Himalayan Blackberry (*Rubus armeniacus*) Effects on Fish Habitat: Impacts from Riparian Zones Inundated with Himalayan Blackberry

by

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COMMITTEE APPROVAL

The members of Jason Thomas Leathem's Thesis Committee certify that they have read the thesis titled Himalayan Blackberry (*Rubus armeniacus*) Effects on Fish Habitat: Impacts from Riparian Zones Inundated with Himalayan Blackberry and recommend that it be accepted as fulfilling the thesis requirements for the Degree of Master of Science in Environment and Management:

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Abstract

This study compared the quality of fish habitat in small lotic reaches (channel width 1.5-5 m) having riparian zones inundated with invasive Himalayan blackberry (*Rubus armeniacus*) plants (test conditions) (3 sites) and reaches with a riparian zone consisting primarily of native vegetation (reference conditions) (5 sites). This thesis studied streams in the lower mainland of British Columbia near Coquitlam, Maple Ridge, and Mission to assess fish habitat quality indicators that included invertebrate drift input (allochthonous and total drift), temperature regulation (instream and riparian temperature), canopy cover, and instream complexity that provides rearing habitat for fish (large woody debris (LWD) habitat and residual pool habitat). I hypothesized that each fish habitat quality indicator would show lower quality in the test sites compared to the reference sites. My findings indicate that test sites had lower canopy cover, in comparison with reference sites made of natural vegetation from differing seral stages of growth (young to mature). Impacts were not detected when comparing invertebrate drift (both allochthonous and total), densities of LWD habitat, presence of residual pool habitat, depth of residual pool habitat, instream temperatures and riparian temperatures. Indicator variables assessed within this study exhibited a high degree of between-site variability both within and between the test and reference sites. Though the sample size was small within this study (3 test sites compared to 5 reference sites), trends in data were observed suggesting that test sites have lower LWD numbers, residual pool numbers, and produce slightly warmer instream temperatures, which aligned with historical literature. It is anticipated that Himalayan blackberry may have a large impact on fish habitat over an extended period due to its ability to inhibit seral growth of a riparian zone when it inundates an area (Feirke & Kauffman, 2003). This study is intended to assist environmental managers when considering habitat enhancements for sites with riparian zones inundated with Himalayan blackberry. Enhancements to these sites might improve instream temperature regulation, canopy cover, and instream complexity when a riparian zone is restored to its natural vegetation and allowed to mature.

Table of Contents

List of Appendices

Acknowledgements

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Introduction

Riparian zones are important for aquatic ecosystems due to their ability to regulate stream temperatures, filter run-off, stabilize banks, produce food for species inhabiting the area, and provide cover for aquatic species (Canadian Science Advisory Secretariat [CSAS], 2020; Naiman & Décamps, 1997; Pusey & Arthington, 2003; Smith & Smith, 2001). Riparian zones support vegetation that is thicker and more diverse than upland vegetative communities due to shallow groundwater tables adjacent to waterbodies, and nutrient rich soil deposits in association with periodic flooding (Bleich et al., 2005). Diverse woody vegetation provides cover in the form of overhanging vegetation, large woody debris (LWD) (i.e. fallen trees, root wads, log jams), and undercut banks which produce higher quality of rearing and overwintering habitats for salmonid species compared to coverless overwintering habitats (Heifetz et al., 1986, as cited in Smokorowski & Pratt, 2006; Naiman & Décamps, 1997).

Himalayan blackberry (*Rubus armeniacus*) is an introduced plant species in North America and is a listed invasive plant species within British Columbia (BC), Canada (Invasive Species Council of British Columbia [ISC of BC], 2021). It is considered one of the most invasive angiosperm weeds in the world (Rajmanek & Richardson, 1996, as cited in Gaire et al., 2015), and typically grows in previously "disturbed areas, forested edges, valleys and riparian zones" (ISC of BC, 2019). It's ability to withstand extended floods; propagate via seed dispersal, root shoots, and budding (i.e. when stalks contact soil, when stalks are cut and left on the ground, and when roots are cut); and its faster growth compared to species of *Rubus* that are native to BC, make Himalayan blackberry a difficult invasive weed to control (Gaire et al., 2015).

When environmental managers are considering habitat enhancement projects in lotic waterbodies, little information is available regarding the impact on fish habitat of riparian zones inundated with Himalayan blackberry. Additional research is required to understand the potential negative effects on fish habitat when Himalayan blackberry is established in a riparian zone.

Research Question

Does a riparian zone inundated with Himalayan blackberry negatively impact fish habitat in comparison to riparian zones comprised of native vegetation? To answer this question, this study attempts to address the following specific questions:

- What is the effect of Himalayan blackberry on allochthonous[1] invertebrate drift and total invertebrate drift as a source of prey for fish?
- What is the effect of Himalayan blackberry on instream temperature and forest floor temperature in a riparian zone?
- What is the effect of Himalayan blackberry on rearing habitat for fish (LWD and residual pools[2])?

Research Objectives

This study aims to assess the habitat quality of riparian zones inundated with Himalayan blackberry in comparison with naturally forested riparian habitats, Using existing literature in combination with field assessments.

The study evaluates the allochthonous input of drift invertebrate, total invertebrate drift, instream temperature, riparian temperature, instream canopy cover, and habitat rearing quality (i.e. abundance of LWD and residual pools, and average residual pool depth differences) to evaluate the ecological value of the two types of riparian zones.

The research outcomes of this study aim to assist environmental managers in evaluating sites for potential habitat restoration/offsetting projects.

Hypothesis

It is predicted that colonization of riparian zones with Himalayan blackberry will negatively affect fish habitat quality as reflected in various indicators, including reducing relative abundance of drifting prey, diminishing

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[1] Allochthonous is the input of a material from a different habitat to another habitat. Within the context of this report, allochthonous input is referencing terrestrial invertebrate input from riparian habitat entering the aquatic habitat as drifting prey for fish.

[2] Residual pool is the remaining pool habitat when a streams-flow initially ceases.

overhead cover, elevating temperature, and reducing rearing habitat quality in comparison with sites consisting primarily of native vegetation.

Information Review

Himalayan blackberry is native to the Caucasus region located between the inland Black Sea and the landlocked Caspian Sea of Eurasia (Gaire et al, 2015). It was first introduced to North America in 1885 for cultivation of its fruit, and the earliest documentation of it growing beyond agricultural settings was in 1945 (Gaire et al., 2015). Since then, Himalayan blackberry has invaded native plant communities and established its distribution throughout temperate coastal habitats in California, Oregon, and Washington in the United States, and British Columbia in Canada (Gaire et al., 2015).

Himalayan blackberry outcompetes native *Rubus* species such as thimbleberry (*Rubus parviflorus*) and salmonberry (*Rubus spectabilis*) by reaching the groundwater table with its deeper and larger spread root system, its fast-growing thorny stalks, its ability to photosynthesize within its stalk in addition to its evergreen leaves, and its ability to bud new plants from cut stalks and roots that contact the ground (Caplan & Yeakley, 2010; Gaire et al., 2015; McDowell, 2002). Many herbivorous mammals, with the exception of goats, are discouraged from grazing on this plant because of its thorny stalk, spiny leaf stem, and spiny leaf margins (Gaire et al., 2015). Larvae from the Order *Lepidoptera* and leaf miner species from the Order *Diptera* have been observed to forage on the leaves (Gaire et al., 2015). Himalayan blackberry leaves contain a lower nitrogen concentration than native *Rubus* species, which may discourage terrestrial and aquatic invertebrates from foraging on it (Kennedy & El-Sabaawi, 2018; McDowell, 2002). If unmanaged, Himalayan blackberry outcompetes most native vegetation, creating thick monocultures where food chain diversity and energetic value for invertebrates, fish, and terrestrial animals are impacted (Gaire et al., 2015; Twining et al., 2019).

Herbivorous terrestrial and aquatic invertebrates can provide different nutrient loads to both riparian and aquatic insectivores (i.e. birds, bats, fish, spiders, wasps, centipedes, dragon flies, and some families of beetles and true bugs). Twining et al. (2019), noted that herbivorous aquatic invertebrates have greater accumulations of highly unsaturated omega 3 fatty acids compared to herbivorous terrestrial invertebrates, providing important nutrients to insectivores. In contrast, they found that the concentration of short chained omega 3 alpha-linolenic acid is similar between terrestrial and aquatic invertebrates, specifically within the *Lepidopteran* Order (Twining et al. 2019), providing an array of omega 3 nutrients to insectivores.

Terrestrial invertebrates provide seasonal gains of nitrogen intake for salmonids, producing important inputs for rearing and young-of-year (YOY) fish during spring and summer, and providing diversity in nutrient inputs for insectivores that reside within aquatic and riparian habitats (Baxter et al., 2005; Twining et al., 2019; Wipfli, 1997). Habitat degradation that affects the relative availability of drifting invertebrates is likely to impact insectivorous species, such as fish (Baxter et al., 2005; Twining et al, 2019).

The habitat quality of riparian zones inundated with Himalayan blackberry should be better understood, if environmental managers are considering them as potential locations for enhancements or offsetting to meet regulatory compliance objectives. This information may also be of value to regulating agencies (i.e. Government of BC, DFO) when reviewing offsetting proposals where this invasive weed is present at sites identified for enhancements.

Comparable Studies

Poole and Berman (2015) reviewed variables that naturally regulate instream temperatures: the various studies reviewed suggest that riparian zones, instream complexity (that produces hyporheic flow), ground water flow, tributaries, and freshets all benefit instream temperature regulation. Within small streams, riparian zones and ground water produced the highest instream temperature regulation followed by tributaries, hyporheic flow, and freshet releases (Poole & Berman, 2015). Differences in instream temperature from anthropogenic disturbances can vary between streams and at separate reaches within a stream; deviations from natural conditions may not be detectable until the mid-reach of the stream, an area impacted from atmospheric conditions, when there is limited regulation from headwater sources, groundwater, or temperature regulation from stream confluence connectivity (Poole & Berman, 2015).

When reviewing allochthonous input within the stomach content of Coastal Cutthroat Trout (*Oncorhynchus clarki clarki*), young seral stage riparian forests, dominated by varying understory species and alder shrubs, produce more allochthonous stream input compared to old growth forests in Alaska (Wipfli, 1997). However, a difference was not detected when Wipfli compared allochthonous invertebrate abundance captured on floating sticky traps. Wipfli (1997) recommended more allochthonous and aquatic (autochthonous) invertebrate research to better understand and more effectively manage aquatic ecosystems, and to standardize sampling methodologies for allochthonous inputs.

A study conducted by Kennedy and El-Sabaawi (2018) attempted to evaluate whether Himalayan blackberry leaf litter impacted autochthonous invertebrate composition within urban streams in Victoria, BC. The study indicated that Himalayan blackberry leaves decay faster than willow (*Salix* sp.), alder (*Alnus* sp.), and English ivy (*Hedera helix*) but not compared to other native riparian vegetation. They also found no statistical differences in invertebrate diversity between watercourses in urbanized areas and rural settings. A variety of other variables (i.e. stream gradients, flashiness, baseline flowrates, presence of signal crayfish (*Pacifastacus leniusculus*), nutrient load differences, and dissolved oxygen differences) may also influence local autochthonous invertebrate diversity and may have obscured any direct influence of blackberry leaf decomposition in the streams (Kennedy & El-Sabaawi, 2018).

Fierke and Kauffman (2006) noted that both reed canary grass (*Phalaris arundinacea*) and Himalayan blackberry are less abundant in riparian zones that are dominated by mature deciduous and coniferous trees (later successional seral stage), likely due to less ideal growing conditions in well shaded riparian habitats. However, within previously disturbed or open canopy habitats, Himalayan blackberry can co-exist with other invasive weeds (such as reed canary grass and English ivy), homogenizing and reducing the spatial diversity of early successional seral staged riparian zones (Fierke & Kauffman, 2006). Due to the ability of these invasive weeds to outcompete natural vegetation in early successional vegetative areas, the regular successional rate of a riparian forest can be permanently altered, which can reduce canopy cover habitat for a waterbody (Fierke & Kauffman, 2006).

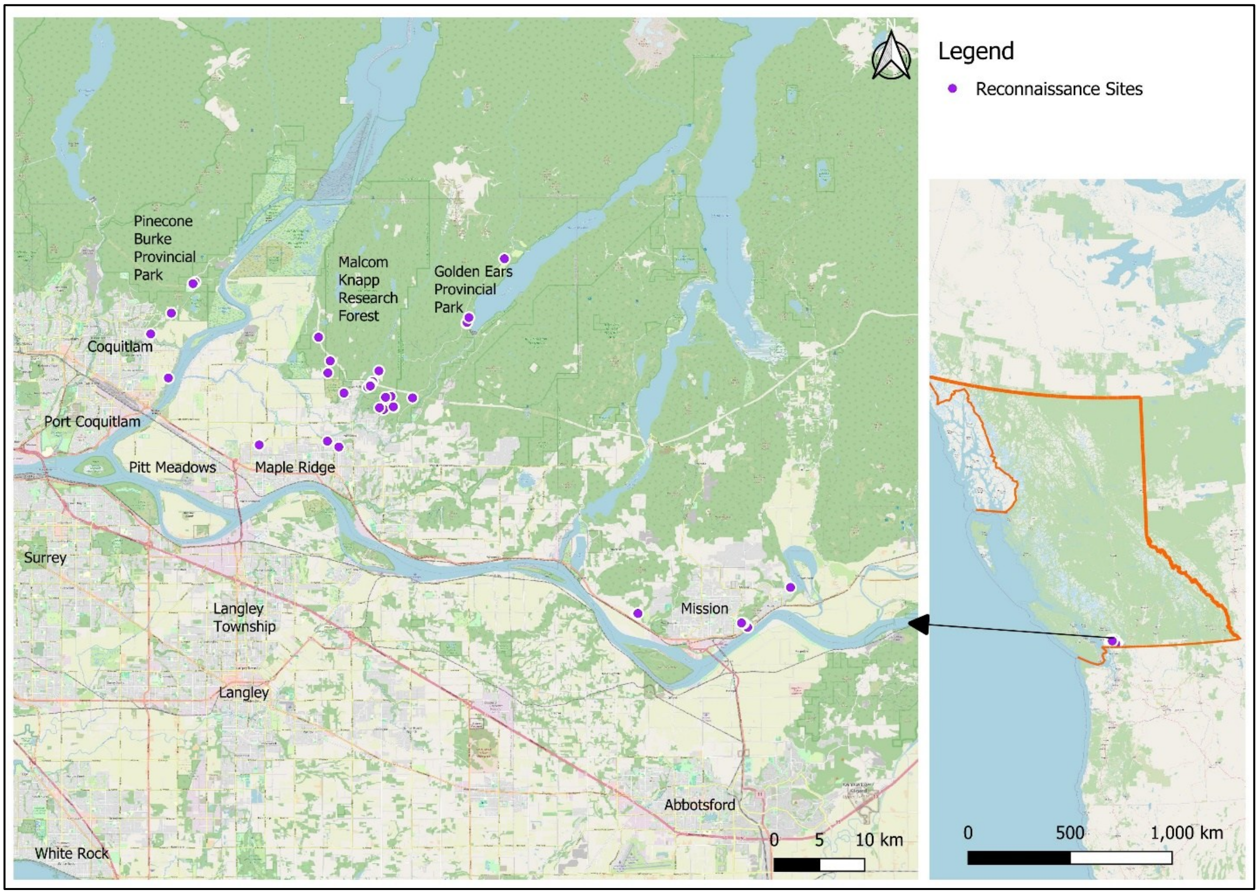
Methods

Study Area

This study was conducted at sites between Coquitlam and Mission in the Lower Mainland of British Columbia (BC), Canada. An extensive reconnaissance of the area was completed in advance to identify suitable sites for this study. A total of 34 sites were visited between April 17th to April 25th in 2023 (Figure 1).

