas are improving, while the others are still impaired to some degree. Seven Brook Trout (*Salvelinus fontinalis*) were captured in 2019 in Reaches 4 and 5 near the confluence of the Maley tributary. All were determined to be part of the trout release held earlier that year. Temperature loggers in 2019 show that only a few sections of Junction Creek have suitable temperatures (<20°C) for Brook Trout (*Salvelinus fontinalis*). Fish health was also evaluated as part of an undergraduate thesis[45].

2022 – O'Meara Undergraduate Thesis

Nolin Creek, one of the previously most damaged sites, was revisited in 2022 as part of an undergraduate thesis[46]. Using minnow traps, **6 fish species** were captured in Nolin Creek with the most abundant being the tolerant Creek Chub (*Semotilus atromaculatus*). The presence of juvenile White Sucker (*Catostomus commersonii*) suggests that adult suckers are managing to move upstream through the underground portion of the creek.

The Maley tributary of Junction Creek was also assessed as a reference site for this thesis and **14 species** of fish were present. Enumeration was done but not presented in the thesis.

2021-2024 – Daylighting at Lion's Park, Garson – unpublished JCSC data

In 2020, a 160m section of Junction Creek near its headwater in Garson was daylighted. Previously, the creek in this area ran through an underground culvert through Lion's Park in Garson south of Spruce Street. Primarily done to remediate deteriorating culverts, this daylighting might provide benefits of the recovery of a food web to this section of the stream, including plants (algae), benthic invertebrates, and fish.

Through a Cambrian College intern project, the fish community in this area was sampled by deploying baited minnow traps in 3 sites (2 in the daylighted section and 1 downstream) in the spring of 2021 (Pool 1&2 - 4.5 hours)[47], 2022 (Pool 1&2 - 7 hours daytime only, Library - 24 hours)[48] and 2024 (Pool 1&2 - 4 hours, Library - 24 hours)[49].

In 2021, 21 fish of **3 species** (Common Shiner (*Luxilus cornutus*), Creek Chub (*Semotilus atromaculatus*), and Northern Redbelly Dace (*Chrosomus eos*)) were captured in Pool 1&2 of the daylighted section. In 2022, 28 of **4 species** (new - Finescale Dace (*Chrosomus neogaeus*)) were captured in the same sites. An additional site downstream of the daylighted section, near the Garson Library, was also sampled and 31 fish of **4 species** Common Shiner (*Luxilus cornutus*), Creek Chub (*Semotilus atromaculatus*), Northern Redbelly Dace (*Chrosomus eos*), and Golden Shiner (*Notemigonus crysoleucas*)) were captured. In 2024, 13 fish of 2 species (Common Shiner (*Luxilus cornutus*), Creek Chub (*Semotilus atromaculatus*)) were captured in Pool 1& 2. At the Library site, 66 fish of **5 species** were captured (new – Brook Stickleback (*Culaea inconstans*)).

Figure 15 – Brook Stickleback (Culaea inconstans) found in daylighted section of Junction Creek in 2024. Photo from Yang et lt., 2024[49].

2024 – Before re-profiling of Flour Mill section – unpublished JCSC data

Planned for 2025-2028, a section of Junction Creek in the Flour Mill neighbourhood (starting near the train tracks that cross Notre Dame Avenue and ending at the underground tunnel at Elm and Lorne Streets) will be dredged with the aim of reducing flooding risk for adjacent neighbourhoods. Junction Creek Stewardship Committee (JCSC) has sampled some sites before the re-profiling.

JCSC looked at the fish community by deploying baited minnow traps at 4 sites in this section of the creek in the summer of 2024[50]. Traps were left for approximately 20 hours on 2 occasions separated by 1-2 weeks. 64 fish of **7 species** were captured. Repeated surveys during and after the re-profiling are planned in the coming years.

2024 – Ontario Stream Assessment Protocol – unpublished JCSC data

In the fall of 2024, JCSC participated in Ontario Stream Assessment Protocol (OSAP) training and conducted electrofishing at 3 sites, 1 in the Maley tributary and 2 in Reach 5 of the main branch, all in or near Twin Forks Playground. A total of 393 fish of **7 species** were captured including 10 Brook Trout (*Salvelinus fontinalis*) assumed to be part of a recent fish release. In the Maley Tributary, 185 fish were captured from **8 species** including a first detection of the cold water Mottled Sculpin (*Cottus bairdii*) (FWIS)[51].

Changes in Fish Diversity

Assessments of the fish community in the main branch of Upper Junction Creek and its tributaries, from the headwaters in Garson to Kelly Lake, have been conducted since 1965. Sampling areas varied over time but in 2004, 2008, and 2019, the main stem of Junction Creek was divided into the same 16 sampling reaches allowing for site-specific comparisons over time. Fish were collected via electrofishing, minnow traps and, rarely, nets (hoop, seine, gill) and angling gear, with the gear used at a specific site/year and sampling protocols varying by assessment. Despite the seasonal and methodological variation, a generalized improvement in fish diversity is noted.

Twenty species of fish have now been found in Upper Junction Creek (Table 2, Figure 16). The number of species found has increased over time, from a couple live specimens of a species, Brook Stickleback (*Culaea inconstans*), in 1965[30] to 12 in 1993[34], 14 in 2004[42], 16 in 2008[43],17 in 2019[44], and 20 by 2024. In the last three full surveys, Creek Chub (*Semotilus atromaculatus*) was the most abundant species, making up approximately 53% of the total catch in 2004[42], 34% in 2008[43], and 57% in 2019[44]. Overall, Reaches 4 (from Carr Avenue to Robin Street) and 5 (from Robin Street to 300m upstream of Lasalle Boulevard at the confluence with the Maley tributary) have had the highest species richness of the main branch, with Reach 4 being the most species rich in 2004[42], Reach 5 being the most species rich in 2008[43], and both reaches tying for top spot in 2019[44].

The number of fish species relatively intolerant to environmental degradation has increased over time, from 2 individual Brook Stickleback (*Culea inconstans*) in the 1960s to two species in 2004 (Brook Trout (*Salvelinus fontinalis)*), to three species in 2008 (Blacknose Shiner (*Notropis heterolepis)*), to four species in 2019 (Logperch (*Percina caprodes)) -* relatively intolerant)[44]. In 2024, a Mottled Sculpin (*Cottus bairdii)*) was captured for the first time in Upper Junction Creek, near the Maley confluence[52]. It should be noted that in 2008, 2019, and 2024, the captured Brook Trout (*Salvelinus fontinalis)* were determined to be from Brook Trout (*Salvelinus fontinalis)* release events that had occurred earlier in the sample year[43,44]. There has also been an increase in the number of fish species with a mid-range environmental tolerance across time[44].

The 2019 assessment suggests that about half of the reaches on Junction Creek are continuing to improve, likely because of restoration efforts[44]. For example, after creosote remediation work in Reach 14, the number of fish in the area increased drastically, from a single fish found in 2004[42] to 10 species in 2008[44].

The Maley, Frood, and Nolin tributaries of Junction Creek have also been part of fish assessment efforts. Without direct environmental impacts, the Maley tributary is often used as a reference condition for the main branch of Junction Creek and consistently has higher species richness of fish (12 species in 1993[34], 14 species in 2004[42], 15 species in 2008[43], 13 species in 2017 and 2019[44], 14 species in 2022[46]). Maley is also the only tributary in which sensitive Brook Trout (*Salvelinus fontinalis)* and Mottled Sculpin (*Cottus bairdii)* have been found, along with Reaches 4 and 5 in the main branch near their confluence. The Frood tributary has seen continued improvements in the fish community since a mine waste diversion project in 2000/2001, with 7 species found in 2004[42] and 9 species in 2008[43]. In 2008, a single fish was found above the Nickeldale dam, while 3 species were found below the dam[43]. In 2004 and 2008, no fish were found in the Nolin Creek tributary[42,43]. However, in 2017, an MECP study detected 3 species and an undergraduate thesis project in 2022 found 6 species of fish[46]. Copper Cliff Creek continues to receive mine waste drainage, and no fish were found above the dam in 2004[42]. However, 3 species (Brook Stickleback (*Culaea inconstans*), Iowa Darter (*Etheostoma exile*), and Creek Chub (*Semotilus atromaculatus*)) were found in 2008[43].

Fish detection is highly dependent on method of collection and effort, which were not consistent across the studies presented here. As such, results should be interpreted with caution. Details from each study are presented below.

Note that fish sampling is known to have been done by T. Delongchamp in 2002, but the report was not located at the time of publication of this report.

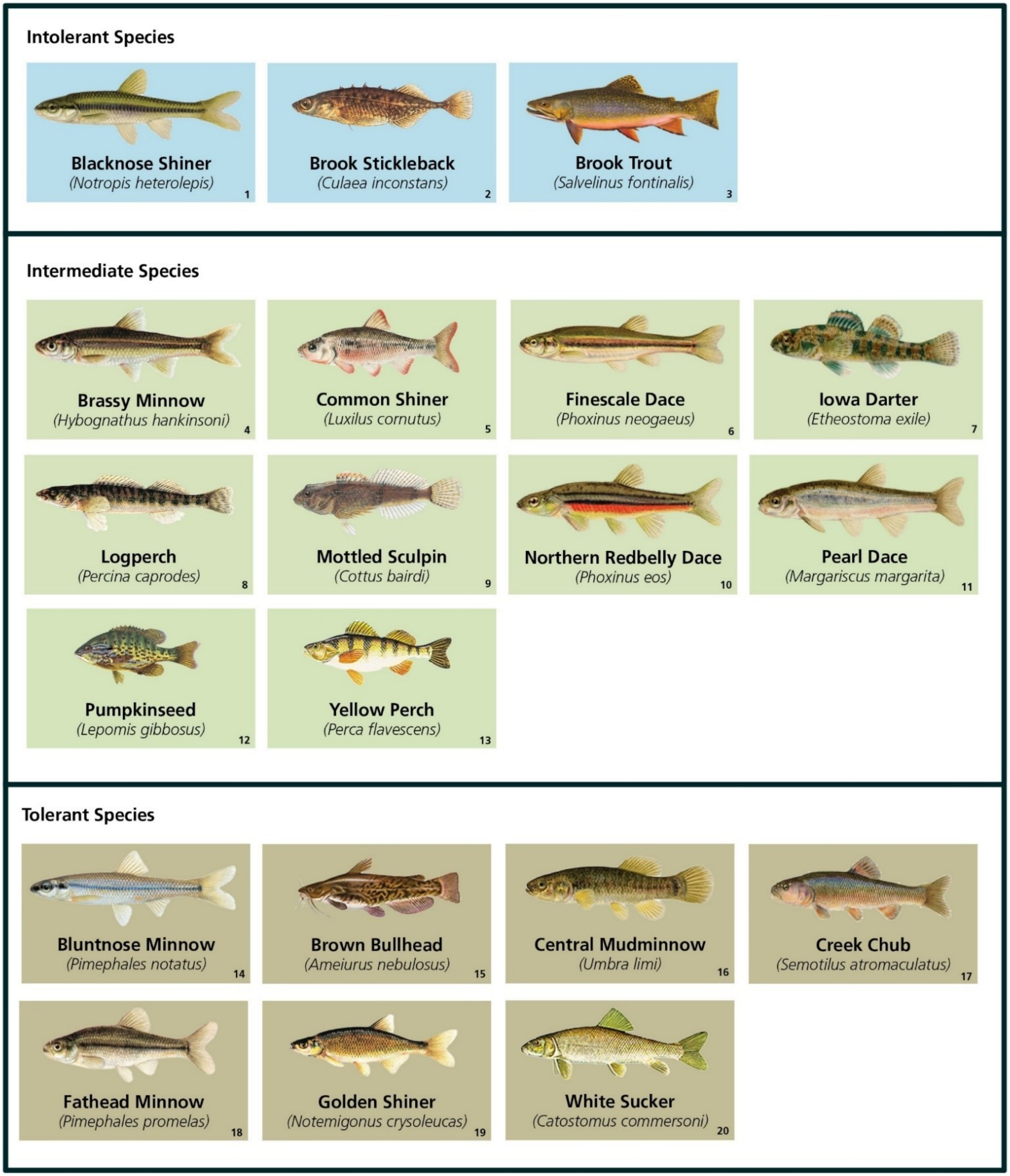

Figure 16 – Fish species detected in Upper Junction Creek and its tributaries with corresponding tolerance levels. Tolerance can be affected by a number of factors; here we present EPA[53] designations but designations from other sources may differ. Numbers in lower right corner refer of image source listed below the references at the end of this document. Note: these general tolerance limits establish from the literature may not apply under all the unique chemical conditions of Junction Creek.

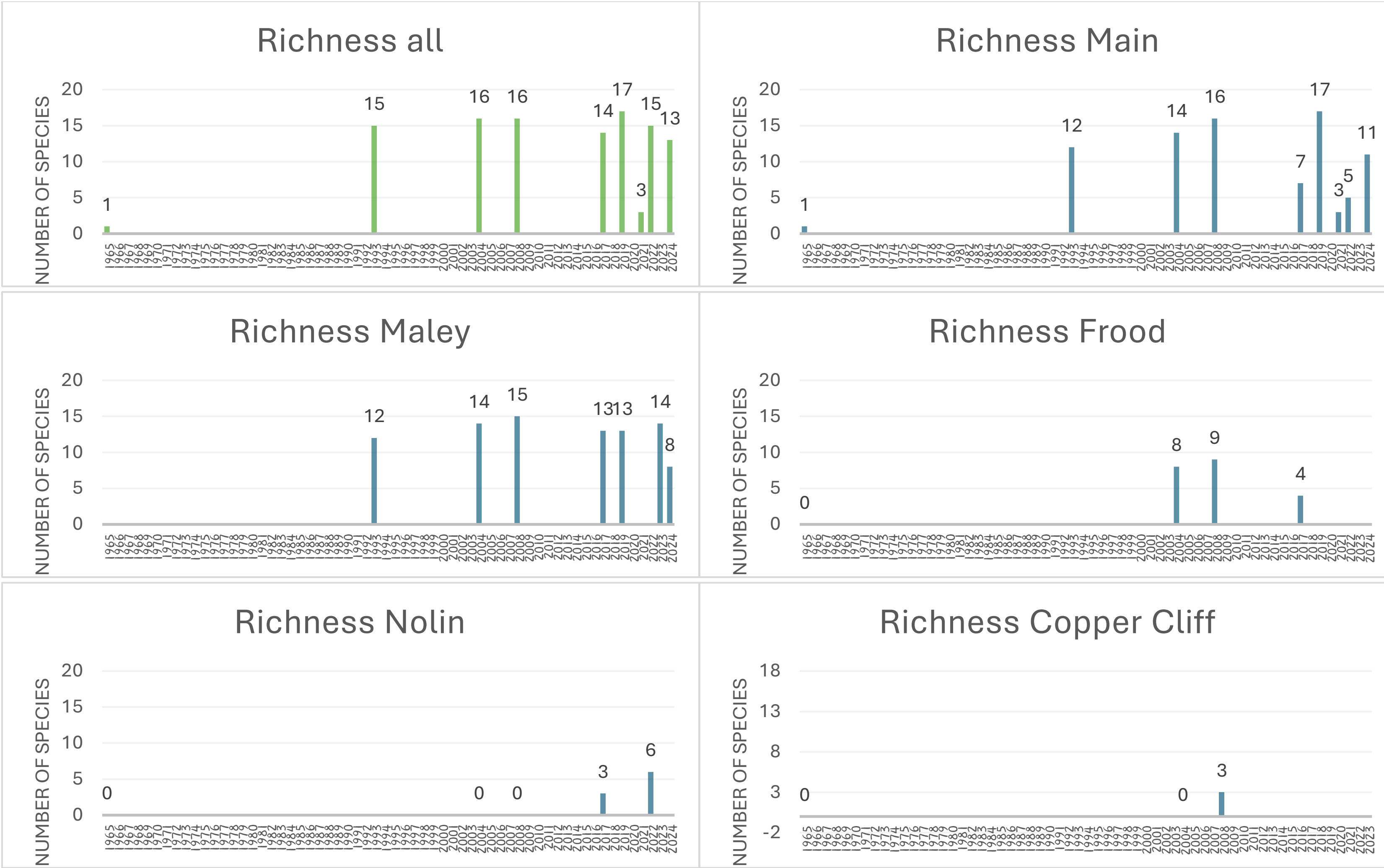

Figure 17 – Number of fish species detected in Upper Junction Creek, at all sites, in the main branch as well as Maley, Frood, Nolin and Copper Cliff tributaries. Sampling method and effort have not been consistent thereby affecting fish detected.

Table 2 – Fish species detected in Upper Junction Creek including the main branch and Maley, Frood, Nolin and Copper Cliff tributaries. Grey shading and "x" indicate a species that was present during minnow trapping but not enumerated as part of smaller studies.