Figure 1

Map of Sites Reconnoitered Between April 17th to April 25th, 2023, QGIS Mapping



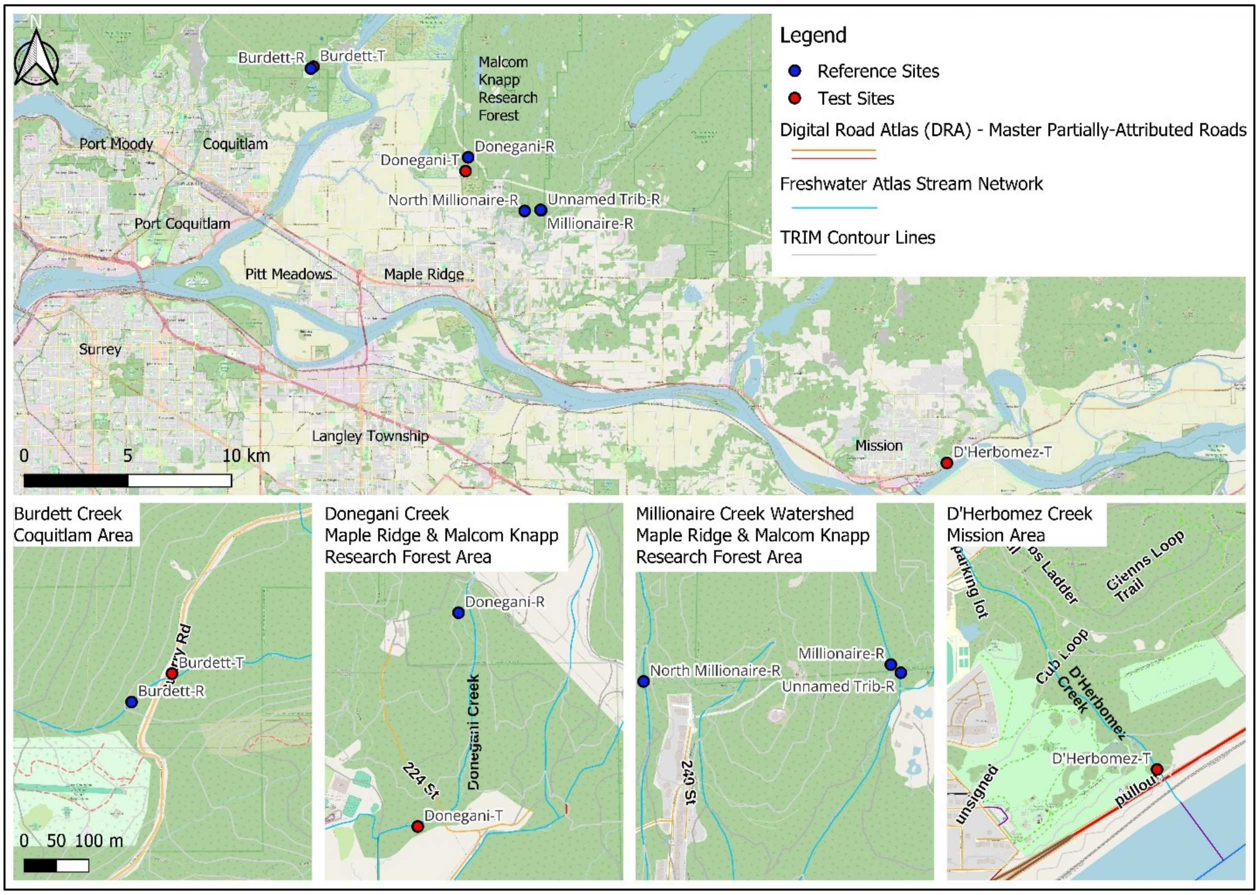
Sites were selected based on similarities in stream widths (channel width between 1.5 to 5 m which is defined as a S3 stream under the *Forest and Range Practice Act* in BC (Government of BC, n.d.a)), slope (< 10%), and dominant riparian vegetation type (native vegetation or Himalayan Blackberry). Selected sites had greater than 100 m length of consistent riparian habitat; were devoid of inflow from tributaries or observable groundwater inputs; and have experienced low adjacent urbanization / development.

Reference sites selected had a combination of salmonberry and/or thimbleberry mixed with black cottonwood (*Populus trichocarpa*) stands, bigleaf maple (*Acer macrophyilum*), and/or shade tolerant tree stands. Black cottonwood was targeted as it has been identified as a key species that further promotes native vegetation seral growth in coastal riparian zones (Fierke & Kauffman, 2006), while salmonberry and thimbleberry are the main species outcompeted by Himalayan blackberry (Gaire et al., 2010). Himalayan blackberry sites (test sites) were identified visually as having >60-100% coverage of the weed within the riparian zone of the 100 m long sites.

Of the 34 sites that were reconnoitered, a total of eight sites met the study requirements and were selected for further investigation (Figure 2). Sampling of these selected sites occurred between May 1st and June 30th of 2023.

Figure 2

Study Area Map, Selected Sites for Research, QGIS Mapping



Of the eight selected sites, two watercourses had test sites located downstream of reference sites (Burdett Creek and Donegani Creek). No suitable reference site was found for a third test site (D'Herbomez-T). Three additional reference sites (North Millionaire-R, Millionaire-R, and Unnamed Trib-R) within Maple Ridge and Malcom Knapp Research Forest were chosen as they matched the reconnaissance criteria (Table 1).

Table 1

Sites Selected Based on Reconnaissance Criteria

Waterbody Name	Type	Characteristics	Anthropogenic Disturbances
Burdett Creek	Test	Gradient <8%, width 3-4 m, 100 m of length, heavy inundation of Himalayan blackberry (>60%).	Under an elevated BC Hydro Right-of-way. A public gravel road through site.
	Reference	Gradient >8%, width 3-4 m, 100 m of length, native riparian vegetation – deciduous dominant.	Under an elevated BC hydro ROW.
Donegani Creek	Test	Gradient 0-1%, width 4-5 m, 100 m of length, heavy inundation of Himalayan blackberry roughly 60% of vegetation.	Private driveway upstream of the site.
	Reference	Gradient 6%, width 4-5 m, 100 m of length, native riparian vegetation – early mixed wood forest.	Downstream of a BC Hydro ROW and an old cut block.
D'Herbomez Creek	Test	Gradient 6%, width 2-3 m, length not assessed during reconnaissance due to heavy Himalayan blackberry within the creek (>90%).	Walking trails ≈ 400 m upstream. Homeless Camp 40 m upstream[2].
North Millionaire Creek	Reference	S3 stream with native riparian habitat – deciduous dominant.	No anthropogenic disturbances upstream
Millionaire Creek	Reference	Gradient 6%, width 4-6 m, 100m of length, native riparian vegetation – late mixed wood forest.	Cut block > 1 km upstream.
Unnamed Tributary	Reference	Gradient 7%, width 4-5 m, 100m of length, native riparian vegetation – coniferous dominant.	No anthropogenic disturbances upstream.

Note. Site D'Herbomez-T was later reduced from 100 m to 40 m, due to the establishment of a homeless encampment 40 m upstream of the sample site post-reconnaissance. Burdett Creek sites were the last to be reconnoitered, due to time constraints their gradients were not measured with a clinometer, but were documented visually to be either < / > 8% during the reconnaissance of these two sites.

Field Data Collection

Data at each site were collected in general accordance with methods described in the Resource Information Standards Committee (RISC) 1:20,000 Fish and Fish Habitat sampling procedures (Government of BC, 2001). RISC standards are available for instream channel measurements of channel width, wetted width, residual pool depth, and gradient. Deviations from these methods and/or additional methodologies are described below.

Invertebrate Input as Prey for Fish Sampling Methodology

Invertebrate drift net traps (18 X 34 cm) were installed at each site within the thalweg to evaluate the available prey for fish. To reduce upstream influences on drift, a small-mesh burlap fence was installed 100 m upstream of the drift traps. Traps were set in late spring when invertebrate abundance was the highest and were set for night samples when fish had a reduced predation on invertebrates (Namen et al., 2016). Either one or two traps were set (side-by-side) to collect thalweg drift depending on total wetted width (less or greater than 1.8 m) or the width of the thalweg within the wetted channel (less or greater than 0.34 m) (Figure 3). Traps were elevated above the streambed with a portion of the net above the surface to collect surface drift (Figure 3). Depth of flowing water entering each trap was recorded to determine area (m^2) (depth x trap width) of drifting water sampled. Velocity at each site was recorded at five equally spaced habitat transects (0, 25, 50, 75, and 100 m). At each transect, five evenly spaced flow rate readings were obtained over the recorded wetted width of that transect. Flow rate was calculated following the velocity head rod (ruler) method with a wooden meter stick (Velocity m/s = $\sqrt{(2(\Delta D/100)*9.81 \text{ m/s})}$ (Government of Canada, 2012). Both area (m^2) and velocity (m/s) were recorded to ensure that the relative abundance of invertebrates could be compared.

Captured invertebrates were field preserved with 99% ethanol for subsequent sorting and identification.

Figure 3

Trap Setup Depending on Stream or Thalweg Widths; Left: Millionaire-R; Right: D'Herbomez-T

Note: Photos taken from Jason Thomas Leathem

Temperature Regulation and Canopy Cover Methodology

A spherical densiometer was used to calculate cover percent (%) of the canopy above the stream. Densiometer data were collected at every transect within each site (five transects per site) between May 23rd and 27th, 2023. A total of four cover readings (facing: upstream, downstream, left bank, and right bank) were recorded in the middle of each transect to determine the average cover per transect. The cover per site was an average of the five transects.

Hoboware@ TidBit loggers were installed at the start of each site (Figure 2) to record temperatures from spring to early summer (May 1st - June 30th, 2023). All loggers were housed within black polyvinyl chloride (PVC) tubing to provide protection from the elements and rodents, and to be more camouflaged from vandalism. Each site had one logger placed in the thalweg of the stream, and one logger under riparian vegetation roughly 5-10 cm above the forest floor and approximately 5 m away from the instream logger. As water levels decreased, instream loggers were relocated within the site when dry. Data from the riparian loggers were used to both collect riparian air temperatures and to determine when their adjacent instream loggers were recording dry data (data to be removed from instream loggers prior to analysis).

Rearing Habitat Methodology

Residual pool habitat depths were measured, and the total number of residual pool habitats as well as total number of LWD were recorded at each site between May 23rd and May 27th, 2023. Data were collected in channel sections between each of the five transects (0-25, 25-50, 50-75, and 75-100 m) to determine mean available rearing habitat for fish per site.

As a standard measurement in the RISC 1:20,000 Fish and Fish Habitat sampling procedures, residual pool habitats were recorded as they are key rearing habitat during low flow conditions and are measurements of pool depth unbiased by flow differences (Government of BC, 2001; Lisle, 1987).

Invertebrate Laboratory Data Collation

Sorting and identification of invertebrates was completed with a WF10X/2X microscope. Invertebrates at each site were sorted from their 1 L field collection jar into individual 15 ml glass vials depending on their Order and/or Family similarities. Confidence in sorting numbers was increased through the use of quality assurance and quality control (QAQC) procedures as per the Government of Canada (2014) Canadian Aquatic Biomonitoring Network (CABIN) protocols.

Invertebrates with heads and/or thoraxes were accounted for, while abdomens were not (Government of Canada, 2014). Moulted husks of hatched invertebrates (exuvia) were also sorted and counted. Exuvia were only counted if their heads and/or thorax were present, and were only identified to the Order level.

Invertebrates sorted into individual vials were further identified and separated to individual Family levels. Family level identification was completed using keys developed by Merrit and Cummins (1984), Marshall (2006), Milne and Milne (1980), and Bouchard (2004). If invertebrates could not be identified using the four listed keys, additional expertise was consulted[3]. When an invertebrate could not be identified to the Family level, the Order was recorded and the invertebrate was given an unidentified (Unid) Family number within that Order (i.e. Unid 1, Unid 2, and so on). Families and Orders of identified invertebrates were separated into either autochthonous or

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[3] A senior biologist from Triton Environmental, curator from Beaty Biodiversity Museum of UBC, and documented materials from Chapman (2007), Humble et al. (1999), and the Picture Insect Bug Identifier Application.

allochthonous classification, as per life cycle descriptions provided in Merritt and Cummins (1984) and Marshall (2006). If an invertebrate could not be distinguished as either allochthonous or autochthonous within the reference material, then the individuals were labelled as allochthonous/autochthonous indicating that the individual's habitat was undetermined.

Habitat Summary

Habitat characteristics are summarized within the results section based on site variables beyond the fish habitat quality indicator variables that are assessed for the objectives of this study. Summaries were derived from data collected at each site, site transects, or during the mapping phase of this report (i.e. site elevation and dominant slope aspect of the stream). A Hanna multi meter was used to collect general water chemistry parameters including instream temperatures (^{o}C), pH, and conductivity (µs) when field sampling commenced between May 22nd and 27th of 2023.

Site Analysis

All data collected throughout this study were presented as either individual study sites or as pooled data sets of test and reference sites. Where possible, error bars on means were used to express confidence intervals to illustrate differences between test sites and reference sites.

For hypothesis testing, pooled data sets were compared using a t-test. The t-test was used due to its robustness to analyze data that is not normally distributed and for data sets that exhibit an unequal number of replicates per grouping (Whitlock & Schluter, 2015). This was chosen as there were three test sites and five reference sites. Hypothesis testing was used to determine if differences exist between test sites and reference sites for each of the following fish habitat quality indicator variables:

- Allochthonous invertebrate input and total drift input as prey for fish, by comparing: invertebrate abundance (no. of invertebrates m^3/hr), family richness (no. of families/site), and diversity (Simpson's Diversity[4])

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[4] As per calculations provided in Barcelona Field Studies Centre (n.d.) and Simpson (1949), Simpson's Diversity had to be calculated with the use of abundance data to provide equal diversity calculations between all

- Temperature and canopy cover, as further indicated by instream temperature (°C), riparian temperature (°C), and canopy cover (%)
- Instream habitat complexity, indicated by LWD habitat (mean # of LWD), residual pool habitat (mean # of pools), and depth of residual pool habitat (mean depth of residual pools).

Results

Habitat Summary

Habitat characteristics for each site are summarized in Table 2 and Figure 4. Site characteristics varied most in conductivity, volume discharge, gradient, and elevation. Wetted depth was lowest at the North Millionaire reference site in comparison to all other sites. The Burdett reference site was unique based on its high gradient (13.6%: Table 2) as well as stream morphology (co-dominance of cascade-type habitat) and bed material (significant bedrock) (Figure 4).

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the sites for appropriate comparisons. However, abundance data had to be multiplied by 10,000 prior to the Simpson's Diversity calculation as the calculation would equate to an error if any invertebrate family had an abundance less than 1. The multiplication of 10,000 occurred as some sites had an abundance at the $10(E)^{-4}$ notation.