Upper Junction Creek

	Blacknose Shiner	Bluntnose minnw	Brassy minnow	Brook Stickleback	Brook trout	Brown Bullhead	Central Mud-minnow	Common Shiner	Creek Chub	Fathead Minnow	Finescale Dace	Golden shiner	Iowa Darter	Mottled Sculpin	Northern Rebelly Dace	Pearl Dace	White Sucker	Yellow perch	Pumpkin-seed	Log Perch	Unknow n	Total	Richness
1965	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
1993	8	0	258	285	47	205	1841	565	2218	399	1215	197	141	0	457	25	121	0	0	0	0	7982	15
2004	x	0	2	904	2	217	340	458	3530	136	x	2	481	0	276	65	229	29	0	0	0	6671+	16
2008	10	0	264	921	2	303	852	998	3481	154	170	132	1509	0	1046	333	282	239	0	0	0	10696	16
2017	9	2	3	51	0	1	59	4	75	12	0	0	92	0	2	9	7	2	0	0	1	329	14
2019	18	0	441	504	7	38	271	596	5696	549	11	0	127	0	704	106	337	533	31	5	12	9986	17
2021	0	0	0	0	0	0	0	4	16	0	0	0	0	0	1	0	0	0	0	0	0	21	3
2022	x	0	x	x	0	x	0	24	20	x	4	1	x	0	10	x	x	x	0	x	0	59+	15
2024	0	0	9	24	10	0	29	90	482	2	1	0	13	2	44	3	10	0	0	0	0	686	13
Total	45	2	977	2691	68	764	3392	2739	15518	1252	1401	332	2363	2	2540	541	986	803	31	5	13	29702	20

Main Branch only

1965	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
1993	4	0	0	231	0	2	7	141	1556	356	120	0	1	0	457	25	121	0	0	0	0	3021	12
2004	0	0	2	892	2	120	288	431	3159	119	0	2	299	0	266	46	223	29	0	0	0	5878	14
2008	7	0	152	886	2	185	833	900	3154	124	22	115	1496	0	719	102	268	34	0	0	0	8999	16
2017	9	0	0	14	0	0	13	0	47	10	0	0	79	0	0	0	2	0	0	0	0	174	7
2019	18	0	429	496	7	1	226	525	5369	472	11	0	116	0	520	77	310	509	30	5	12	9133	17
2021	0	0	0	0	0	0	0	4	16	0	0	0	0	0	1	0	0	0	0	0	0	21	3
2022	0	0	0	0	0	0	0	24	20	0	4	1	0	0	10	0	0	0	0	0	0	59	5
2024	0	0	0	24	1	0	21	27	365	2	1	0	10	0	44	2	4	0	0	0	0	501	11
	38	0	583	2545	12	308	1388	2052	13686	1083	158	118	2001	0	2017	252	928	572	30	5	12	27788	18

Maley

1965																							
1993	4	0	0	258	0	54	47	203	1834	424	662	0	43	0	1095	197	140	0	0	0	0	4961	12
2004	x	0	x	2	0	82	24	27	135	4	x	0	64	0	6	19	6	x	0	0	0	369	14
2008	3	0	112	4	0	118	5	84	34	13	148	17	6	0	268	222	9	205	0	0	0	1248	15
2017	0	2	3	7	0	1	46	4	21	2	0	0	9	0	2	4	5	2	0	0	0	108	13
2019	0	0	12	8	0	37	45	71	327	77	0	0	11	0	184	29	27	24	1	0	0	853	13
2021																							
2022	x	0	x	x	0	x	0	x	x	x	x	0	x	0	x	x	x	x	0	x	0	na	14
2024	0	0	9	0	0	0	8	63	93	0	0	0	3	2	0	1	6	0	0	0	0	185	8
	7	2	136	279	0	292	175	452	2444	520	810	17	136	2	1555	472	193	231	1	x	0	7724	19

Frood

1965	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993																							
2004	0	0	0	10	0	15	28	0	236	13	0	0	118	0	4	0	0	0	0	0	0	424	8
2008	0	0	0	30	0	0	14	14	292	17	0	0	5	0	59	9	5	0	0	0	0	445	9
2017	0	0	0	33	0	0	0	0	0	0	0	0	6	0	0	4	0	0	0	0	1	44	4
2019																							
2021																							
2022																							
2024																							
	0	0	0	73	0	15	42	14	528	30	0	0	129	0	63	13	5	0	0	0	1	913	10

Nolin

1965	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993																							
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2017	0	0	0	0	0	0	0	0	7	0	0	0	4	0	0	1	0	0	0	0	1	13	3
2019																							
2021																							
2022	0	0	0	x	0	0	0	0	x	0	x	0	x	0	x	0	x	0	0	0	0	na	6
2024																							
	0	0	0	x	0	0	0	0	7	0	x	0	4	0	x	1	x	0	0	0	1	13	7

Copper Cliff

1965	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993																							
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	1	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	4	3
2017																							
2019																							
2021																							
2022																							
2024																							
	0	0	0	1	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	4	3

Benthic macroinvertebrates (BMI) Assessment

Benthic macroinvertebrate (BMI) sampling was conducted in the main branch of Upper Junction Creek (from the headwaters in Garson to Kelly Lake) at various sites in 1965, 1972, 1996, 2000-2002, 2003-2021, and 2021-2024. Sampling sites were subsequently assigned to the reaches created in fish surveys described above to facilitate description of trends in the different sections of the creek (Figure 19). The Maley, Frood, and Nolin tributaries of Junction Creek have also been sampled.

BMI data throughout Upper Junction Creek were sourced from provincial and local monitoring programs, data reports, and theses. This included 564 BMI samples from 94 sampling stations (individual sites) representing approximately 55 discrete sampling locations (visited over multiple years and overlapping between studies). A brief summary of the 13 data sources is provided below.

1965 – Ontario Water Resources Commission (n=16)

In the context of the biological assessment of Junction Creek in June 1963, one 20-minute collection of invertebrates from of a variety of habitats at each station was examined in the laboratory and the number of individuals of each selected taxon was noted.

Thirteen BMI taxonomic groups were detected at 16 sites. At site J1 in the Garson area (headwaters), only two invertebrate families (Chironomidae and Ephydridae), both thought to be tolerant of heavy metals, were collected, likely indicating mining contamination[30].

Sites J2 (downstream of the Garson lagoon) and J3 (downstream of the Maley tributary) were among the sites with the highest richness (4-6 families) and diversity with some relatively sensitive families (Caddisfly-Polycentropodidae and Cranefly-Tipulidae) as well as taxa indicative of organic enrichment (Figure 18). Invertebrates collected from both the Frood and Stobie tributaries (J4, J5, J6) indicated heavy contamination, with mainly Midge larva (Chironomidae) and Worms (Oligochaeta) found, tolerant of both organic enrichment and heavy metals, as well as the tolerant Damselfly-Coenagrionidae and 2 Beetles. The invertebrates collected at sites J8 and J10 suggested a slight improvement of water quality in these areas with relatively higher richness (4-5 families) with Waterboatmen-Corixidae and a Dragonfly-Gomphidae. No invertebrates were found in Nolin Creek (sites J9a and J9b) or at Junction Creek site J11 downstream of the confluence with Nolin Creek. A slight improvement in invertebrate community was noted again at site J13a. Copper Cliff Creek was also heavily polluted with little invertebrate community present at sites J12a and J12b, or at Junction Creek sites J13b and J14 below Copper Cliff Creek's entry point

Figure 18 – Images representing some of the benthic invertebrate families found as part of the 1965 biological assessment. From left to right: Polycentropodidae, Tipulidae, Chironomide, Coenagrionidae. Photos by Lynne M. Witty

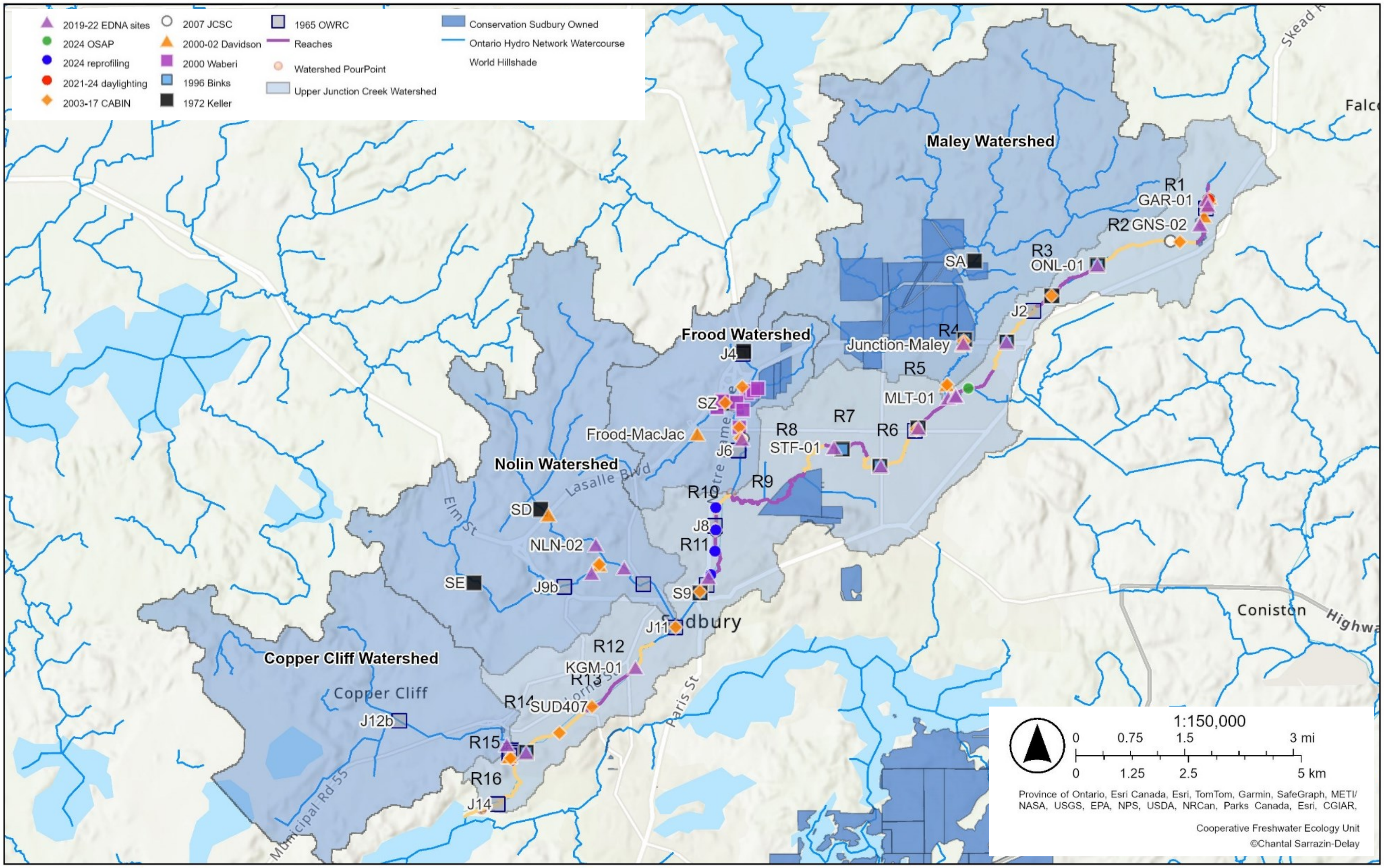

Figure 19 – Map of benthic macroinvertebrate sampling locations in the Upper Junction Creek watershed (blue shading) from 1965-2024. As per the fish studies, contemporary sampling reaches on the main branch are indicated as purple and yellow lines labelled with "R" and reach numbers 1-16 ordered upstream from Kelly Lake. Sites sampled in 1965, 1972 and 1996 are indicated as grey, black and blue squares respectively. Sites in 2000-2002 are indicated as orange triangles, sites in 2003-2021 are indicated as orange diamonds, eDNA sites in 2019-2021 are indicated as purple triangles, and all are labelled with site codes. Sites in 2007, sites for daylighted area in Reach 1, reprofiling in Reach 11, and 2024 OSAP sites are indicated as white, red, blue and green circles respectively.

1972 – Keller Report (n=22)

Keller's report to the Ministry of the Environment included water chemistry from 22 stream sites and 5 lakes, and "bottom fauna" survey results for 18 stream and 15 lake sites. Of the stream sites, 14 were in Upper Junction Creek[33]. Invertebrate collection gear was chosen based on bottom substrate with 6"x6" Eckman Grabs used in muddy to sandy sites and 12"x12" Surber Samplers in gravelly to cobbly sites with 2-3 replicates per site. Samples were taken in July and again in October of 1972.

The BMI community was dominated by worms and midges, but more caddisflies were detected compared to 1965. Six families of Ephemeroptera, Plecoptera and Trichoptera (EPT) were detected (3 Caddisfly-Trichoptera, 3 Mayflies-Ephemeroptera, 0 Stoneflies-Plecoptera) in 1972.

1996 – Binks and Donato Undergraduate Thesis (n=24)

As part of their undergrad thesis, Binks and Donato sampled 11 of the sites done by Keller, 8 of which were in Upper Junction Creek[35]. Invertebrate collection gear followed Keller (Eckman or Surber), however, for 3 sites a change in sampling method was warranted due to substrate. Samples were taken on 3 separate occasions in October/November of 1996.

1996 data are presented at family level in this report, but individuals were identified to lowest practical. Invertebrates collected in fall of 1972 were re-identified to lowest practical for the purpose of comparison between sampling events. Improvement in taxa richness since 1972 was noted at every sample site; richness ranged from 3 to 21 families while EPT ranged from 0 to 25%. Six families of EPT were detected (5 Caddisflies-Trichoptera, 1 Mayfly-Ephemeroptera, 0 Stoneflies-Plecoptera).

2000-2002 – Frood Branch Acid Mine Drainage Early Diversion Study (n=96)

In Waberi's undergraduate thesis[36], 8 sites in the area affected by acid mine drainage (AMD) from Frood Stobie mine and a nearby airstrip built in the 1950s from waste rock, were sampled before diversion in 2000 and after in 2001 to track recovery of benthic communities. Samples were taken 4 times between May and November. A 1m^2 kick-and-sweep technique was used and organisms were identified to family level (mostly). Many of the same sites were sampled again in 2002 by CFEU staff.

Results showed that the diversion significantly improved water quality, as evidenced by a dramatic increase in the diversity and abundance of benthic invertebrates downstream of the Frood-Stobie tributary.

The follow up to this thesis is described below in "2000-2024 Junction Creek Frood Tributary Acid Mine Drainage diversion long-term benthic macroinvertebrate study".

2000-2002 – Davidson Master Thesis (n=43)

Davidson's MSc thesis, Applying the Reference Condition Approach to Monitor Invertebrates in Streams of the Sudbury Mining Area, was a pilot study to gauge the feasibility of the Reference Condition Approach (RCA) for monitoring in the Sudbury area[54]. RCA involves comparing a test site (receiving mining effluent or other pollutant) to a group of minimally impacted reference sites of similar habitat. A reference database of 46 reference sites from diverse stream habitats and 8 test (subject to mining effluent) sites were sampled using rapid bioassessment techniques (1m^2 kick-and-sweep, live pick) in the summer and fall of 2000, and spring of 2001. Reference sites were divided into three broad biological groups using correspondence analysis, and a discriminant model was created to predict sites to the appropriate group using small-scale habitat descriptors. Davidson concluded that the RCA as applied in their study could be successfully used to model communities and monitor mining (and other) test sites in the region, which led to the FIRNNO project described below.

Group 3 of this reference dataset was used as a reference group for site JC2 in “2000-2024 Junction Creek Frood tributary” below.

Many of the sites sampled as part of Davidson’s thesis were sampled again in 2002 by CFEU staff.

In the 8 sites that are in the Upper Junction Creek, similar richness and EPT was noted as in 1996, with 4-14 families and 0-22% EPT from 6 families (4 Caddisflies-Trichoptera, 2 Mayflies-Ephemeroptera, 0 Stoneflies-Plecoptera).

2007 – JCSC Macroinvertebrate Study (n=21)

Seven sites corresponding with JCSC water sampling sites, spanning Reaches 1-11 as well as the Maley and Frood tributaries, were sampled in late fall 2007 for benthic invertebrates[55]. The substrate of three 1m^2 subsamples (2 riffles, 1 pool) was kicked to dislodge the invertebrates that were captured with a downstream seine net for about 1 minute or until 100 were found.

This data, identified mostly to order level as per Ontario Benthic Biomonitoring Network (OBBN) protocol, is difficult to compare to past samples which were identified to at least family. Four to eight taxa (mostly orders) were detected. Proportion of EPT ranged from 0 to 18% and has not increased since previous studies. However, a Stonefly-Plecoptera was detected for the first time at the Paquette Street site in Reach 5.

2003-2021 – Canadian Aquatic Biomonitoring Network (n=185)

Since its inception in 2003, the Freshwater Invertebrate Research Network of Northern Ontario (FIRNNO) has built a reference database of over 400 reference and test sites to define the normal range of BMI communities, including chemical and physical characteristics of northern Ontario lakes and rivers. This database maintained by the Ontario Ministry of Environment and Parks (MECP), was originally designed for Ontario mining companies needing to meet the Environmental Effect Monitoring requirements of the Fisheries Act. Mines can use the Reference Condition Approach (RCA) to assess the BMI community at their effluent sites against that of many minimally impacted reference sites with similar habitat characteristics. BMI were sampled in September to November by a single, 3-min travelling kick-and-sweep with a 500 µm mesh D-net, following the Canadian Aquatic Biomonitoring Network (CABIN) protocol[56]. Samples were preserved and subsampling was done with a 100-cell Marchant box and sorted under stereomicroscope until 300 animals were reached, with the final cell being processed in its entirety (Figure 20).

A subset of sites has been sampled concurrently with the CABIN method and the 1m^2 method to allow for comparison and eventual integration of data collected using other methods.

Temporal trends continue to be tracked with resampling of a subset of sites every 4 years including some sites in the Upper Junction Creek.

Figure 20 – Techniques and equipment used when sampling BMI using the CABIN protocol. From left to right: collecting BMI using a kick-and-sweep technique; collected BMI sample; D-net; Marchant box; microscope.

These data are housed in both the national CABIN and provincial Ontario Benthic Biomonitoring Network (OBBN) online databases and can be applied to other sectors including hydroelectric, sewage, urbanization, construction and climate change.

In the Upper Junction Creek watershed, 17 sites have been sampled, 10 in the main branch, 2 in the Maley tributary, 4 in the Frood tributary, and 1 in the Nolin tributary, some over multiple years.

2008 – Davidson and Gunn

Davidson and Gunn's[57] paper, *Effects of Land Cover Disturbance on Stream Invertebrate Diversity and Metal Concentrations in a Small Urban Industrial Watershed*, investigated the risks of unrestored landscapes and modern impervious surfaces on Upper Junction Creek, a small headwater stream, by digitizing land cover at a fine scale and relating it to BMI diversity and metal concentration at 13 sites. They sampled in the fall of 2008 with the CABIN protocol and calculated Shannon Diversity for each site. Correlations were calculated between Diversity, land cover, and water chemistry.