Table 2

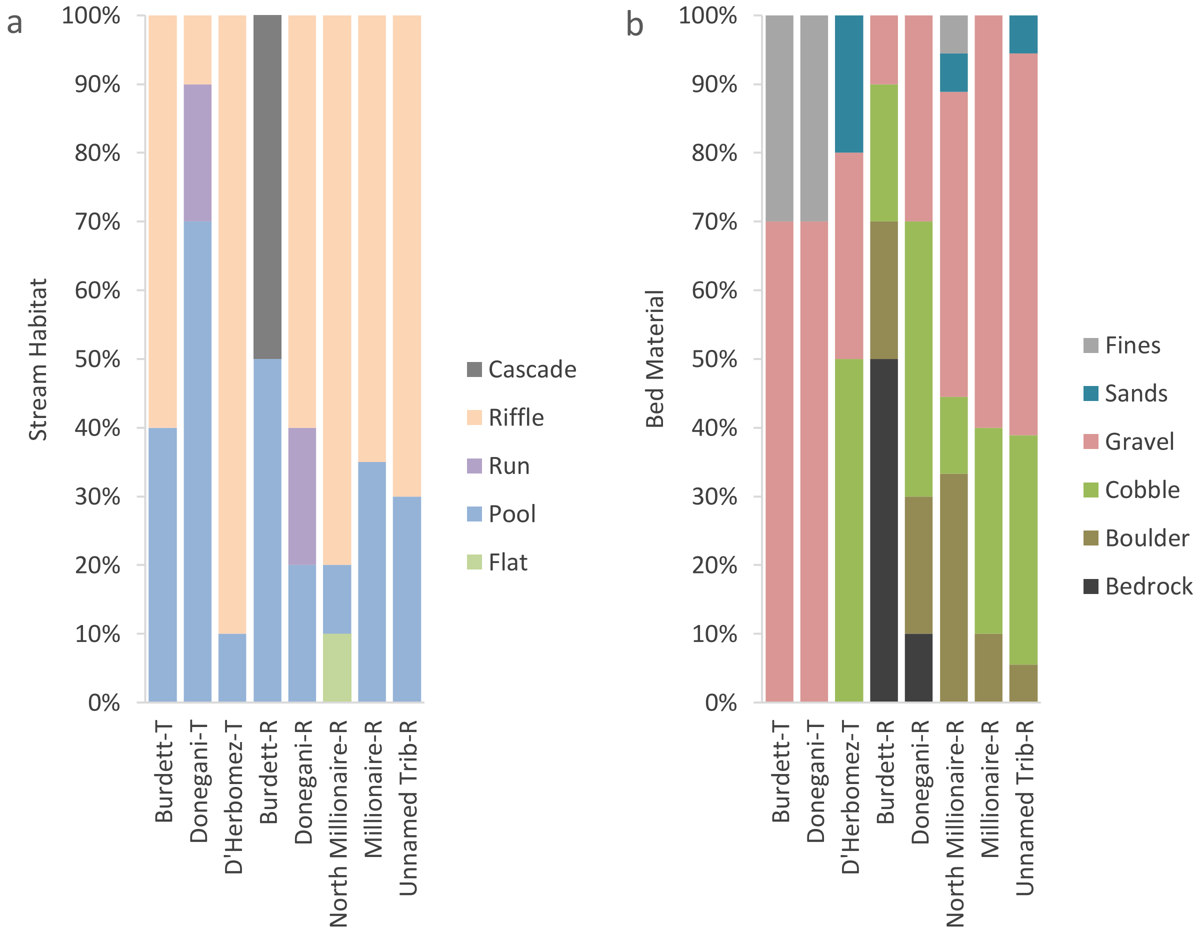
Average Habitat Characteristics for Each Study Site

	Test Site			Reference Sites				
Habitat Parameters	Burdett-T	Donegani-T	D'Herbomez-T	Burdett-R	Donegani-R	North Millionaire-R	Millionaire-R	Unnamed Trib-R
Instream Temp (^{o}C)	12.1	12.6	12.5	11.7	12.3	13.6	12.0	12.0
pH	6.63	7.66	7.64	6.85	7.46	7.43	7.29	7.38
Cond (µS)	16	33	198	13	30	27	36	25
Channel Width (m)	2.98	3.00	3.06	4.99	4.16	2.79	4.21	3.36
Wetted Width (m)	1.79	2.47	2.08	2.12	2.18	0.95	2.05	1.30
Wetted Depth (m)	0.10	0.22	0.11	0.08	0.11	0.03	0.07	0.05
Velocity (m/s)	0.20	0.20	0.34	0.25	0.30	0.12	0.26	0.25
Discharge (m^3/s)	0.037	0.112	0.074	0.042	0.070	0.004	0.035	0.016
Gradient %	3.2	0.4	8.0	13.6	2.8	5.5	2.4	5.2
Elevation (m)	10	7	18	19	44	132	113	111
Riparian Vegetation	Shrubs	Shrubs	Shrubs	Shrubs	Mixed Forest	Mixed Forest	Conifer	Conifer
Slope Aspect	East	West	South	East	West	South	South	South

Note. Temp = temperature, Cond = conductivity, Conifer = coniferous. Data collection period between May 23rd and 27th of 2023. Averages derived from 5 habitat transects per site in exception to D'Herbomez-T which had 3 transects.

Figure 4

Stream Morphology (a) and Bed Material (b) Instream Composition per Site



Note. Data collection period between May 23rd and 27 of 2023. Data derived from 5 habitat transects per site in exception to D'Herbomez-T which had 3 transects.

Analysis of Data

Invertebrate Input as Prey for Fish

Between-site variability of the raw abundance of trapped invertebrates was high (20-fold difference between Burdett-T and D'Herbomez-T) (Table 3). However, variability between sites was lower when drift invertebrate abundances were normalized against the total volume of water estimated to flow through their drift traps at each site during their sampling period, i.e. when abundance data were converted to abundance per cubic meter of water sampled per hour. Normalized total drift invertebrate abundances for the eight sites ranged from 0.027 to 0.59 invertebrates m^3/hr (Table 4).

Table 3

Raw Abundance of Total Drifting Invertebrates Captured per Site

Original set up and catch	Test Sites			Reference Sites				
	Burdett-T	Donegani-T	D'Herbomez-T	Burdett-R	Donegani-R	North Millionaire-R	Millionaire-R	Unnamed Trib -R
Traps set	1	2	1	1	2	1	2	1
Invertebrates	11	154	215	37	90	26	121	86
Exuvia	25	45	275	33	392	9	73	22

Note. Several fish were incidentally captured in drift traps: Burdett-T = 1 salmonid, D'Herbomez-T = 1 lamprey, and Millionaire-R = 3 salmonids.

There were 64 different families captured throughout this study (Appendix 1 and Table 4), of which 37 families were classified as autochthonous, 22 families as allochthonous, and 5 families as undetermined (autochthonous/allochthonous). Relative abundance in total drift varied from a low of 0.03 invertebrates m^3/hr (Burdett-T) to a high of 0.59 invertebrates m^3/hr (D'Herbomez-T). D'Herbomez-T site had higher family richness and relative abundance, of both living invertebrates and exuvia than all other sites (Table 4 and Appendix 1).

Total catch (abundance) and composition (family richness) by Order of drift invertebrates at each site is summarized in Table 4. Appendix 1 presents detailed invertebrate enumeration data identified to the Family biological classification level, and exuvia identified to the Order level.

Table 4

Relative Abundance (Abun) per Invertebrate Order, Family Richness (FR) per Invertebrate Order, and Total Drifting Exuvia Abundance per Site

	Order	Test Sites						Reference Sites									
		Burdett-T		Donegani-T		D'Herbomez-T		Burdett-R		Donegani-R		North Millionaire-R		Millionaire-R		Unnamed Trib-R	
		FR	Abun (m^3/hr)	FR	Abun (m^3/hr)	FR	Abun (m^3/hr)	FR	Abun (m^3/hr)	FR	Abun (m^3/hr)	FR	Abun (m^3/hr)	FR	Abun (m^3/hr)	FR	Abun (m^3/hr)
Autochthonous	*Amphipoda*	-	-	-	-	1	2.73E^{-02}	-	-	-	-	-	-	-	-	-	-
	Coleoptera	1	2.47E^{-03}	2	7.95E^{-02}	3	6.54E^{-02}	2	8.34E^{-03}	2	1.78E^{-03}	-	-	4	3.82E^{-02}	-	-
	Diptera	1	2.47E^{-03}	3	1.50E^{-02}	3	8.18E^{-02}	2	5.42E^{-02}	2	2.23E^{-02}	3	1.97E^{-01}	2	1.27E^{-02}	2	3.75E^{-02}
	Ephemeroptera	1	9.89E^{-03}	4	1.26E^{-01}	6	1.45E^{-01}	2	3.75E^{-02}	6	4.28E^{-02}	2	2.31E^{-02}	6	2.21E^{-01}	5	4.31E^{-01}
	Hemiptera	-	-	-	-	1	5.45E^{-03}	-	-	-	-	-	-	-	-	-	-
	Isopoda	-	-	-	-	1	3.54E^{-02}	-	-	-	-	-	-	-	-	-	-
	Plecoptera	1	2.47E^{-03}	1	3.00E^{-03}	1	5.45E^{-03}	-	-	1	3.57E^{-03}	-	-	1	7.64E^{-03}	1	2.50E^{-02}
	Trichoptera	1	4.94E^{-03}	1	7.50E^{-03}	7	8.18E^{-02}	1	8.34E^{-03}	1	3.57E^{-03}	1	1.16E^{-02}	3	1.78E^{-02}	2	3.12E^{-02}
	Trombidiformes	-	-	-	-	-	-	1	4.17E^{-03}	-	-	-	-	-	-	-	-
	Total	5	2.22E^{-02}	11	2.31E^{-01}	23	4.47E^{-01}	8	1.13E^{-01}	12	7.40E^{-02}	6	2.31E^{-01}	16	2.98E^{-01}	10	5.25E^{-01}
Allochthonous	*Araneae*	-	-	-	-	2	8.18E^{-03}	1	4.17E^{-03}	1	8.92E^{-04}	1	1.16E^{-02}	-	-	-	-
	Coleoptera	1	2.47E^{-03}	-	-	4	6.00E^{-02}	2	1.25E^{-02}	-	-	2	2.31E^{-02}	3	7.64E^{-03}	1	6.25E^{-03}
	Diptera	-	-	-	-	1	5.45E^{-03}	-	-	-	-	-	-	-	-	-	-
	Hemiptera	1	2.47E^{-03}	-	-	1	2.73E^{-03}	-	-	-	-	-	-	-	-	-	-
	Hymenoptera	-	-	-	-	2	1.09E^{-02}	-	-	-	-	-	-	-	-	-	-
	Julida	-	-	-	-	1	2.73E^{-03}	-	-	-	-	1	1.16E^{-02}	1	2.55E^{-03}	-	-
	Lepidoptera	-	-	-	-	-	-	-	-	2	1.78E^{-03}	-	-	-	-	-	-
	Oribatida	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	6.25E^{-03}
	Poduromorpha	-	-	-	-	1	5.45E^{-03}	-	-	-	-	-	-	-	-	-	-
	Raphidioptera	-	-	-	-	-	-	-	-	1	8.92E^{-04}	-	-	-	-	-	-
	Stylommatophora	-	-	-	-	1	2.73E^{-03}	-	-	-	-	-	-	-	-	-	-
	Symphypleona	-	-	-	-	-	-	1	8.34E^{-03}	-	-	-	-	-	-	-	-

Order		Test Sites						Reference Sites									
		Burdett-T		Donegani-T		D'Herbomez-T		Burdett-R		Donegani-R		North Millionaire-R		Millionaire-R		Unnamed Trib-R	
		FR	Abun (m^3/hr)	FR	Abun (m^3/hr)	FR	Abun (m^3/hr)	FR	Abun (m^3/hr)	FR	Abun (m^3/hr)	FR	Abun (m^3/hr)	FR	Abun (m^3/hr)	FR	Abun (m^3/hr)
Total		2	$4.94E^{-03}$	0	-	13	$9.82E^{-02}$	4	$2.50E^{-02}$	4	$3.57E^{-03}$	4	$4.63E^{-02}$	4	$1.02E^{-02}$	2	$1.25E^{-02}$
Autochthonous / Allochthonous	*Diptera*	-	-	-	-	1	$3.82E^{-02}$	2	$8.34E^{-03}$	1	$2.68E^{-03}$	1	$2.31E^{-02}$	-	-	-	-
	Hymenoptera	-	-	-	-	-	-	1	$8.34E^{-03}$	-	-	-	-	-	-	-	-
	Lepidoptera	-	-	-	-	1	$2.73E^{-03}$			-	-	-	-	-	-	-	-
Total		0	-	0	-	2	$4.09E^{-02}$	3	$1.67E^{-02}$	1	$2.68E^{-03}$	1	$2.31E^{-02}$	0	-	0	-
Total Drifting Invertebrates		7	$2.72E^{-02}$	11	$2.31E^{-01}$	38	$5.86E^{-01}$	15	$1.54E^{-01}$	17	$8.03E^{-02}$	11	$3.01E^{-01}$	20	$3.08E^{-01}$	12	$5.37E^{-01}$
Total Drifting Exuvia		$6.18E^{-02}$		$6.75E^{-02}$		$7.50E^{-01}$		$1.38E^{-01}$		$3.50E^{-01}$		$1.04E^{-01}$		$1.86E^{-01}$		$1.37E^{-01}$	

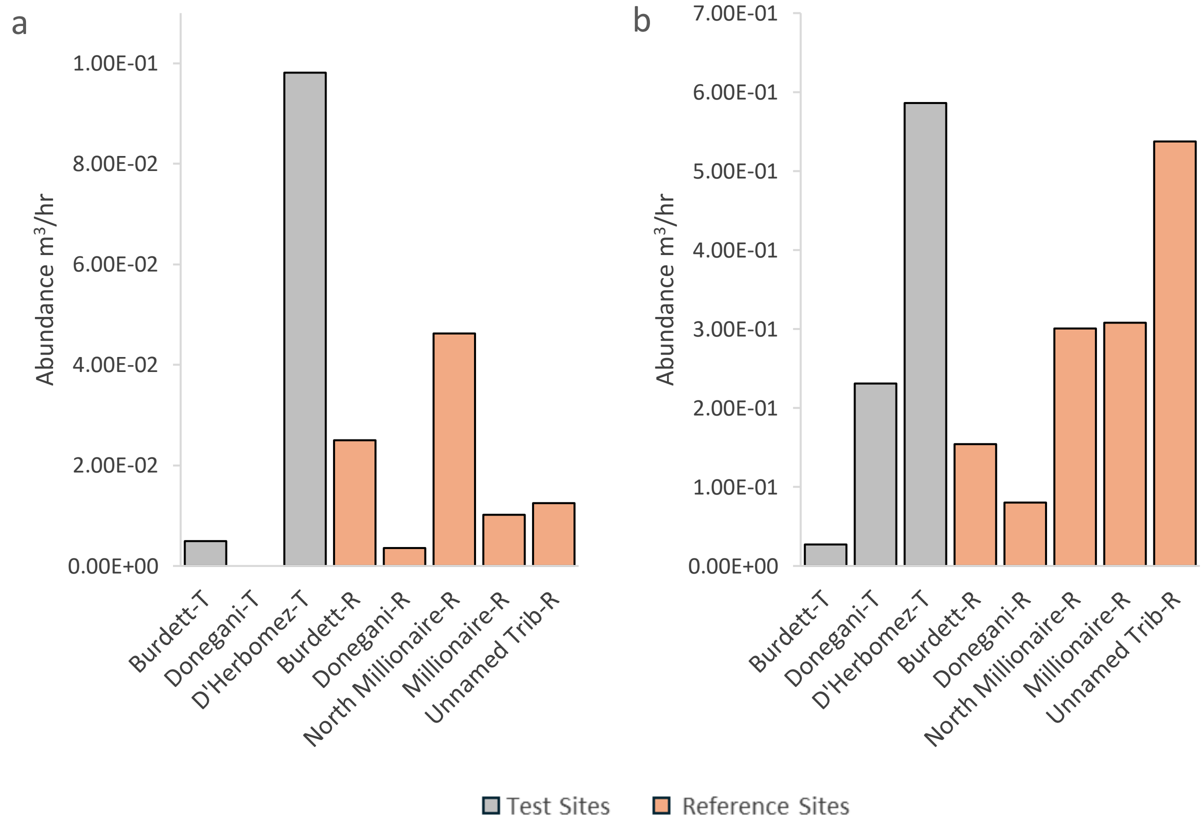
Note. For consistency to match the lower abundance records, relative abundance was displayed to the exponent level throughout. See Appendix 1 for greater details of invertebrate Families captured and exuvia Orders captured per site.

Invertebrate Abundance.