The combination of historically barren landscape and modern impervious surfaces such as asphalt, roofs, and hard gravel, was associated with decreased BMI community diversity at all four watershed spatial scales measured. The same combination of barren bedrock and impervious surface was associated with increased levels of potentially toxic Ni, whereas increased Cu was most strongly associated with bedrock alone.

Elevated metals and impervious surfaces are likely affecting invertebrate diversity in Junction Creek. Shannon Diversity was highest at the main branch headwater site (C1), and lowest immediately downstream of the city core, after the confluence with the Nolin tributary (C7).

This dataset was contributed to the CABIN/FIRNNO database with results described in the previous section.

2019-2022 – eDNA (n=26)

In 2019-22, Junction Creek Stewardship Committee participated in STREAM (Sequencing The Rivers for Environmental Assessment and Monitoring), a Canadian biomonitoring project that combines community-based monitoring with DNA metabarcoding to study benthic macroinvertebrates in watersheds across Canada[58–61]. STREAM is a collaboration between WWF Canada, Living Lakes Canada, Environment and Climate Change Canada, and the Hajibabaei Lab at the Centre for Biodiversity Genomics, University of Guelph.

Nineteen sites in the Upper Junction Creek Watershed were sampled in the falls of 2019, 2020, 2021, and 2022 following the CABIN protocol as well as the STREAM protocol which aims to minimize contamination and preserve DNA (ex. bleaching nets and gloving)[58]. Samples were preserved in alcohol, homogenized, and DNA was extracted using the DNeasy® PowerSoil® Pro kit. Extracted DNA was sequenced using the Hajibabaei Lab's protocol and processed with the MetaWorks pipeline.

Between 2019 and 2022, eDNA analysis was conducted on samples from 20 sites along Upper Junction Creek. A total of 20 EPT families were detected (9 Caddisflies-Trichoptera, 5 Mayflies-Ephemeroptera, and 6 Stoneflies-Plecoptera), surpassing the number found in any previous studies (Table 3). Notably, the stonefly family Pteronarcyidae was detected for the first time in Upper Junction Creek, a surprising finding given that this family is considered the most sensitive of all benthic macroinvertebrates (scoring 0 on the Hilsenhoff biotic index sensitivity scale). It was particularly unexpected that this family was found at the Copper Cliff site (CCT01) in Copper Cliff Creek, one of the locations least likely to harbor sensitive species due to the effluent from the Copper Cliff mine. There are a number of limitations to eDNA related to methodology and the source of detected DNA, therefore these findings should be interpreted with caution.

Table 3 – Ephemeroptera, Plecoptera, Trichoptera (EPT) aka Mayfly, Stonefly, Caddisfly families detected in an eDNA project. An "x" indicates presence.

		REACH	1		3				4	5			6	7	11	12	14	M					F	N			C		
			2021	2020	2019	2019	2020	2021	2019	2022	2020	2019	2020	2021	2020	2020	2019	2022	2020	2019	2019	2020	2020	2020	2021	2021	2019	2019	2020
Order	Family	Common Name	GNS-3-A	GSN-2-A	ONL-1-A	ONL-1-B	ONL-1-A	ONL-1-A	MLY-1-A	TWF-1-A	TWF-1-A	LSA-1-A	BYD-1-A	STF-1-A	STJ-1-A	KGM-1-A	KLY-1-A	MLT-1-A	MLT-2-A	MLT-1-A	MLT-1-B	MLT-1-A	FRD-1-A	NLN-1-A	NLN-2-A	NLN-3-A	CCT-1-A	CCT-1-B	CCT-1-A
Ephemeroptera	Baetidae	Small minnow mayflie							x			x		x	x			x	x	x	x	x						x	
	Caenidae	Small square-gilled m	x															x	x										
	Ephemerellidae	Spiny crawler mayflies						x						x					x		x	x			x	x			
	Heptageniidae	Flat-headed mayflies		x			x			x		x		x	x	x		x	x	x	x	x				x			x
	Leptophlebiidae	Prong-gilled mayflies		x		x					x	x	x		x		x	x	x	x	x	x		x			x		
Plecoptera	Nemouridae	Spring stoneflies			x						x		x		x	x			x	x			x	x					x
	Perlidae	Common stoneflies						x						x												x			
	Perlodidae	Springflies				x											x			x							x		
	Pteronarcyidae	Giant stoneflies				x			x			x					x			x							x		
	Taeniopterygidae	Winter stoneflies					x								x	x			x				x	x					x
Trichoptera	Dipseudopsidae	Pilot-tube caddisflies										x																	
	Hydropsychidae	Net-spinning caddisfli	x	x	x	x	x	x	x		x	x	x	x	x				x	x	x	x	x	x	x	x			x
	Hydroptilidae	Microcaddisflies												x					x										
	Leptoceridae	Long-horned caddisfli									x			x	x		x		x										
	Limnephilidae	Northern caddisflies			x	x					x	x								x	x	x							
	Philopotamidae	Finger-net caddisflies																					x						
	Phryganeidae	Giant casemaker			x			x				x		x					x		x	x							
	Polycentropodidae	Trumpet-net caddisfli										x		x					x	x	x								
	Psychomyiidae	Net-tube caddisflies													x					x	x								

2021-2024 – Daylighting at Lion's Park, Garson (n=12)

In 2020, a 160m section of Junction Creek near its headwater which previously ran through an underground culvert beneath Lion's Park in Garson, south of Spruce Street, was daylighted, meaning that it is now open to sunlight and natural processes(Figure 21). Primarily done to remediate deteriorating culverts, this daylighting should have the added benefit of the recovery of a food web to this section of the stream including plants (algae), benthic invertebrates, and fish. In concurrent studies, Junction Creek Stewardship Committee (JCSC) and the Cooperative Freshwater Ecology Unit (CFEU) at Laurentian University are studying recovery of some of these communities. CFEU data was not available at time of publication.

Through a Cambrian College intern project, the benthic community was sampled in the spring of 2021, 2022 and 2024 with the OBBN protocol[62] of travelling kick-and-sweep with a D-net at 1 site in the daylighted section (2 riffles and 1 pool sample) and 1 upstream site (riffle sample) with subsequent subsampling and live picking to a minimum of 100 organisms per sample and identification to order level (mainly).

Average richness, diversity, and percentage of sensitive EPT has increased over time following the daylighting of that section of the creek. This preliminary study indicates the beginning of the establishment of a diverse benthic invertebrate community, however, family level identification, as recommended by OBBN, would provide more detailed information.

Figure 21 – Section of Junction Creek in Lion's Park that was daylighted in 2021. Photo taken in 2024 by Cassidy McAuliffe

2024 – Before Re-profiling of Flour Mill section (n=4)

Planned for 2025-2028, a section of Junction Creek in the Flour Mill area (starting near the train tracks that cross Notre Dame Avenue and ending at the underground tunnel at Elm and Lorne Streets) will be dredged with the aim of reducing flooding risk for adjacent neighbourhoods. In concurrent studies, Junction Creek Stewardship Committee (JCSC) and the Cooperative Freshwater Ecology Unit (CFEU) at Laurentian University have sampled some of these communities before the re-profiling. CFEU data was not yet available at the time of publication.

JCSC studied the benthic community by sampling in the summer of 2024 with the OBBN protocol[62] of travelling kick-and-sweep with a D-net at 3 sites in the creek section to be re-profiled and 1 upstream site (each with 2 riffles and 1 pool), with subsequent pooling and subsampling/live picking of a minimum of 100 organisms per site and identification to order level (mainly) (Figure 22).

Figure 22 – Sampling "Downstream" site of the reprofiling section of Upper Junction Creek running through the Flour Mill neighbourhood of Sudbury. Photo by Junction Creek Stewardship Committee.

All 4 sites had relatively similar order richness, diversity, and low percentage (2-9%) of sensitive EPT. This limited data may serve to quantify the benthic invertebrate community before the reprofiling and allow for comparison to the recovery following the disturbance caused by the re-profiling project.

2024 – Ontario Stream Assessment Protocol - unpublished JCSC data (n=5)

In the fall of 2024, the team at JCSC participated in Ontario Stream Assessment Protocol (OSAP) training and sampled benthic invertebrates at 2 sites in Reach 5 of the Main Branch, in Twin Forks Playground. Three OSAP methods were used[63]: Rapid Macroinvertebrate Collections where the macroinvertebrates were collected from the underside of 10 randomly selected cobbles, Stationary Kick Survey where one person kicks the substrate in 1m^2 while a second person holds a 60X110cm net with 1000µm window screen downstream to collect dislodged macroinvertebrates, and

Travelling Kick-and-Sweep Survey, where a person travels a maximum of 10m from bank to bank in about 3 minutes while kicking the substrate and holding a D-net downstream to collect dislodged macroinvertebrates. In all three cases, macroinvertebrates were picked unaided and identified to order level (mostly).

The site upstream of Gary Avenue (GaryUPB) was dominated by tolerant Midges (Chironomidae) and Worms (Oligochaeta), while the site in Twin Forks (JCSITE) was dominated by sensitive EPT (up to 90% EPT – mainly Caddisflies (Trichoptera) but no Stoneflies (Plecoptera)). This difference in BMI community is likely a function of substrate with GARYUPB having a soft sediment bottom and JCSITE having cobble offering refugia to several BMI families.

2003-2024 – Nolin Creek (n=54)

Nolin Creek receives effluent from upstream mining and runs through Beatty Park before entering a tunnel to join the main branch of Junction Creek.

Benthic invertebrates have been sampled at Nolin Creek at McNeil Street (NMCN) downstream of the decking in Beatty Park (Figure 23) with a rapid bioassessment technique[54] in late October to early November semi-regularly for 18 years (2003–2024). A 500-μm mesh D-net and a kick-and-sweep technique[54] were used to sample three 1m^2 quadrants of stream substrate at the NMCN site. The netted materials from each replicate sample were live picked.

Richness has remained the same over the 18 years at 5-8 families but %EPT has increased from 0% in 2003 to over 50% in 2024 (Table 4).

Figure 23 – Nolin Creek at Beatty Park upstream of sampling site Nolin-McNeil (NMCN). Photo by C. Sarrazin-Delay

Table 4 – Biological summary metrics at the NMCN sites from 2003 to 2024. Site values are the mean of three replicate (1 m^2) samples. N is the total number of organisms enumerated.

	N	Family Richness	EPT Richness	EPT %	Chironomidae %	Simpson Diversity	% shredder
NM-03	191	8.33	0.00	0	100.00	0.00	0
NM-05	308	5.00	1.00	2	92.53	0.14	95
NM-06	327	4.67	0.33	11	78.89	0.32	90
NM-07	343	5.00	0.67	3	72.03	0.36	76
NM-08	323	6.67	0.67	19	34.76	0.63	55
NM-09	355	6.33	1.00	3	24.39	0.51	28
NM-10	318	4.67	1.00	21	62.05	0.51	83
NM-11	268	6.33	1.00	21	45.33	0.61	66
NM-12	286	4.67	1.00	38	51.93	0.37	90
NM-15	311	5.67	1.00	27	60.85	0.41	87
NM-17	304	7.00	1.67	31	33.82	0.70	65
NM-18	210	5.67	1.67	45	36.65	0.62	81
NM-19	304	6.00	2.00	52	35.01	0.40	87
NM-20	316	6.00	1.67	22	16.92	0.72	38
NM-21	243	7.00	1.67	22	30.45	0.64	51
NM-22	235	5.33	1.33	39	32.01	0.57	71
NM-23	322	5.33	1.33	43	28.26	0.61	71
NM-24	315	6.00	1.33	54	29.61	0.38	83

2000-2024 – Frood Tributary Acid Mine Drainage diversion long-term study (n=75)

The Frood tributary of Junction Creek historically received inputs of acid mine drainage (AMD) from a 1 km long airstrip constructed of sulfide-rich waste rock at Vale Ltd.'s Frood-Stobie Complex (Figure 24). Water draining off the waste rock pile was very acidic and had extremely elevated levels of Cu, Ni, and many other metals[64]. In the winter of 2000/2001 Vale (then Inco Ltd.) dammed (using an excavated collection channel) and diverted the runoff from the airstrip and rerouted it approximately 1000 m underground through a constructed drainage drift. The diverted water joined with mine waters that were later pumped to the surface approximately 7 km away and then sent through water treatment facilities before being discharged back into Junction Creek outside the Frood tributary catchment area (Figure 24).

Benthic invertebrates from the downstream test site called JC2(Figure 25) were sampled with a rapid bioassessment technique[54] in late October to early November. The test site was sampled for 23 years (2000–2024) including one year before and 22 years after the AMD diversion. A 500-µm mesh D-net and a kick-and-sweep technique[54] were used to sample three 1m^2 quadrants of stream substrate at the site. The netted materials from each replicate sample were placed into separate 18-liter buckets and transported back to the laboratory for processing with a live-pick protocol.

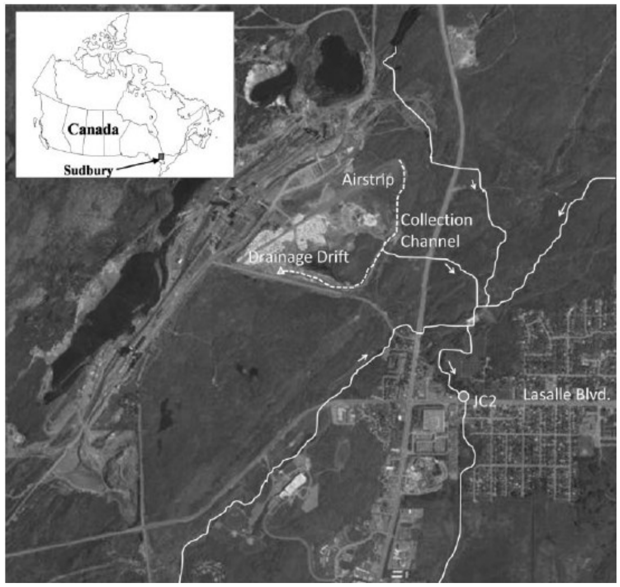

Figure 24 – Network of headwater streams that form the Frood tributary of Junction Creek in Sudbury, Canada. The collection channel and drainage drift to the underground workings of the Frood Mine were excavated in the winter of 2000/2001 to divert AMD underground from the waste rock pile that forms the air strip. The location of the downstream monitoring site (JC2) is shown.

Several (n = 42) potential reference sites in the Greater Sudbury area were sampled by Davidson (2002)[54] using the same sampling technique. Nine suitable reference sites were determined for JC2 based on similar habitat composition using a discriminant model of 12 habitat variables[54]. These reference sites were well away from urban and industrial influences and were mainly on groundwater dominated headwater streams within the Sudbury region.

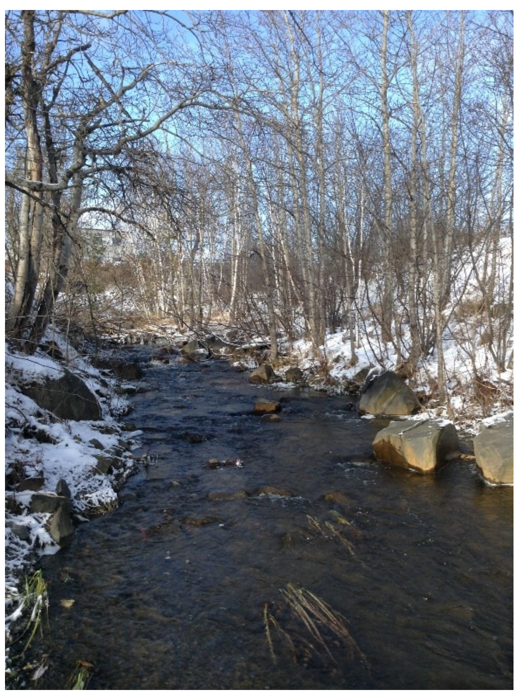

Figure 25 – The JC2 site, looking upstream, in early November, 2019. Photo by C. Sarrazin-Delay

A large suite of biological summary metrics were calculated to characterize invertebrate communities at the test and reference sites, but a reduced set of metrics including family richness, EPT richness (sum of taxa from the orders Ephemeroptera, Plecoptera, Trichoptera), and Simpson diversity were retained for this report. The reference condition was defined as 2 standard deviations (SD) away from the mean reference metric.

Family richness has increased since diversion but still isn't within the reference range. EPT and diversity, however, has occasionally entered the reference range (Figure 26, Table 5).

Table 5 – Biological summary metrics at the JC2 sites for one year before (2000) and 23 years after the diversion. Site values are the mean of three replicate (1 m^2) samples. N is the total number of organisms enumerated.

year	N	Family Richness	EPT Richness	EPT %	Chironomidae %	Simpson Diversity	% shredder
JC-00	2	0.33	0.00	0	100.00	0.00	0
JC-01	69	3.33	1.00	38	54.99	0.45	3
JC-02	302	7.67	1.00	39	42.17	0.66	0
JC-03	310	8.00	1.67	10	72.88	0.44	0
JC-04	301	6.33	1.33	27	54.37	0.52	0
JC-05	70	5.67	1.33	11	69.21	0.46	1
JC-06	209	6.67	1.33	31	54.25	0.56	3
JC-07	294	7.33	2.33	15	59.82	0.60	0
JC-08	326	7.67	2.00	44	34.33	0.58	0
JC-09	320	6.33	1.67	53	21.46	0.58	0
JC-10	316	6.33	1.00	79	3.81	0.36	0
JC-11	245	7.00	1.67	20	51.97	0.55	0
JC-12	254	8.00	1.33	23	16.12	0.78	2
JC-13	316	7.67	1.67	42	26.35	0.67	1
JC-14							
JC-15	313	5.33	1.33	29	57.44	0.44	0
JC-16							
JC-17	313	8.67	1.33	22	46.43	0.66	0
JC-18	296	8.33	2.33	63	14.86	0.64	2
JC-19	348	9.33	2.00	55	22.03	0.69	1
JC-20	311	9.67	3.33	64	10.94	0.74	1
JC-21	423	8.00	2.67	77	14.21	0.64	1
JC-22	418	8.00	2.33	76	15.50	0.63	0
JC-23	463	7.00	2.33	71	19.97	0.69	2
JC-24	318	6.67	2.00	69	20.79	0.68	2
Reference group mean +/-2 SD		18+/- 4.6	10+/-3.8	53+/-35	27+/-26.7	0.82+/-0.15	9+/-9.8