There was an average of 0.034 invertebrates m^3/hr (SE ± 0.03) for allochthonous taxa captured in drift nets at the three test sites (pooled test site data), in comparison with an average of 0.020 invertebrates m^3/hr (SE ± 0.01) for the five reference sites (pooled reference site data) (Figure 5). Pooled total drift invertebrate counts averaged 0.28 invertebrates m^3/hr (SE ± 0.16) in test sites and 0.28 invertebrates m^3/hr (SE ± 0.08) in reference sites (Figure 5). No significant difference between the pooled test sites (n=3) and pooled reference sites (n=5) was observed for the relative abundance of allochthonous drift (two-tailed t-test: df = 6, p = 0.58) or total drift (two-tailed t-test: df = 6, p = 0.97).

Figure 5

Relative Abundance (m^3/hr) at Study Sites of; a: Allochthonous Invertebrate Drift; b: Total Invertebrate Drift

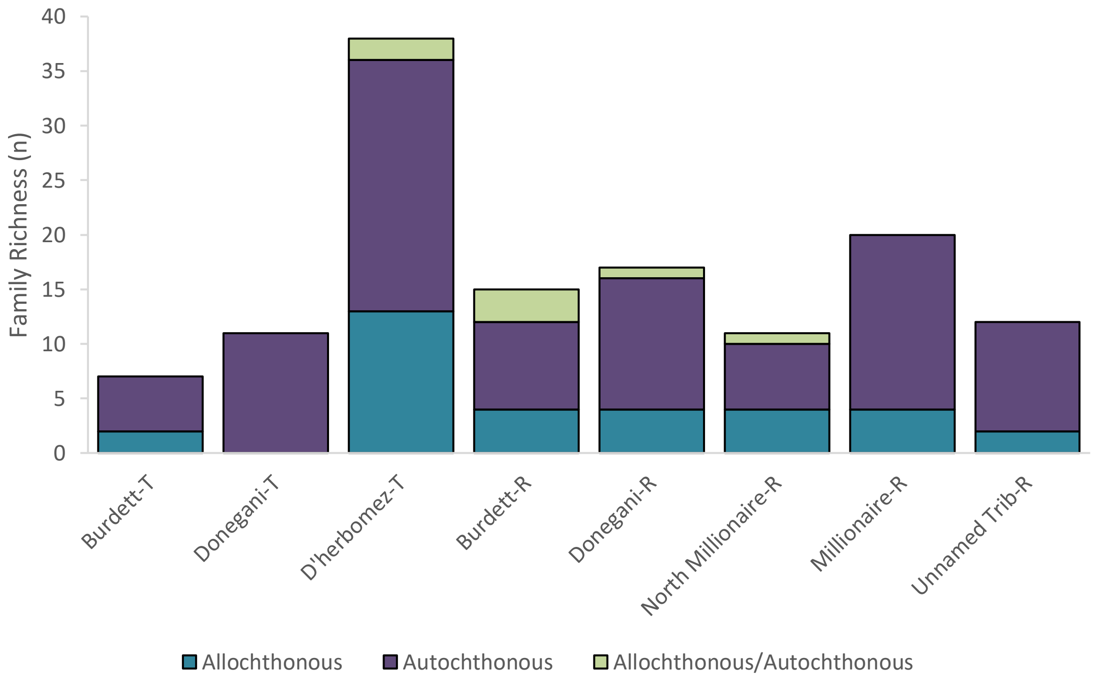


Family Richness.

Family richness across all sites included 64 families within three categories (allochthonous, autochthonous, and allochthonous/autochthonous) (Figure 6, Appendix 1). Pooled data sets of allochthonous drift indicated that test sites, averaging 5 families (SE ± 4.04), produced higher family richness than reference sites, averaging 3.6 Families (SE ± 0.4). Pooled data sets of total drift indicated that test sites, averaging 18.67 families (SE ± 9.74), produced higher family richness than reference sites, averaging 15 families (SE ± 1.64). No significant difference was observed between test and reference sites in family richness for allochthonous drift (two-tailed t-test: df = 6, p = 0.66) or total drift (two-tailed t-test: df = 6, p = 0.64).

Figure 6

Family Richness (Number of Invertebrate Families per Site)



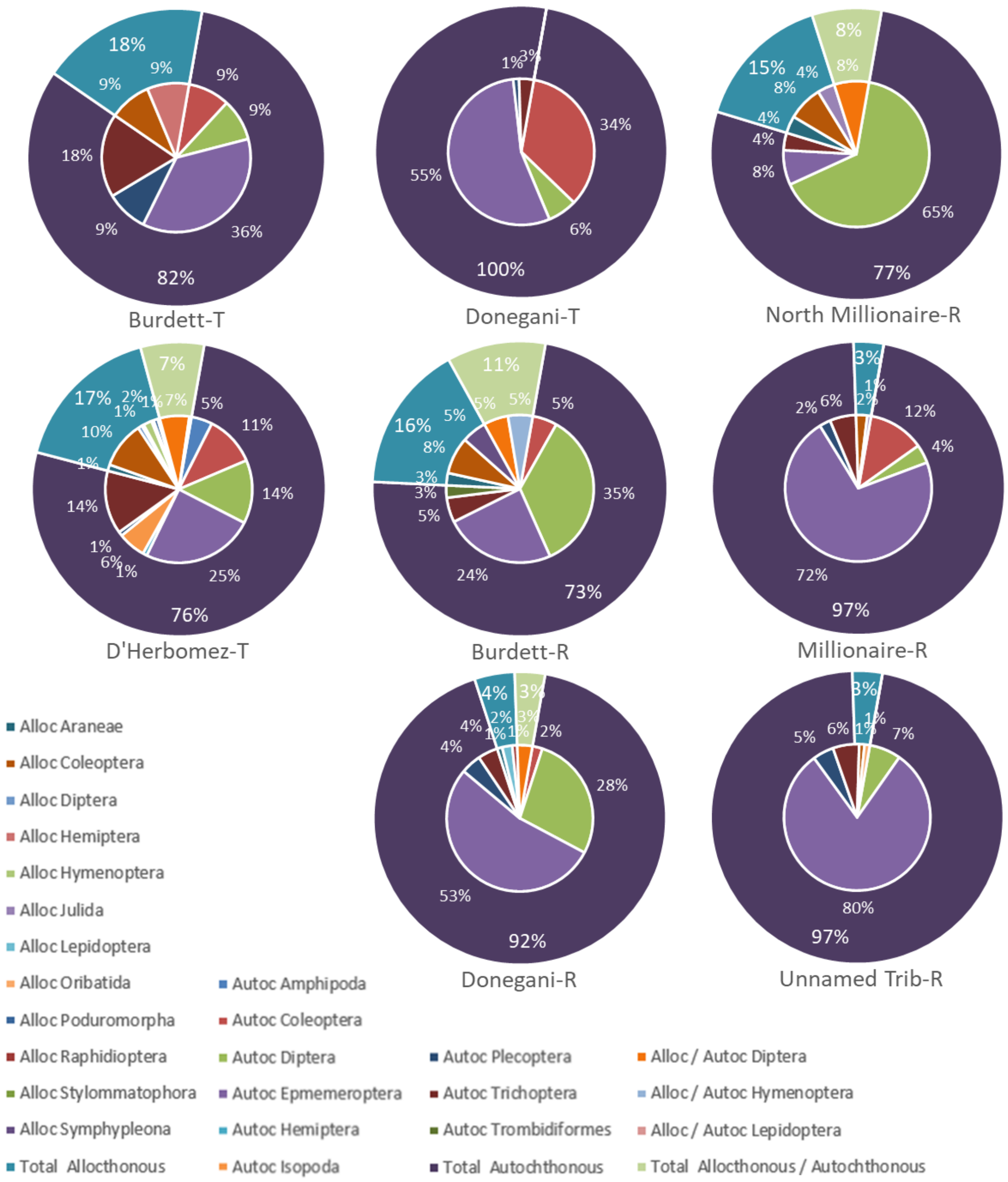
Invertebrate Community Composition and Family Diversity.

The taxonomic composition (to Order) of invertebrates at each site illustrates that D'Herbomez-T had the most diverse composition of invertebrates, whereas Donegani-T had the least diverse composition (Figure 7).

Invertebrate composition was predominantly autochthonous taxa across all eight sites (73 to 100% of all invertebrates captured). *Diptera* were the most abundant autochthonous invertebrates at North Millionaire-R and Donegani-T, whereas *Ephemeroptera* dominated the autochthonous composition at all other sites. *Coleoptera* had the highest composition of allochthonous prey at five of the eight sites. No discernable patterns in the relative ratios of autochthonous and allochthonous invertebrates between test and reference sites were observed.

Figure 7

Percentage of Drifting Invertebrates Captured per Site



Note. Autoc=autochthonous, Alloc=allochthonous. Order level percentages were displayed within the inner circles and the total invertebrate percentages (groupings) were displayed in the outer circles. Orders within the inner circles were lined up within their outer circle groupings. Percentages that are tight to each other consist of a composition < 2 % each. Percentages may not fully equal 100 % as the percent is derived from the exponential scale of the relative abundance, some percentages will be less due to rounding of numbers.

Family diversity was quantified based on the Simpson's Diversity calculation (Barcelona Field Studies Centre, n.d.; Simpson, 1949) (Table 5). Diversity of allochthonous drift for the pooled test sites resulted in a mean Simpson's Diversity of 0.43 (SE ± 0.23) while pooled reference sites had a mean Simpson's Diversity of 0.70 (SE ± 0.05). The Simpson's Diversity of total drift for pooled test sites had a mean of 0.84 (SE ± 0.05) and pooled reference sites had a mean of 0.78 (SE ± 0.04) (Table 5). No significant difference was detected between test sites and reference sites for Simpson's Diversity of allochthonous drift (two-tailed t-test: df = 6, p = 0.19) or total drift (two-tailed t-test: df = 6, p = 0.39).

Table 5

Simpson's Diversity at a Family Level

Measures of Diversity	Test			Reference				
	Burdett-T	Donegani-T	D'Herbomez-T	Burdett-R	Donegani-R	North Millionaire-R	Millionaire-R	Unnamed Trib-R
Allochthonous Drift	0.51	nil	0.79	0.73	0.77	0.75	0.76	0.50
Total Drift	0.80	0.80	0.93	0.84	0.86	0.72	0.85	0.66

Note. nil represents that there were no individuals captured, as a single captured Family would equal 0 within the Simpson's diversity calculation.

Temperature Regulation and Canopy Cover

Riparian temperature loggers were used to confirm whether adjacent instream temperature loggers were dry or not, based on fluctuations in temperature readings (Table 6 and Appendix 2). With dry datasets removed, instream data points could be analyzed (Table 6). Temperatures were graphed in detail within Appendix 2 to illustrate temperature differences at each stream and their adjacent riparian zones, where each comparable data point were graphed on line charts or summarized in mean daily temperatures on strip charts.

Table 6

Analyzable Instream Temperature Data Points

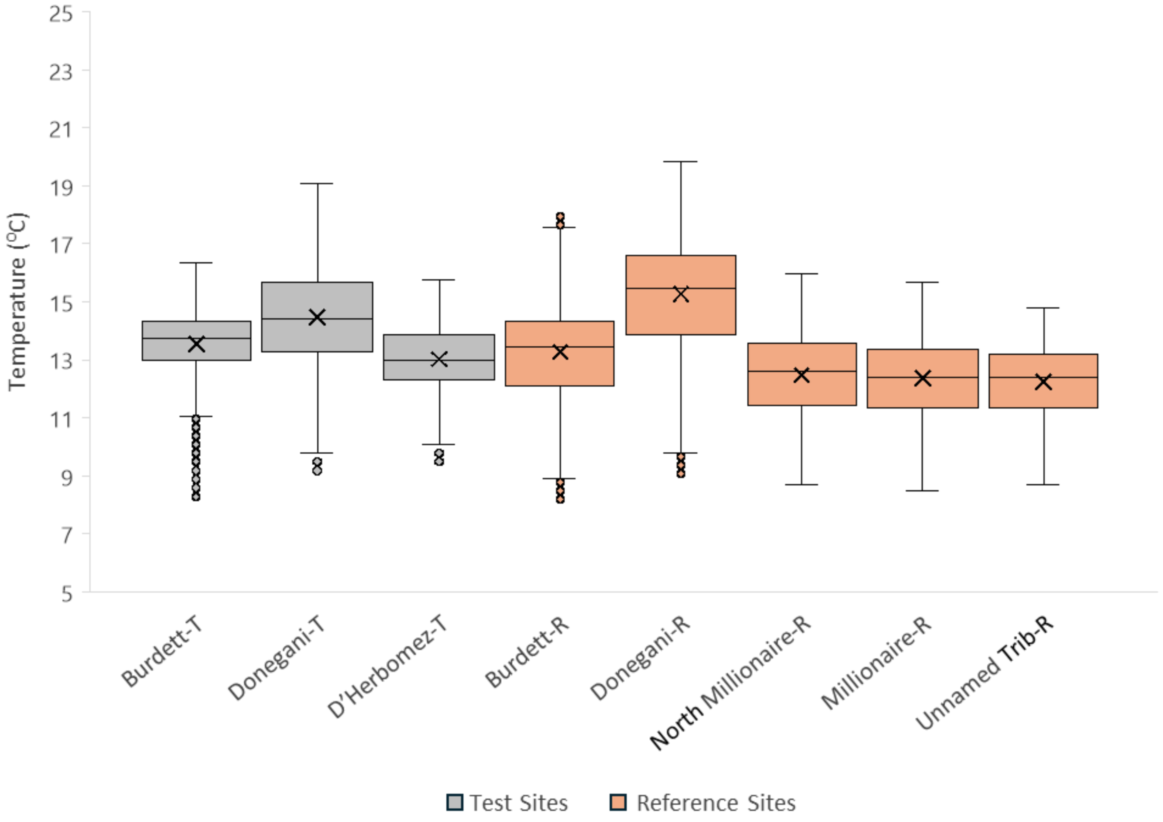
Waterbody	Sites	Analyzed Sampling Period	Number of Data Points per Site
Burdett Creek	Burdett-T and Burdett-R	May 1st – June 2nd, June 9th – June 27th	2,496
Donegani Creek	Donegani-T and Donegani-R	May 5th – May 9th, May 24th – June 29th	2,016
D'Herbomez Creek	D'Herbomez-T	May 1st – June 29th	2,905
Millionaire Creek Watershed	North Millionaire-R, Millionaire-R, and Unnamed Trib-R	May 8th – June 24th	2,304

Instream Temperature Data Analysis.

A box chart was created from a total of 1,344 instream data points per site (10,752 data points for all sites) between May 8th-9th, May 24th-June 2nd, and June 9th-24th (Figure 8). Reference sites averaged cooler temperatures than test sites, apart from the Donegani-R site. The daily mean instream temperature for pooled test site data ($n = 3$) was 13.68 °C (SE ± 0.43) while pooled reference sites ($n = 5$) had a mean instream temperature of 13.13 °C (SE ± 0.56). A difference of 0.55 °C was observed between the average stream temperatures of the test sites and reference sites (Figure 8 & Appendix 2). This is a very small difference in comparison with observed temperature variations between each site. No significant difference between test and reference sites was observed (two-tailed t-test: $df = 6$, $p = 0.52$).

Figure 8

Box Chart of Instream Temperatures



Note. Within this box chart, the min value is the bottom line, the first quartile is the bottom of the box, the median is the line in the middle of the box, the mean is the X within the box, the third quartile is the top of the box, the maximum value is the top line, and the extreme temperature values (outliers) are displayed as dots.