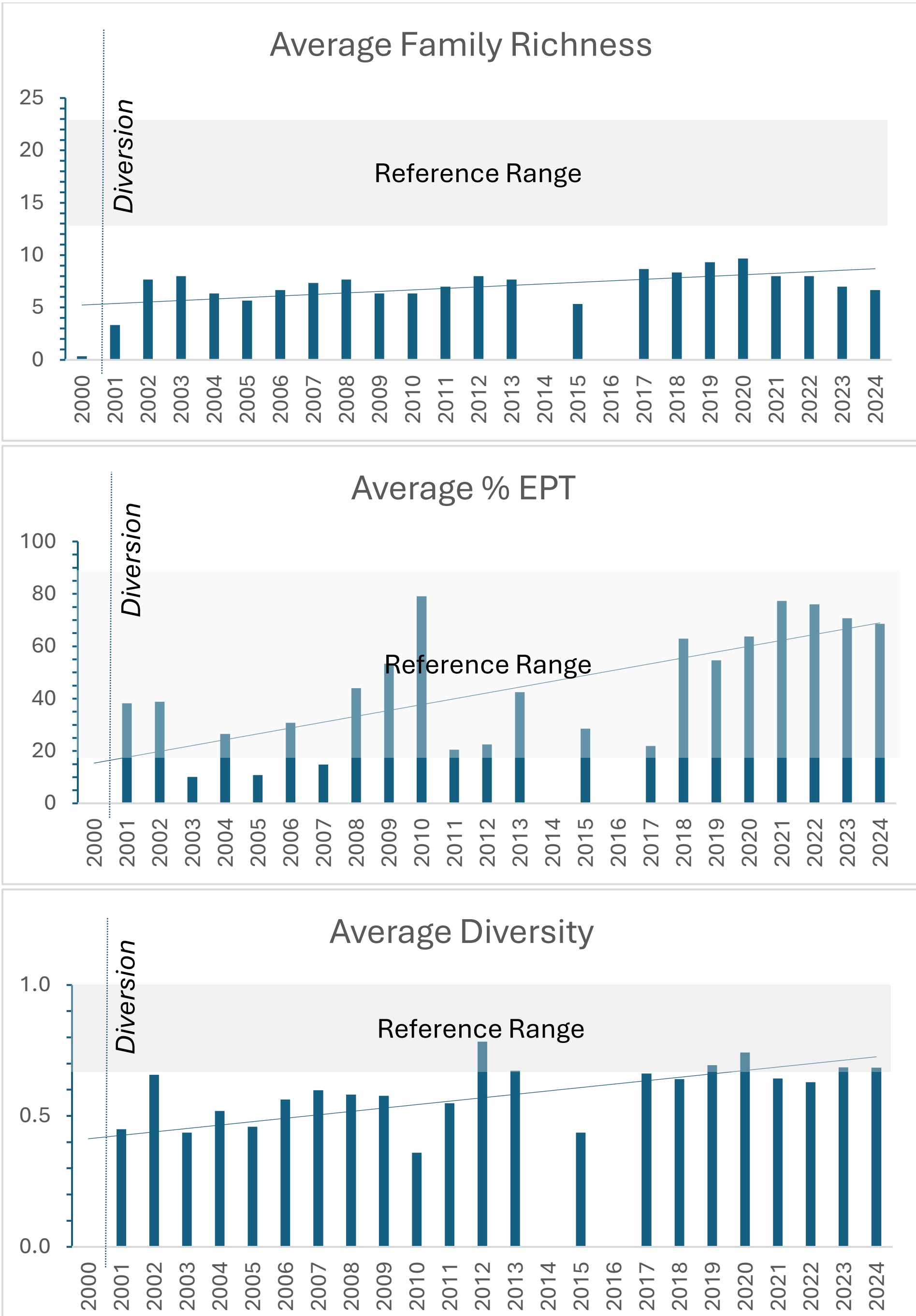

Figure 26 – Family richness, % EPT and diversity of Lasalle Cemetery site (JC2) in the Frood tributary with reference range in grey.

Changes in Benthic Macroinvertebrate Communities

The generalized trend of improved BMI community over almost 60 years of sampling is compelling despite variation within sites and across years in sampling methods and timing known to affect BMI detection. Upper reaches and the Maley and Frood tributaries also have higher richness than lower reaches, especially downstream of Nolin Creek and the tunnel downtown.

Watershed level trends

Early studies in 1965 and 1972 revealed an impacted BMI community dominated by tolerant Midges (Chironomidae) and Worms (Oligochaeta) in all sites tested except for site 3 in Reach 3 (Garson) in 1972 which had 80% EPT, mainly Hydropsychidae caddisflies.

By 1996, family richness increased in all sites, but stoneflies (Plecoptera) were not detected until 2007 in Reach 5 at Paquette Street where the main branch receives the relatively clean water of the Maley tributary. By 2017, 24 families of sensitive EPT (12 Caddisflies-Trichoptera, 6 Mayflies-Ephemeroptera, 6 Stoneflies-Plecoptera) were detected, even dominating the BMI community in some sites.

In 2019 through to 2022, eDNA analysis was performed from samples at 19 sites on Upper Junction Creek. Twenty EPT families were detected (9 Caddisflies-Trichoptera, 5 Mayflies-Ephemeroptera, 6 Stoneflies-Plecoptera), more than in any previous studies. These results should be interpreted with caution.

Site-specific trends

Several sites have been sampled periodically since 1965, with some locations providing up to 20 years of semi-consecutive data. These sites with Family-level data sampled in the fall season offer valuable insights into both temporal and spatial trends (Figure 27 and Figure 28).

At the Spruce Street site, located downstream of the Garson Mine in Reach 1, no obvious increase in family richness is observed. However, richness has remained relatively stable over the past two decades, fluctuating between 13 and 20 families. Notably, there has been an increase in the abundance of sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) over the last 20 years.

In contrast, at the Lasalle Paquette site in Reach 5, an increase in family richness is evident since 1965, though this trend is not reflected in the sensitive EPT taxa, which have remained unchanged.

The site where the creek crosses Maley Drive, located in the Maley tributary, shows a notable increase in richness since 1972. However, the trend in the proportion of EPT is confounded by an anomalous 50% value, which resulted from the capture of only two benthic macroinvertebrates (BMI), one of which was a mayfly. When the 1972 data point is excluded, the trend shows a generalized increase in the proportion of EPT over time.

Sampling at the Frood tributary site, which has been ongoing for over 20 years, tracks the changes following the diversion of acid mine drainage from an upstream waste rock pile in 2001. Since the diversion, the BMI community has shown improvement, with family richness increasing, although it has plateaued at 13–18 families. The proportion of sensitive EPT has fluctuated but is generally on an upward trajectory.

At the Louis Street site in Reach 11, just before the creek flows underground, both family richness and the proportion of EPT have increased over time. At the Beatty Park site on Nolin Creek, richness has not increased, but there has been a marked improvement in EPT proportion.

Further downstream, the site of the tunnel exit (Reach 12) at its confluence with Nolin Creek, and the site at the confluence with Copper Cliff Creek (Reach 14), family richness has increased since

1965 but the proportion of EPT remains below 3% and 5-10% respectively, making these sites the poorest sites in the dataset.

Overall, trends show varying levels of biodiversity improvement across sites, with some reflecting positive changes for sensitive species, while others remain poor in terms of EPT taxa.

Note that water and benthic sampling is known to have been done by Jaagumagi and Bedard[64] in 1999, but their report did not include raw data, and this data was not located at the time of publication of this report.

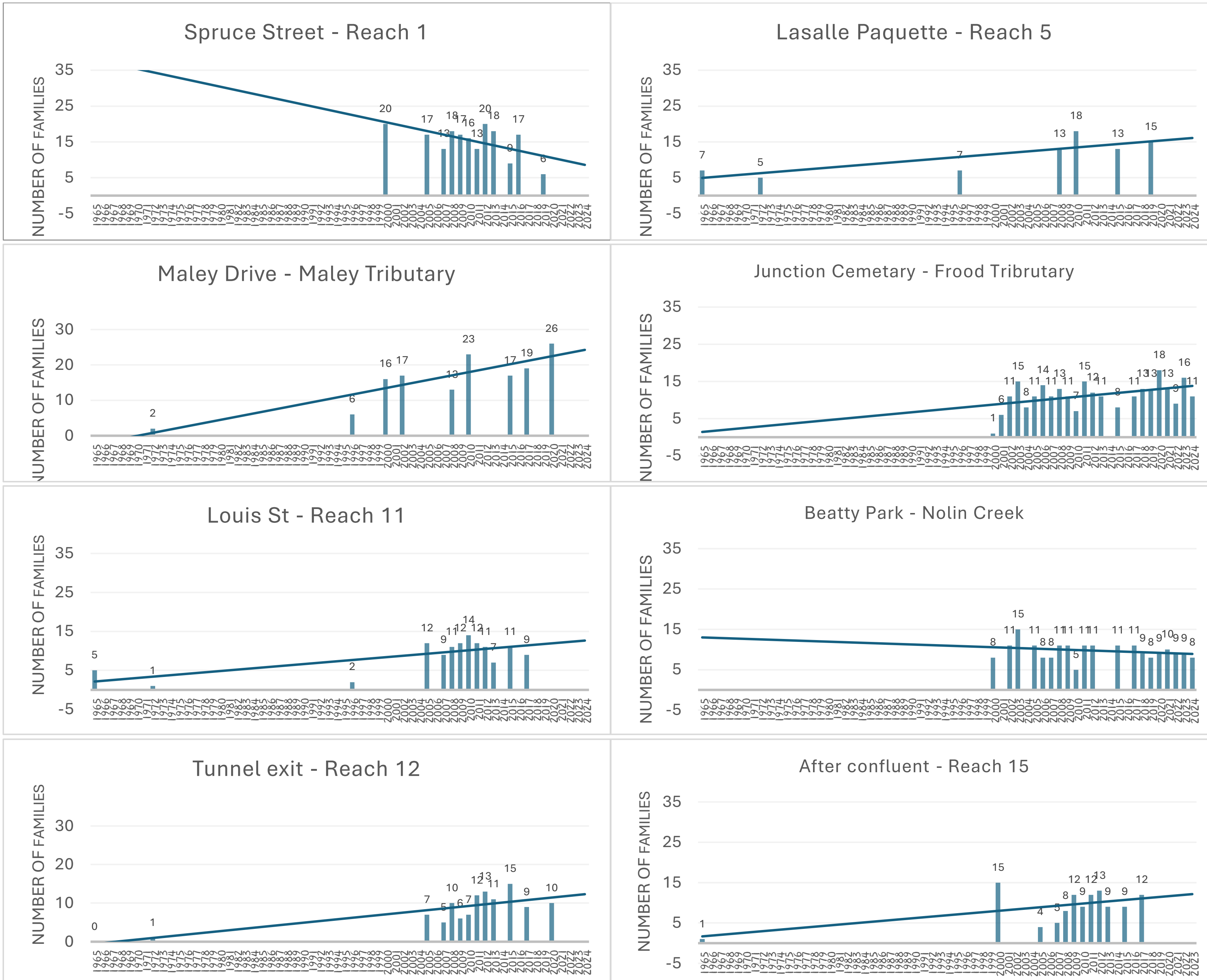

Figure 27 – Family richness at 8 sites along Upper Junction Creek.

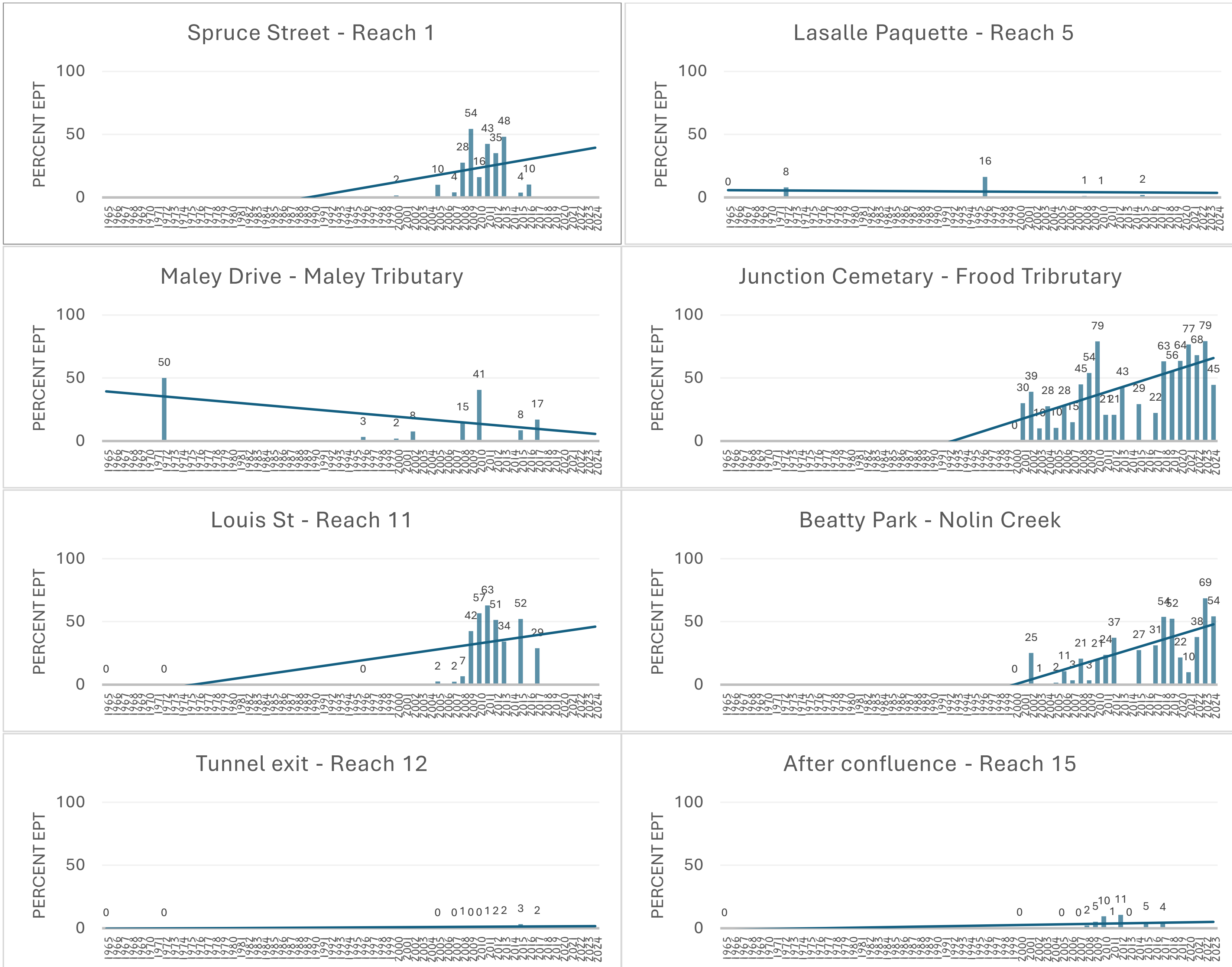

Figure 28 – Percent of sensitive Ephemeroptera (Mayflies), Plecoptera (Stoneflies) and Trichoptera (Caddisflies) (EPT) at 8 sites along Upper Junction Creek. Note that EPT at the Maley Drive site in 1972 was inflated by 1 mayfly to 2 BMIs captured. Removal this data point reveals a generalized increase in the proportion of EPT over time.

Conclusion

Remarkable biotic and chemical recovery continues in Upper Junction Creek, but legacy (metal, acid, sewage) and contemporary challenges (climate change, road salt, effluent, potential new contaminants) remain. The UJCW is now a wonderful public asset with many people enjoying the trails and the access to nature within the city. The data sets associated with this report now provide a rich resource for further research and public education. However, it is essential that we look forward, focusing on strategies to further enhance the resilience of the ecosystem and ways of protecting it in a changing climate.

General Recommendations

To ensure the continued recovery and protection of the UJCW, the following recommendations are made:

- **Climate Strategies:** Develop climate adaptation strategies to mitigate the impacts of extreme weather events and flooding.
- **City Planning:** Implement city planning practices that avoid development in flood-prone areas and maintain efficient natural and engineered drainage systems to reduce stormwater runoff.
- **Protection of Land and Waterways:** Enhance and protect wetlands, which serve as critical buffers for both flood management and biodiversity conservation. Prevent further development in vulnerable areas, such as the Ponderosa Wetland.
- **Wetland Restoration:** Focus on the restoration of peatlands and other wetlands, which play an important role in water filtration, carbon storage, and fire suppression.
- **Monitoring:** Continue comprehensive water quality and biodiversity monitoring to track improvements and detect emerging threats.
- **Erosion Control and Shade:** Implement measures to control erosion, particularly along riparian zones, and plant more trees and vegetation to provide shade and improve water quality. Implement bioengineering techniques in trail maintenance protocol along the creek.
- **Reduction of Impervious Surfaces:** Aim to significantly reduce impervious surfaces to decrease runoff and improve groundwater infiltration.
- **Water Protection Plan:** Establish a comprehensive water protection plan that includes monitoring water levels and quality, stormwater management, and pollutant mitigation to ensure the long-term health of the watershed.
- **Data archive:** Establish a searchable data storage site and repository for reports, theses and publications related to Junction Creek.

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