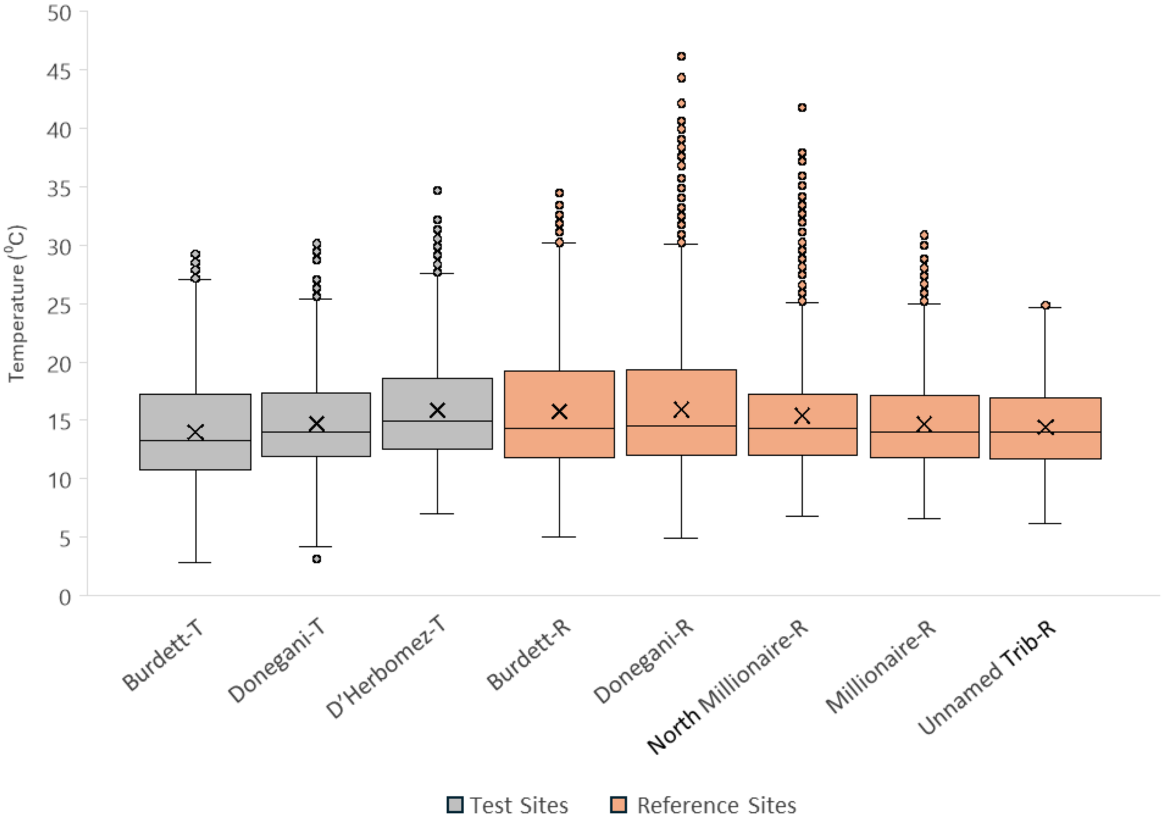
Riparian Temperature Data Analysis.

A box chart of riparian zone temperatures was created from a total of 2,544 data points per site (20,352 data points for all sites) between May 8th and June 29th of 2023 (Figure 9). No discernable patterns in the mean or median riparian temperature between test sites and reference sites were observed. Burdett-T and Donegani-T had the coldest minimum riparian temperature values in comparison to others, at 2.8 °C (Burdett min temp) and 4.0 °C

(Donegani min temp). Unnamed Trib-R had the lowest spread between maximum and minimum temperature values (between 6.2 °C and 24.8 °C) with a single extreme value (25.1 °C) in contrast to all other sites. Pooled mean riparian temperatures within the test sites (n = 3) resulted in a mean of 14.88 °C (SE ± 0.55) while pooled reference sites (n = 5) had a mean riparian temperature of 15.25 °C (SE ± 0.30). In average, reference sites were marginally warmer (0.37 °C) than test sites in riparian temperature (Figure 9 & Appendix 2). Riparian temperatures were not significantly different between the test and reference pooled data sets when analyzed with a t-test (two-tailed t-test: df = 6, p = 0.53).

Figure 9

Box Chart of Riparian Temperatures



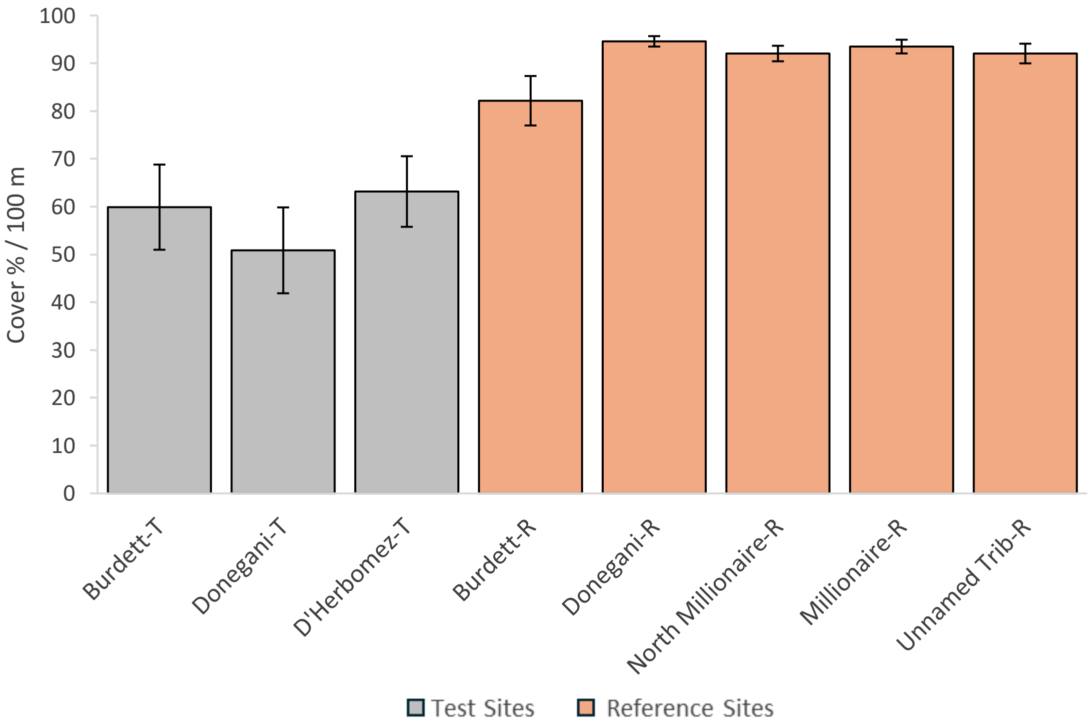
Note. Within this box chart, the min value is the bottom line, the first quartile is the bottom of the box, the median is the line in the middle of the box, the mean is the X within the box, the third quartile is the top of the box, the max value is the top line, and the extreme temperatures values (outliers) are displayed as dots.

Canopy Cover Data Analysis.

Mean percent of canopy cover was determined from the five transect reads at each site with exception of Burdett-T (n = 4) and D'Herbomez-T (n = 3). A greater mean percent canopy cover was observed at reference sites (n = 5; mean = 90.87%; SE ± 2.23) than at test sites (n = 3; 57.97%; SE ± 3.68) (Figure 10). A significant difference in canopy cover was observed between pooled data for test sites and reference sites (two-tailed t-test: df = 6, p = <0.001). On average, test sites provided significantly less cover than reference sites.

Figure 10

Mean Percent Canopy Cover per Site



Note. Confidence intervals illustrate standard error between each sites mean.

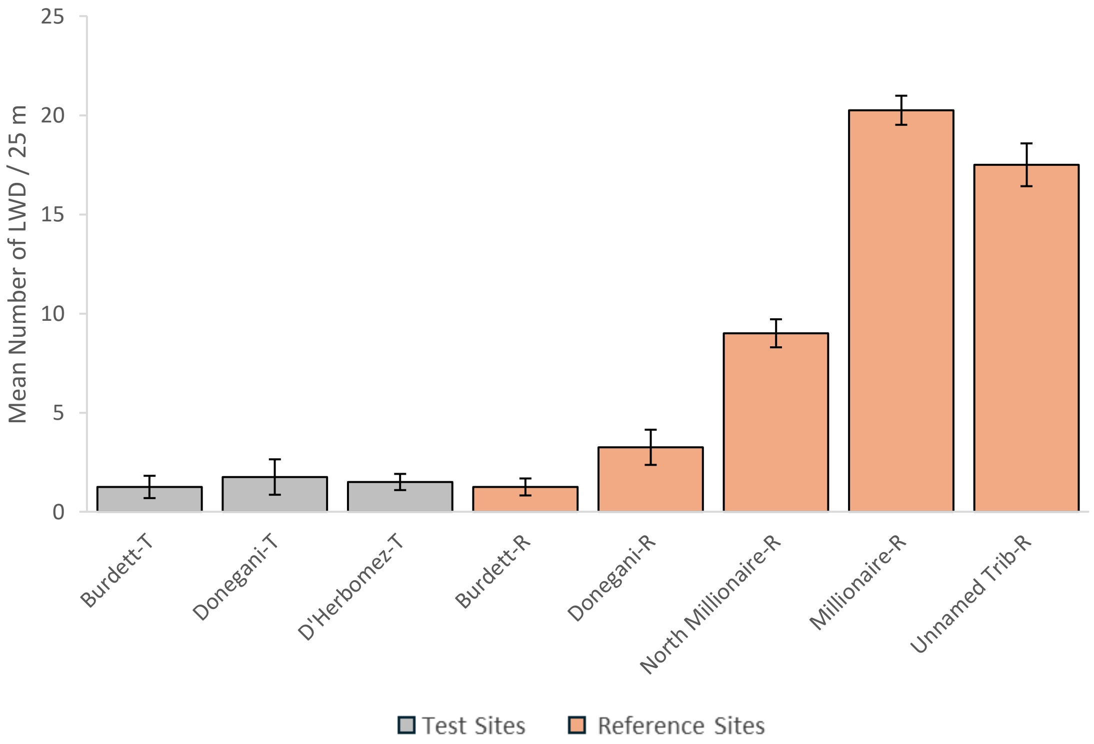
Rearing Habitat

Large Woody Debris Data Analysis.

LWD had a higher density at North Millionaire-R, Millionaire-R, and Unnamed Trib-R in comparison to all other sites, increasing the average or LWD at reference sites (Figure 11). Pooled test site data (n = 3) averaged 1.50 LWD (SE ± 0.14), while pooled reference sites (n = 5) averaged 10.25 LWD (SE ± 3.78). A non-significance between test and reference sites was observed when pooled data were analyzed (two-tailed t-test: df = 6, p = 0.13).

Figure 11

Mean Large Woody Debris Present per Site



Note. Confidence intervals illustrate standard error between each sites mean. Data derived from 220 individual LWD pieces recorded in channel sections (25 m sections) of test sites (n=10) and reference sites (n=20).

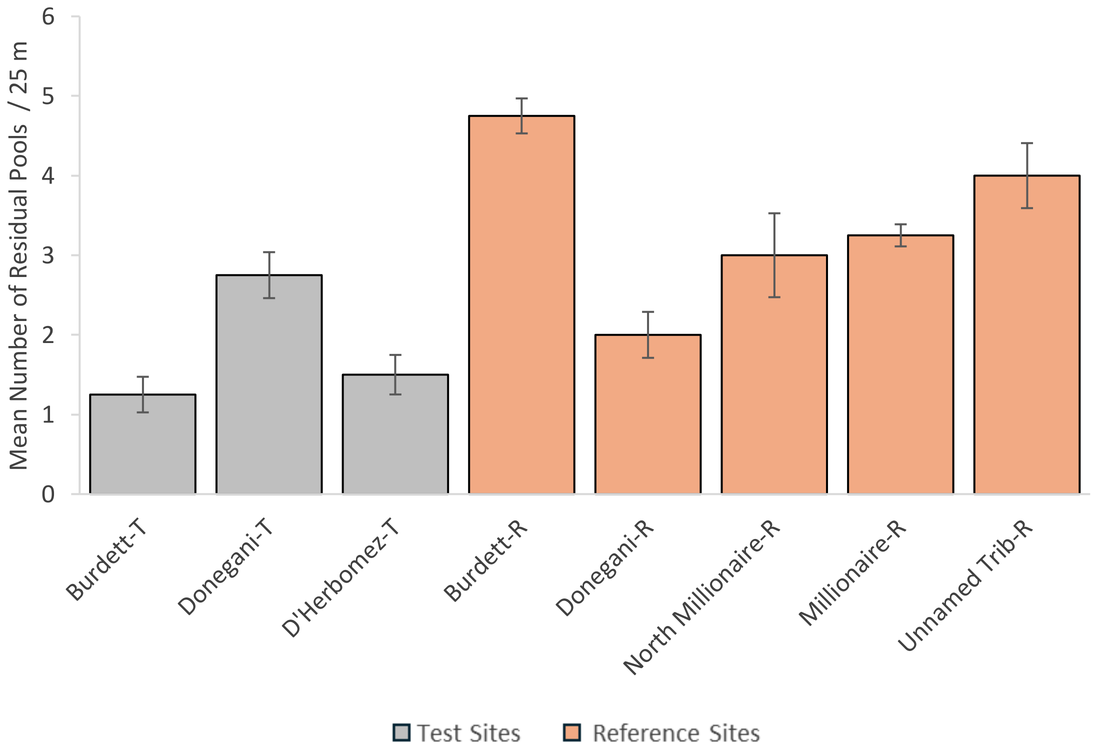
Pool Habitat Data Analysis.

Presence of Residual Pool Habitat.

Mean number of residual pools were higher within Burdett-R and Unnamed Trib-R compared to all other sites (Figure 12). On average, there were 1.8 residual pool habitats (SE ± 0.46) at test sites (n = 3), and 3.4 residual pool habitats (SE ± 0.47) for reference sites (n = 5). A non-significance between test and references site residual pool abundance was observed (two-tailed t-test: df = 6, p = 0.07).

Figure 12

Mean Number of Residual Pool Habitats Present per Site



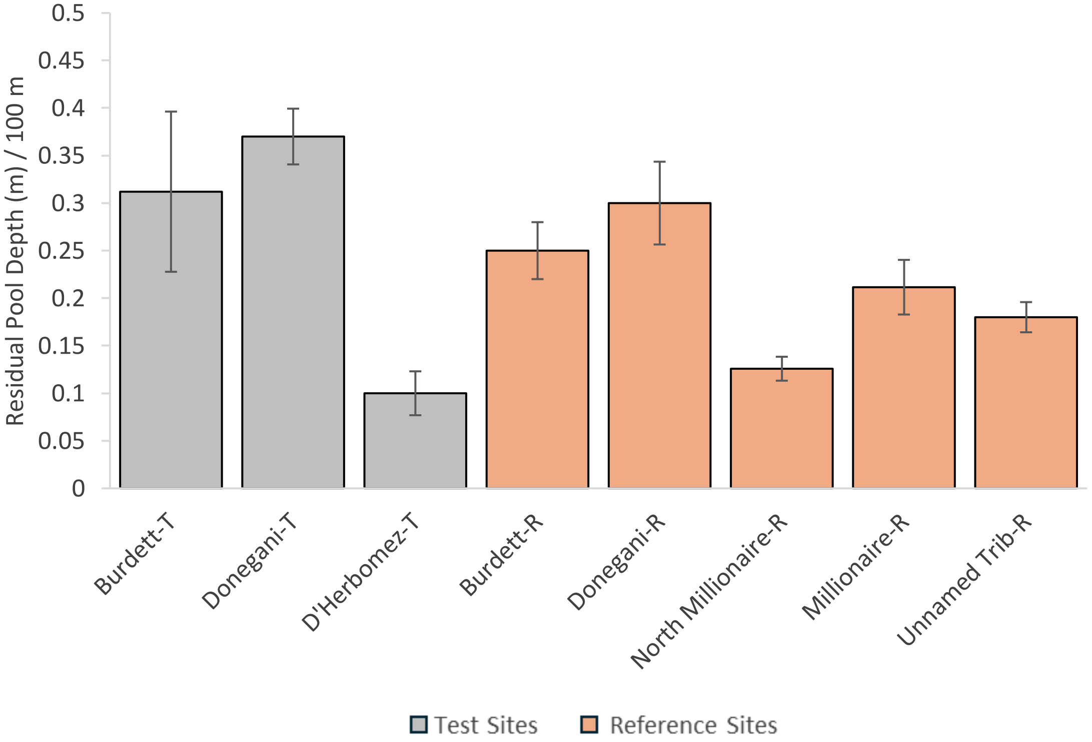
Note. Confidence intervals illustrate standard error between each sites mean. Data derived from 87 individual residual pool habitats recorded in channel sections (25 m sections) of test sites (n=10) and reference sites (n=20).

Depth of Residual Pool Habitat.

The mean depth of residual pool habitats averagely had a greater depth at test sites (0.26 m; SE ± 0.08) compared to reference sites (0.21 m; SE ± 0.03) (Figure 13). A non-significant difference in the depth of residual pool habitats was observed when pooled data of test sites and reference sites were compared (two-tailed t-test: df = 6, p = 0.54).

Figure 13

Mean Depth of Residual Pool habitats per Site



Note. Confidence intervals illustrate standard error between each sites mean. Data derived from 87 individual residual pool habitats from: Burdett-T n=5, Donegani-T n=11, D’Herbomez-T n=3, Burdett-R n=19, Donegani-R n=8, North Millionaire-R n=12, Millionaire-R n=13, Unnamed Trib-R n=16.

Discussion

The results of my study highlighted potential impacts to fish habitat when Himalayan blackberry inundates a riparian zone in the lower mainland of British Columbia. Variability between sites was high, and there was a limited number of sites sampled in this field-based study. In addition, this study was conducted during a year that was dissimilar to the majority of years with regard to watershed hydrology and temperatures. A record-breaking drought occurred throughout the summer of 2023, which resulted in 80% of the streams in BC having lower than average water levels and some smaller channels drying out (Freshwater Fisheries Society of BC, n.d.; Government of BC, n.d.b). Factors leading up to the 2023 drought included but were not limited to: previous drought conditions (2022), record breaking heat waves in May, and lower than average precipitation in June-July which diminished the snowpack for the region (Freshwater Fisheries Society of BC, n.d.; Government of BC, n.d.b). Outcomes within my report were based on the current conditions of those sample sites during late spring/early summer (May 1st to June 29th) of 2023.

My findings aligned with historical literature, supporting the negative impacts to fish habitat from riparian zones inundated with Himalayan blackberry. The findings of my study confirmed differences between native riparian habitat and habitat invaded with Himalayan blackberry in the canopy cover fish habitat quality indicator variable; however, no significant differences were found in invertebrate drift (allochthonous and total), instream temperatures, riparian temperatures, LWD abundance, residual pool abundance, and residual pool depth.

Canopy cover was significantly higher at reference sites compared to sites inundated with Himalayan blackberry, with the highest cover observed in sites comprised of mixed forest and coniferous forest riparian zones (Figure 10 & Table 2). These results were anticipated, as the disturbance of forested riparian areas with naturally high canopy cover is often a precursor to the establishment of Himalayan blackberry invasions. Also, the inundation of Himalayan blackberry along with other weeds are known to stunt or inhibit the seral staged growth of young or disturbed forests and riparian zones (Fierke & Kauffman, 2006), keeping them in a shrub or grass dominated habitat. These results may be due in part to the inundation of Himalayan blackberry or due to the natural reach habitat of the stream (open shrub dominated habitat). Burdett-R was the only reference site to have similar riparian reach habitat characteristics to the test sites (Table 2) and provided more canopy cover in comparison to each test site (Figure 10), suggesting that the inundation of Himalayan blackberry may be the cause of lower canopy cover compared to natural vegetation in similar reaches of a stream.

Instream temperatures were not statistically different between test sites and reference sites, while temperatures of test sites, that were typically located lower in watercourses in comparison to reference sites, were observed to be 0.55°C warmer than reference sites. A lack of a significant difference may be due in part to the small sample size, or other factors such as the natural warming of stream temperatures from atmospheric conditions as streams pass further down their watersheds (Poole & Berman, 2001). Removal of or other impacts to a riparian zone, however, are known to have an effect on instream temperatures when both overhead canopy cover and instream complexity (including hyporheic flow) are reduced (Poole & Berman, 2001). Instream temperatures were observed to be the coolest at sites located in the oldest seral staged riparian zones (North Millionaire-R, Millionaire-R, and Unnamed Trib-R; Figure 8), which had higher canopy cover (Figure 10) and instream complexity abundance (Figure 11, Figure 12), suggesting that an inundation of Himalayan blackberry may have some impact on instream temperatures if a riparian zone is arrested from further seral development.

Inaccuracies with the Donegani-R instream temperature logger may have occurred, as instream temperatures were found to be warmer in comparison to Donegani-T, which is not typical as Donegani-T was located 600 m downstream from Donegani-R (Figure 2). Field temperature measurements conducted at each site indicated an inconsistency at Donegani-R, since this site had an instream temperature of 12.3 °C using the Hanna meter and 12.8 °C with the instream logger at 10:30 am on May 24, 2023 (Table 2 and Appendix 2). The discrepancy in Donegani-R logger data may have been due to the placement of the logger within the channel as it was found to be on the margin of the stream when it was pulled at the end of June. Low water levels in the summer of 2023 may have explained higher logger temperatures at Donegani-R with this placement, whereas the logger at Donegani-T was placed in the thalweg which was deeper and likely cooler. Proper placement of Donegani-R tidbit potentially could have resulted in observing a greater difference between test and reference site (>0.55 °C). Though statistically significant differences were not detected, the majority of the reference sites were slightly cooler than the test sites.

The presence of LWD habitat and residual pool habitats did not significantly differ between test and reference sites; however reference sites exhibited higher numbers of LWD and residual pools on average in comparison to sites inundated with Himalayan blackberry. These findings may be due to the Himalayan blackberry inundation, or due to natural reach habitat variation (shrub dominant open areas). Burdett-R had different instream morphology in comparison to all other sites indicating a direct comparison of residual pools may not be suitable. Burdett-R did have similar riparian reach characteristics to the rest of the study sites, supporting a reasonable comparison of LWD between sites (Table 2, Figure 4). No LWD differences between Burdett-R and each test site were found (Figure 11).

The higher LWD and residual pool presence at the reference sites in my study likely reflect the later seral stage of the natural riparian zones, potentially providing greater amounts of rearing habitat from fallen branches or trees (Figure 11, Figure 12). Due to the ability of Himalayan blackberry to arrest seral stage succession in a riparian zone (Fierke & Kauffman, 2006), the influence of Himalayan blackberry on these two fish rearing habitat indicators is likely to be long-term. It is expected that Himalayan blackberry, once established, will prevent a riparian zone from maturing beyond a shrub dominated stage, limit LWD input into the wetted channel, and reduce residual pool production, thereby decreasing instream habitat complexity for rearing fish in the form of cover or pools, which are considered important habitats (Heifetz et al., 1986, as cited in Smokorowski & Pratt, 2006; Roni & Quinn, 2001).

The average depth of residual pool habitat was observed to be greater in test sites than reference sites; however, the differences in averages was not significantly different between test and reference sites. The average differences in depth might be attributable to substrate texture (Figure 4), water volume (Table 2), freshet velocities, and/or the small sample size of this project. Test sites were located at lower elevations in their watersheds than reference sites; therefore, it was expected that a larger seasonal and annual stream discharge would occur at the test sites in comparison to reference sites. As shown in Table 2, test sites (n=3) had an average volumetric flow of 0.08 m^3/s (4.5 m^3/hr) whereas reference sites (n=5) had and average volumetric flow of 0.03 m^3/s (2.0 m^3/hr). Deeper pools can aid in fish survival, but fewer pools, specifically fewer pools with smaller amounts of LWD associated with them, can have implications for rearing fish habitat (Roni & Quinn, 2001).

No significant differences in riparian temperatures were observed between reference sites and test sites. A lack of warmer air temperature at the ground level of the test sites was not surprising, as an inundation of Himalayan blackberry is known to produce nearly 100% cover that can attenuate solar radiation at the ground level (Gaire et al., 2015). In addition, black housing PVC used to protect the loggers and reduce vandalism due to it being more camouflaged, may have masked potential temperature differences between sites, as black PVC has been shown to retain more heat from solar radiation compared to lighter colours (Mauger et al., 2014). Depending on dominant cover present at each site, the PVC housing may have been more or less influenced by solar radiation (Figure 9, Appendix 2, Table 7).

The average temperature observed in the riparian zones with notably different canopy covers (Table 7) was compared to evaluate weather solar radiation that penetrated the ground level of the forest floors, differed in response to differences in dominant riparian zone vegetation. The degree of which warmer temperatures would be recorded by the temperature loggers was expected to reflect the extent to which unfiltered and filtered sunlight penetrates the canopy. On average, riparian temperatures were lower in coniferous dominated sites but higher in mixed forest and natural shrub when compared to Himalayan blackberry dominated test sites. Overall, the ground temperatures at the Himalayan blackberry sites were similar to a mature coniferous riparian zone, whereas natural shrub and mixed forest sites were roughly one degree warmer. Mixed forest dominated reference sites (Donegani-R and North Millionaire-R) had the most frequent extreme high temperatures (Figure 9). The natural shrub dominated riparian zone (Burdett-R) was anticipated to be warmer than the other reference sites as it has not developed a large tree canopy cover; however, it was not anticipated that it would be within a tenth of a degree of the mixed wood dominated riparian zones. This small difference may have been influenced by the slope aspect of the single shrub dominated reference site. It is anticipated that the inclusion of more study sites would have resulted in observing higher ground-level solar radiation on average for naturally shrub dominated riparian zones with lower variability. All three Himalayan blackberry sites were located on differing slope aspects (Table 2), consequently the riparian mean temperature of the test sites showed less variability than each of the differing dominated riparian habitats of the reference sites (Table 7), suggesting that Himalayan blackberry blocks solar radiation to the ground similarly on differing aspects of slope.

Table 7

Mean Riparian Temperature (^{o}C) of Dominant Riparian Habitats

Dominant Riparian Habitat	Mean temperature (^{o}C)	Standard error (+/-)	Mean Canopy Cover (%)	Standard error (+/-)
Test – Shrub	14.88	0.19	56.95	8.10
Reference – Shrub	15.77	0.35	82.16	7.94
Reference – Mixed Forest	15.68	0.25	93.32	0.74
Reference – Coniferous Forest	14.57	0.23	92.77	1.72

Note. Test - shrub were averaged from the daily mean temperatures from Burdett-T, Donegani-T, and D’Herbomez-T (n= 159). Reference – shrub was averaged from the daily means at Burdett-R (n=53). Reference – mixed forest was averaged from the daily means from Donegani-R and North Millionaire-R (n=106). Reference – coniferous was averaged from the daily means from Millionaire-R and Unnamed Trib-R (n=106).

Several comparisons between invertebrate abundance, family richness, and diversity of the two drifting invertebrate groups (allochthonous drift and total drift) between test sites and reference sites were conducted. No significant differences between test and reference sites were detected on any of these biotic fish health indicators, suggesting that Himalayan blackberry establishment at the test sites did not negatively impact invertebrate input overall, or there was too few of sites to accurately determine a difference.

Though other studies have not directly compared drifting invertebrate impacts from Himalayan blackberry, there were some similarities between the findings described herein and those of Kennedy and El-Sabaawi (2018), and Wipfli (1997). Kennedy and El-Sabaawi (2018) showed no significant difference between autochthonous invertebrate abundance and diversity when urban streams (which were littered with garbage, Himalayan blackberry leaves, leaves of other weeds, and leaves of natural vegetation) were compared to rural streams in Victoria BC (which were primarily made up of natural leaf litter). My study illustrated similar findings to Kennedy and El-Sabaawi (2018); i.e., no significant difference between test sites and reference sites when comparing total drifting abundance and total drifting diversity. This further suggests that the abundance and diversity of autochthonous or total drifting invertebrate abundance do not differ between sites that have a riparian zone inundated with Himalayan blackberry compared to sites that have a riparian zone made up of natural vegetation.

A study completed by Wipfli (1997), indicated that young forested riparian zones (<30 years of age) were associated with significantly higher abundances of allochthonous invertebrates within the stomach contents of coastal cutthroat trout (*Oncorhynchus clarki clarki*) in comparison with old growth / mature riparian zones (coniferous riparian zones). However, no significant difference in allochthonous invertebrate abundance was observed in the Wipfli (1997) study when analyzing allochthonous prey abundance obtained using sticky floating traps. Assuming that Himalayan blackberry invasion in a riparian zone also reflects an immature riparian forest stage, my study similarly showed no significant differences between sites inundated with Himalayan blackberry and older successional forest stages of riparian areas in the abundance of allochthonous invertebrates captured in drift traps, even when additionally comparing each dominant riparian habitat to one another (for all two-tailed t-tests, $p \geq 0.59$; Table 8). Wipfli (1997) predicted that a similar result between their traps and coastal cutthroat trout stomach content could have been achieved if they sampled more trap sites (n=6). The few sites sampled within my study (n=8) as well as the high variability between riparian habitat types may have reduced statistical power to detect a significant effect if one existed. Though my results did not provide clear evidence of a statistically significant difference in the abundance of drifting allochthonous invertebrates, a higher mean abundance of allochthonous prey is suggestive at the Himalayan blackberry sites (Table 4, Appendix 1, Figure 5, Table 8).

Table 8

Mean Abundance of Allochthonous Invertebrate drift per Dominant Riparian Habitats

Dominant Riparian Habitat	Mean Abundance (m^3/hr)	Standard error (+/-)
Test – Shrub	0.034	0.032
Reference – Shrub	0.025	N/A
Reference – Mixed Forest	0.025	0.021
Reference – Coniferous Forest	0.011	0.001

Note. Test shrub (n=3), reference shrub (n=1), reference mixed forest (n=2), reference coniferous forest (n=2). Reference – shrub invertebrate data were obtained from only one site (Burdett-R). Thus, it was not possible to estimate a standard error off the mean.

Several aspects of this study may have contributed to the observed high between-site variability of my invertebrate drift measurements, including low sample size (relatively few study sites and biotic sampling on one occasion for each site), fish presence, or an unexpected high abundance of invertebrates observed from one site (D'Herbomez-T). As seen in Table 2, Table 4, and Appendix 1, D'Herbomez-T had the highest conductivity (198 µs/cm) and had higher diversity of invertebrate families than all other sites, making it the most productive site for invertebrates within this study. Higher conductivity, between 50-1500 µs, is commonly known to increase invertebrate productivity within a waterbody (Atlas Scientific, 2025; Krueger & Waters, 1983); conductivity is a measure of ionic particles present in a waterbody, this measure indicates if external sources enter a waterbody when there is a notable difference in conductivity (Atlas Scientific, 2025; US Environmental Protection Agency [US EPA], 2013). Potential sources contributing to the elevated conductivity at D'Herbomez-T may include nearby anthropogenic disturbances (municipal park upstream, it being downstream of a homeless encampment, being adjacent to a municipality), or the sites close proximity to the Fraser River.

A *post-hoc* Ephemeroptera, Plecoptera, and Trichoptera (EPT) Index calculation was conducted in an effort to determine if anthropogenic disturbances were driving higher invertebrate productivity in D'Herbomez Creek (Table 9). The EPT Index can be used to determine if the local ecosystem is stressed by anthropogenically driven issues that decrease water or substrate quality, as Ephemeroptera, Plecoptera, and Trichoptera Orders are known as aquatic bio-indicators of disturbance from anthropogenic related inputs (Usable Freshwater Center [UFC], n.d.). The EPT index revealed that D'Herbomez-T had the lowest EPT index in comparison to other test sites. The index, however, was in a similar range to some of the reference sites (Burdett-R, and North Millionaire-R): No significant difference was observed between the mean EPT index of test sites (0.63 EPT index, SE (±) 0.08) to reference sites (0.60 EPT index, SE (±) 0.14) (two-tailed t-test: df = 6, p = 0.88). Though an analysis of an EPT index illustrated D'Herbomez did not impact the findings of this study, it is still anticipated that the higher conductance at the site may have influenced the results for the small number of sample sites that were analyzed. It is anticipated that a study with more sites could potentially illustrate a different result in invertebrate drift with higher probabilities.

Table 9

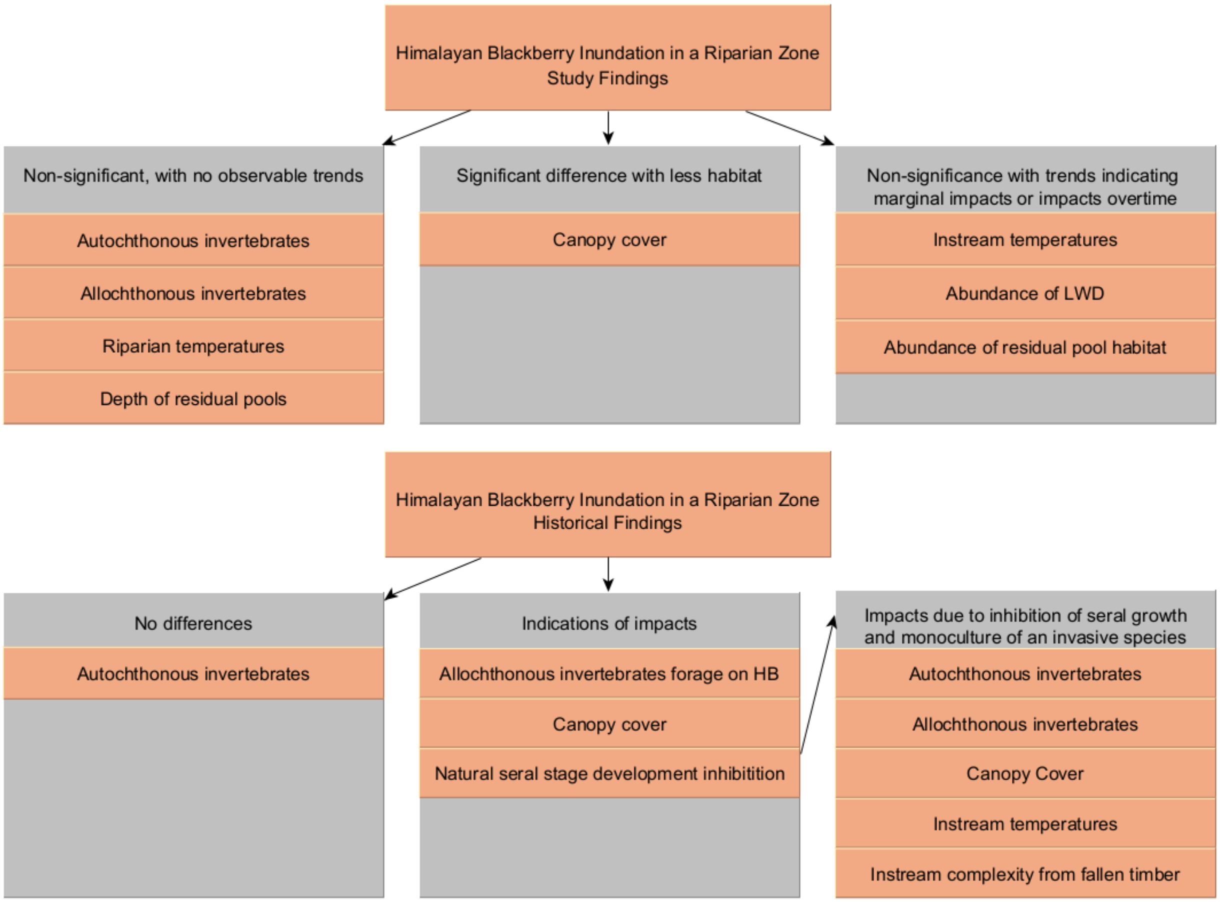
EPT Index of Autochthonous Drift

Site	EPT Index
Burdett-T	0.78
Donegani-T	0.59
D'Herbomez-T	0.52
Burdett-R	0.41
Donegani-R	0.67
North Millionaire-R	0.15
Millionaire-R	0.83
Unnamed Trib-R	0.93

Limited findings from this study and other studies suggest that fish habitat quality can be impacted by Himalayan blackberry invasion of a riparian zone (Figure 14). Though the number of observation sites was small in this study, insights from previous studies help to provide a coherent conceptual model of riparian area invasion by Himalayan blackberry. The larger set of site observations from this study are aligned with conclusions by other researchers, that there is increased risk of longer-term negative effects on fish habitat quality, especially when an invasive weed creates a monoculture and inhibits seral growth of a riparian zone.

Figure 14

Conceptual map of Difference Found Within this Study and in Historical Information



Note: Historical information derived from: Baxter et al. (2005), Fierk and Kauffman (2006), Gaire et al. (2015), Kennedy and El-Sabaawi (2018), McDowell (2002), Richardson et al. (2007), Twining et al (2019).

As this was a site-based study, a thorough reconnaissance was completed to ensure sites were as similar as possible, with an intention to sample sites with fewer anthropogenic disturbances (Table 1). Test sites with less anthropogenic disturbance proved difficult to find as Himalayan blackberry grows well in disturbed areas, specifically near recent anthropogenic disturbances (Gaire et al., 2015). All three test sites were anthropogenically disturbed, being either upstream or downstream of a culvert crossing of a roadway, within or up to 100 m away.

To ensure that reference sites had similar habitat characteristics to test sites (including anthropogenic disturbances), all 5 reference sites were close to trails or were within 200m of a road. All eight sites were well established in their vegetative dominance / growth and stream characteristics, and no recent anthropogenic or natural disturbances (e.g., flood damage) were observed, with the exception to the previously noted homeless encampment found at D'Herbomez-T. In contrast to the disturbances observed in the vicinity of the D'Herbomez-T site, all other sites exhibited low disturbances. The majority of the variables that may have impacted my findings were documented within the habitat data tables and figures (Table 2 and Figure 4).

Drought conditions during my study impacted stream levels and water temperatures. Stream levels, in particular, are expected to influence the quantity of invertebrate drift (prey for fish) within the flowing channel. The North Millionaire-R site had the lowest velocity and stream discharge, and also the lowest total drift abundance compared to all other sites, which may have impacted its EPT index in Table 9. Other factors that potentially influenced the abundance of drifting invertebrate prey between sites may include abundance of fish per site, elevation of sites, and the aspect of the stream (Table 2 and Figure 4). This study evaluated habitat and invertebrate drift in a short section of each stream, it is anticipated that more sites per stream could have augmented the dataset for drifting invertebrates.

When temperature loggers were pulled at the end of June, instream sites were visually observed to have been impacted from the drought. Burdett-T, Burdett-R, and North Millionaire-R went completely dry, whereas Donegani-R and Unnamed Trib-R were nearly dry with some flow. While, Millionaire-R and Donegani-T had considerably lower than normal water levels, and D'Herbomez-T did not visually change in flow throughout the study. The minimal flow reduction observed at D'Herbomez-T suggests the stream has a strong groundwater influence, whereas all other channels may have been more influenced by surface water inputs.

Conclusion and Recommendations

The aim of this study was to provide information that may assist environmental managers when considering sites inundated with Himalayan blackberry for enhancement opportunities. Information from this thesis indicates that some fish habitat quality indicator variables were adversely impacted in riparian zones dominated by Himalayan blackberry, while other fish habitat indicator variables were not. As this project was a site-based assessment, variability between sites and between pooled data sets were high in some of the analyzed results. Habitat differences between sites and pooled data sets were carefully documented to understand the variables that may have influenced the relevant fish habitat quality indicators. The conclusion provided in this thesis is a result from the data collected from these specific sites in 2023, which may or may not be adequately representative of other sites or other time periods.

The results of this study suggest that there is a significant increase in canopy cover at sites where riparian habitat is made up of native vegetation. Allochthonous drifting invertebrate abundance and diversity, total drifting invertebrate abundance and diversity, instream temperatures, riparian temperatures, natural LWD habitat, number of residual pools and depth of residual pools did not differ significantly between test and reference sites. Trends in LWD presence, and residual pool abundance, though not significantly different between test and reference sites, suggest that sites made up of natural vegetation, specifically sites made up of later staged riparian zones, produce better quality fish habitat than sites inundated with Himalayan blackberry. In the absence of intervention, Himalayan blackberry invasion could inhibit the natural seral growth of a riparian zone, and riparian vegetation community succession over very long time periods. On this scale of time, Himalayan blackberry's impact to overhead canopy cover and instream complexity would additionally alter instream temperatures, as temperature regulation provided from riparian zone cover and complexity as hyporheic flow (or local base flow) would decrease with the extent and duration of Himalayan blackberry invasion. The temperature change associated with arrested succession of the invaded riparian zone in an early stage is estimated herein to be very small; however, the effect would be present.

The findings from this study should be considered in context to similar studies when environmental managers are assessing sites inundated with Himalayan blackberry for habitat enhancements. Fierke and Kauffman (2006) and Gaire et al (2015) found that if Himalayan blackberry (in association with reed canary grass) is left unchecked it will impede the natural seral growth of a riparian zone. My study extends their findings, by demonstrating that other riparian habitat features such as over head canopy cover and rearing habitat for fish can be negatively impacted if the invasion of Himalayan blackberry is left unchecked.

Enhancements to sites inundated with Himalayan blackberry are likely to improve in instream temperature regulation, canopy cover, and instream complexity when a riparian zone is restored to its natural vegetation and allowed to mature. Further research is recommended to determine additional benefits when an inundated riparian zone from one of the world's most invasive angiosperm weeds (Himalayan blackberry) is restored to its natural condition.

This study found a statistically significant difference between three Himalayan blackberry invaded sites and five reference sites for only one fish habitat value: canopy cover. Nonetheless, it is recommended that further studies be completed with more sites to better tease out any effects of Himalayan blackberry on invertebrate drift. Similar to a recommendation made from Wipfli (1997), environmental managers should promote allochthonous invertebrate drift monitoring in conjunction with autochthonous aquatic invertebrate monitoring when conducting environmental assessments to better understand the aquatic-riparian connections of those sites.

When environmental managers are considering work in the lower mainland of BC, it is noted that disturbed sites will most likely become inundated with Himalayan blackberry if not properly managed or monitored overtime. Specifically, if management or monitoring is not done in the early stage of riparian growth, as Himalayan blackberry can easily out compete other vegetation. It is recommended that mitigations be taken to ensure that monitoring and control of invasive species such as Himalayan blackberry be conducted up to the mixed forest stage of a riparian zone. Where possible, it is recommended that black cottonwood be planted in restored riparian zones to assist in riparian seral stage growth due to its fast-growing properties and its ability to provide ongoing instream complexity via fallen branches.

Due to Himalayan blackberry seed (berry) dispersal from wildlife, humans and floods (Gaire et al, 2015), it is anticipated that recently disturbed areas may potentially be invaded by Himalayan blackberry specifically if this plant is already identified near or upstream of a site. When remediating or offsetting sites that are inundated with Himalayan blackberry or are downstream of a Himalayan blackberry invasion, it is recommended that riparian habitat enhancements be of a larger proportion, as Himalayan blackberry has a high chance of re-establishment on the margins of the enhancements, decreasing the remediation or offsetting value.

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APPENDIX 1

Drift Invertebrate Composition and Abundance Data

Appendix 1.1

Invertebrate Abundance (m^3/hr), Total Invertebrate Drift per Site

Habitat	Order	Family	Test sites			Reference Sites					Grand Total
			Burdett-T	Donegani-T	D'herbomez-T	Burdett-R	Donegani-R	North Millionaire-R	Millionaire-R	Unnamed Trib-R	
Autoc[a] (Aquatic)	*Amphipoda*	*Gammaridae*	-	-	$2.73E^{-02}$	-	-	-	-	-	$2.73E^{-02}$
		Total	-	-	$2.73E^{-02}$	-	-	-	-	-	$2.73E^{-02}$
	Coleoptera	*Coccinellidae*	-	-	-	$4.17E^{-03}$	-	-	-	-	$4.17E^{-03}$
		Dytiscidae	$2.47E^{-03}$	-	-	$4.17E^{-03}$	-	-	-	-	$6.64E^{-03}$
		Elmidae	-	$7.20E^{-02}$	$5.45E^{-02}$	-	$8.92E^{-04}$	-	$1.53E^{-02}$	-	$1.43E^{-01}$
		Haliplidae	-	-	$5.45E^{-03}$	-	-	-		-	$5.45E^{-03}$
		Hydraenidae	-	-	-	-	-	-	$7.64E^{-03}$	-	$7.64E^{-03}$
		Hydrophilidae	-	$7.50E^{-03}$	$5.45E^{-03}$	-	-	-	$1.27E^{-02}$	-	$2.57E^{-02}$
		Lampyridae	-	-	-	-	-	-	$2.55E^{-03}$	-	$2.55E^{-03}$
		Melyridae	-	-	-	-	$8.92E^{-04}$	-		-	$8.92E^{-04}$
		Total	$2.47E^{-03}$	$7.95E^{-02}$	$6.54E^{-02}$	$8.34E^{-03}$	$1.78E^{-03}$	-	$3.82E^{-02}$	-	$1.96E^{-01}$
	Diptera	*Ceratopogonidae*	-	-	-	-	-	$1.16E^{-02}$	-	$1.25E^{-02}$	$2.41E^{-02}$
		Chironomidae	$2.47E^{-03}$	$1.20E^{-02}$	$6.27E^{-02}$	$5.00E^{-02}$	$2.14E^{-02}$	$3.47E^{-02}$	$7.64E^{-03}$	$2.50E^{-02}$	$2.16E^{-01}$
		Dixidae	-	$1.50E^{-03}$	$1.64E^{-02}$	-	$8.92E^{-04}$	$1.50E^{-01}$	$5.09E^{-03}$	-	$1.74E^{-01}$
		Dolichopodidae	-	-	$2.73E^{-03}$	-	-	-	-	-	$2.73E^{-03}$
		Simuliidae	-	$1.50E^{-03}$	-	-	-	-	-	-	$1.50E^{-03}$
		Tipulidae	-	-	-	$4.17E^{-03}$	-	-	-	-	$4.17E^{-03}$
		Total	$2.47E^{-03}$	$1.50E^{-02}$	$8.18E^{-02}$	$5.42E^{-02}$	$2.23E^{-02}$	$1.97E^{-01}$	$1.27E^{-02}$	$3.75E^{-02}$	$4.23E^{-01}$
	Ephemeroptera	*Ameletidae*	-	$4.35E^{-02}$	$2.73E^{-03}$	-	$7.13E^{-03}$	$1.16E^{-02}$	$1.02E^{-01}$	$6.87E^{-02}$	$2.35E^{-01}$
		Baetidae	-	$5.70E^{-02}$	$5.45E^{-03}$	$8.34E^{-03}$	$1.07E^{-02}$	$1.16E^{-02}$	$3.31E^{-02}$	$5.00E^{-02}$	$1.76E^{-01}$
		Ephemerellidae	-	-	$7.63E^{-02}$	-	$5.35E^{-03}$	-	$3.05E^{-02}$	$6.25E^{-03}$	$1.18E^{-01}$
		Heptageniidae	-	$1.20E^{-02}$	$5.45E^{-02}$	$2.92E^{-02}$	$3.57E^{-03}$	-	$2.80E^{-02}$	$6.25E^{-03}$	$1.34E^{-01}$
		Leptophlebiidae	$9.89E^{-03}$	$1.35E^{-02}$	$2.73E^{-03}$	-	$1.52E^{-02}$	-	$2.55E^{-02}$	$3.00E^{-01}$	$3.67E^{-01}$
		Unid-E1	-	-	-	-	$8.92E^{-04}$	-	-	-	$8.92E^{-04}$

Habitat	Order	Family	Test sites			Reference Sites					Grand Total
			Burdett-T	Donegani-T	D'herbomez-T	Burdett-R	Donegani-R	North Millionaire-R	Millionaire-R	Unnamed Trib-R	
		Unid-E2	-	-	$2.73E^{-03}$	-	-	-	-	-	$2.73E^{-03}$
		Unid-E3	-	-	-	-	-	-	$2.55E^{-03}$	-	$2.55E^{-03}$
		Total	$9.89E^{-03}$	$1.26E^{-01}$	$1.45E^{-01}$	$3.75E^{-02}$	$4.28E^{-02}$	$2.31E^{-02}$	$2.21E^{-01}$	$4.31E^{-01}$	1.04E
	Hemiptera	*Gerridae*	-	-	$5.45E^{-03}$	-	-	-	-	-	$5.45E^{-03}$
		Total	-	-	$5.45E^{-03}$	-	-	-	-	-	$5.45E^{-03}$
	Isopoda	*Asellidae*	-	-	$3.54E^{-02}$	-	-	-	-	-	$3.54E^{-02}$
		Total	-	-	$3.54E^{-02}$	-	-	-	-	-	$3.54E^{-02}$
	Plecoptera	*Chloroperlidae*	-	$3.00E^{-03}$	$5.45E^{-03}$	-	$3.57E^{-03}$	-	-	-	$1.20E^{-02}$
		Nemouridae	$2.47E^{-03}$	-	-	-	-	-	$7.64E^{-03}$	-	$1.01E^{-02}$
		Perlodidae	-	-	-	-	-	-	-	$2.50E^{-02}$	$2.50E^{-02}$
		Total	$2.47E^{-03}$	$3.00E^{-03}$	$5.45E^{-03}$	-	$3.57E^{-03}$	-	$7.64E^{-03}$	$2.50E^{-02}$	$4.71E^{-02}$
	Trichoptera	*Brachycentridae*	-	-	$5.45E^{-03}$	-	-	-	-	-	$5.45E^{-03}$
		Glossosomatidae	-	-	$1.36E^{-02}$	-	-	-	-	-	$1.36E^{-02}$
		Hydropsychidae	-	-	$2.18E^{-02}$	-	-	-	$2.55E^{-03}$	-	$2.44E^{-02}$
		Lepidostomatidae	-	-	$1.36E^{-02}$	-	-	$1.16E^{-02}$	$1.27E^{-02}$	$6.25E^{-03}$	$4.42E^{-02}$
		Limnephilidae	-	$7.50E^{-03}$	$8.18E^{-03}$	-	-	-	$2.55E^{-03}$	-	$1.82E^{-02}$
		Philopotamidae	-	-	$1.64E^{-02}$	-	$3.57E^{-03}$	-	-	$2.50E^{-02}$	$4.49E^{-02}$
		Polycentropodidae	$4.94E^{-03}$	-	-	$8.34E^{-03}$	-	-	-	-	$1.33E^{-02}$
		Rhyacophilidae	-	-	$2.73E^{-03}$	-	-	-	-	-	$2.73E^{-03}$
		Total	$4.94E^{-03}$	$7.50E^{-03}$	$8.18E^{-02}$	$8.34E^{-03}$	$3.57E^{-03}$	$1.16E^{-02}$	$1.78E^{-02}$	$3.12E^{-02}$	$1.67E^{-01}$
	Trombidiformes	*Hydryphantidae*	-	-	-	$4.17E^{-03}$	-	-	-	-	$4.17E^{-03}$
		Total	-	-	-	$4.17E^{-03}$	-	-	-	-	$4.17E^{-03}$
Total Autochthonous Abundance			$2.22E^{-02}$	$2.31E^{-01}$	$4.47E^{-01}$	$1.13E^{-01}$	$7.40E^{-02}$	$2.31E^{-01}$	$2.98E^{-01}$	$5.25E^{-01}$	1.94
Alloc[b] (Terrestrial)	*Araneae*	*Amaurobiidae*	-	-	-	-	$8.92E^{-04}$	-	-	-	$8.92E^{-04}$
		Araneidae	-	-	-	-	-	$1.16E^{-02}$	-	-	$1.16E^{-02}$
		Linyphiidae	-	-	$2.73E^{-03}$	-	-	-	-	-	$2.73E^{-03}$
		Theridiidae	-	-	$5.45E^{-03}$	$4.17E^{-03}$	-	-	-	-	$9.62E^{-03}$

Habitat	Order	Family	Test sites			Reference Sites					Grand Total
			Burdett-T	Donegani-T	D'herbomez-T	Burdett-R	Donegani-R	North Millionaire-R	Millionaire-R	Unnamed Trib-R	
		Total	-	-	8.18E^{-03}	4.17E^{-03}	8.92E^{-04}	1.16E^{-02}	-	-	2.48E^{-02}
	Coleoptera	*Carabidae*	-	-	2.73E^{-03}	-	-	-	2.55E^{-03}	-	5.27E^{-03}
		Chrysomelidae	-	-	-	-	-	-	-	6.25E^{-03}	6.25E^{-03}
		Coccinellidae	-	-	-	4.17E^{-03}	-	1.16E^{-02}	-	-	1.57E^{-02}
		Curculionidae	2.47E^{-03}	-	4.09E^{-02}		-	-	2.55E^{-03}	-	4.59E^{-02}
		Staphylinidae	-	-	1.09E^{-02}	8.34E^{-03}	-	1.16E^{-02}	2.55E^{-03}	-	3.34E^{-02}
		Unid-C1	-	-	5.45E^{-03}	-	-	-	-	-	5.45E^{-03}
		Total	2.47E^{-03}	-	6.00E^{-02}	1.25E^{-02}	-	2.31E^{-02}	7.64E^{-03}	6.25E^{-03}	1.12E^{-01}
	Diptera	*Empididae*	-	-	5.45E^{-03}	-	-	-	-	-	5.45E^{-03}
		Total	-	-	5.45E^{-03}	-	-	-	-	-	5.45E^{-03}
	Hemiptera	*Nabidae*	2.47E^{-03}	-	2.73E^{-03}	-	-	-	-	-	5.20E^{-03}
		Total	2.47E^{-03}	-	2.73E^{-03}	-	-	-	-	-	5.20E^{-03}
	Hymenoptera	*Apidae*	-	-	2.73E^{-03}	-	-	-	-	-	2.73E^{-03}
		Formicidae	-	-	8.18E^{-03}	-	-	-	-	-	8.18E^{-03}
		Total	-	-	1.09E^{-02}	-	-	-	-	-	1.09E^{-02}
	Julida	*Julidae*	-	-	2.73E^{-03}	-	-	1.16E^{-02}	2.55E^{-03}	-	1.68E^{-02}
		Total	-	-	2.73E^{-03}	-	-	1.16E^{-02}	2.55E^{-03}	-	1.68E^{-02}
	Lepidoptera	*Geometridae*	-	-	-	-	8.92E^{-04}	-	-	-	8.92E^{-04}
		Noctuidae	-	-	-	-	8.92E^{-04}	-	-	-	8.92E^{-04}
		Total	-	-	-	-	1.78E^{-03}	-	-	-	1.78E^{-03}
	Oribatida	Unid Mite-1	-	-	-	-	-	-	-	6.25E^{-03}	6.25E^{-03}
		Total	-	-	-	-	-	-	-	6.25E^{-03}	6.25E^{-03}
	Poduromorpha	*Hypogastruridae*	-	-	5.45E^{-03}	-	-	-	-		5.45E^{-03}
		Total	-	-	5.45E^{-03}	-	-	-	-	-	5.45E^{-03}
	Raphidioptera	*Raphidiidae*	-	-	-	-	8.92E^{-04}	-	-	-	8.92E^{-04}
		Total	-	-	-	-	8.92E^{-04}	-	-	-	8.92E^{-04}

Habitat	Order	Family	Test sites			Reference Sites					Grand Total
			Burdett-T	Donegani-T	D'herbomez-T	Burdett-R	Donegani-R	North Millionaire-R	Millionaire-R	Unnamed Trib-R	
	Stylommatophora	*Oxychilidae*	-	-	2.73E^{-03}	-	-	-	-	-	2.73E^{-03}
		Total	-	-	2.73E^{-03}	-	-	-	-	-	2.73E^{-03}
	Symphypleona	*Sminthuridae*	-	-	-	8.34E^{-03}	-	-	-	-	8.34E^{-03}
		Total	-	-	-	8.34E^{-03}	-	-	-	-	8.34E^{-03}
Total Allochthonous Abundance			4.94E^{-03}	-	9.82E^{-02}	2.50E^{-02}	3.57E^{-03}	4.63E^{-02}	1.02E^{-02}	1.25E^{-02}	2.01E^{-01}
Alloc[b] or Autoc[a] (Terrestrial / Aquatic)	*Diptera*	*Empididae*	-	-	3.82E^{-02}	4.17E^{-03}	-	2.31E^{-02}	-	-	6.55E^{-02}
		Tipulidae	-	-	-	4.17E^{-03}	-	-	-	-	4.17E^{-03}
		Unid-D1	-	-	-	-	2.68E^{-03}	-	-	-	2.68E^{-03}
		Total	-	-	3.82E^{-02}	8.34E^{-03}	2.68E^{-03}	2.31E^{-02}	-	-	7.23E^{-02}
	Hymenoptera	*Braconidae*	-	-	-	8.34E^{-03}	-	-	-	-	8.34E^{-03}
		Total	-	-	-	8.34E^{-03}	-	-	-	-	8.34E^{-03}
	Lepidoptera	*Noctuidae*	-	-	2.73E^{-03}	-	-	-	-	-	2.73E^{-03}
		Total	-	-	2.73E^{-03}	-	-	-	-	-	2.73E^{-03}
Total Allochthonous or Autochthonous Abundance			-	-	-	-	2.68E^{-03}	2.31E^{-02}	-	-	8.34E^{-02}
Total Invertebrate Drift			2.72E^{-02}	2.31E^{-01}	5.86E^{-01}	1.54E^{-01}	8.03E^{-02}	3.01E^{-01}	3.08E^{-01}	5.37E^{-01}	2.23

Note: a-Autochthonous, b-Allochthonous

Appendix 1.2

Exuvia Abundance (m3/hr), Total Exuvia Drift per Site

Habitat	Order	Family	Test sites			Reference Sites					Grand Total
			Burdett	Donegani	D'herbomez	Burdett	Donegani	North Millionaire	Millionaire	Unknown Trib	
			T010	T003	T004	R017	R018	R009	R004	R008	
Autoch[a] (Aquatic)	*Amphipoda*	Unidentified	-	-	$2.73E^{-03}$	-	-	-	-	-	$2.73E^{-03}$
	Diptera	Unidentified	$9.89E^{-03}$	$2.10E^{-02}$	$4.36E^{-02}$	$4.59E^{-02}$	$2.68E^{-02}$	$3.47E^{-02}$	$4.84E^{-02}$	$6.25E^{-03}$	$2.36E^{-01}$
	Ephemeroptera	Unidentified	$3.95E^{-02}$	$4.65E^{-02}$	$6.24E^{-01}$	$7.09E^{-02}$	$3.12E^{-01}$	$5.78E^{-02}$	$1.27E^{-01}$	$1.06E^{-01}$	1.38
	Hemiptera	Unidentified	-	-	$2.73E^{-03}$	-	$2.68E^{-03}$	-	$2.55E^{-03}$	-	$7.95E^{-03}$
	Isopoda	Unidentified	-	-	$1.64E^{-02}$	-	-	-	-	-	$1.64E^{-02}$
	Plecoptera	Unidentified	$1.24E^{-02}$	-	$1.91E^{-02}$	$4.17E^{-03}$	$7.13E^{-03}$	$1.16E^{-02}$	$7.64E^{-03}$	$2.50E^{-02}$	$8.69E^{-02}$
	Trichoptera	Unidentified	-	-	$4.09E^{-02}$	$1.67E^{-02}$	$8.92E^{-04}$	-	-	-	$5.85E^{-02}$
Total Exuvia Drift			$6.18E^{-02}$	$6.75E^{-02}$	$7.50E^{-01}$	$1.38E^{-01}$	$3.50E^{-01}$	$1.04E^{-01}$	$1.86E^{-01}$	$1.37E^{-01}$	1.79

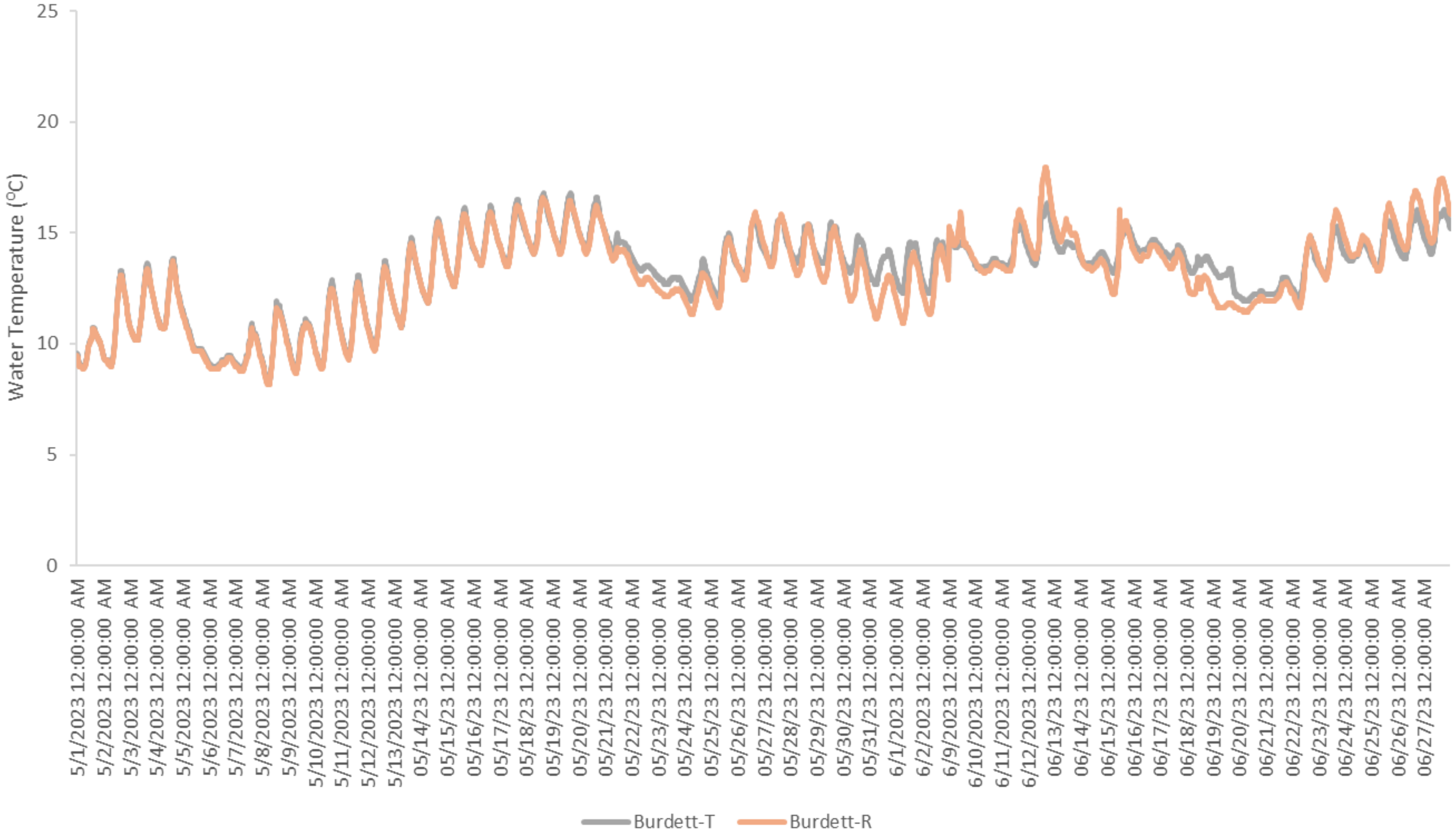
Note: a = Autochthonous

APPENDIX 2

Riparian and Instream Temperature Data

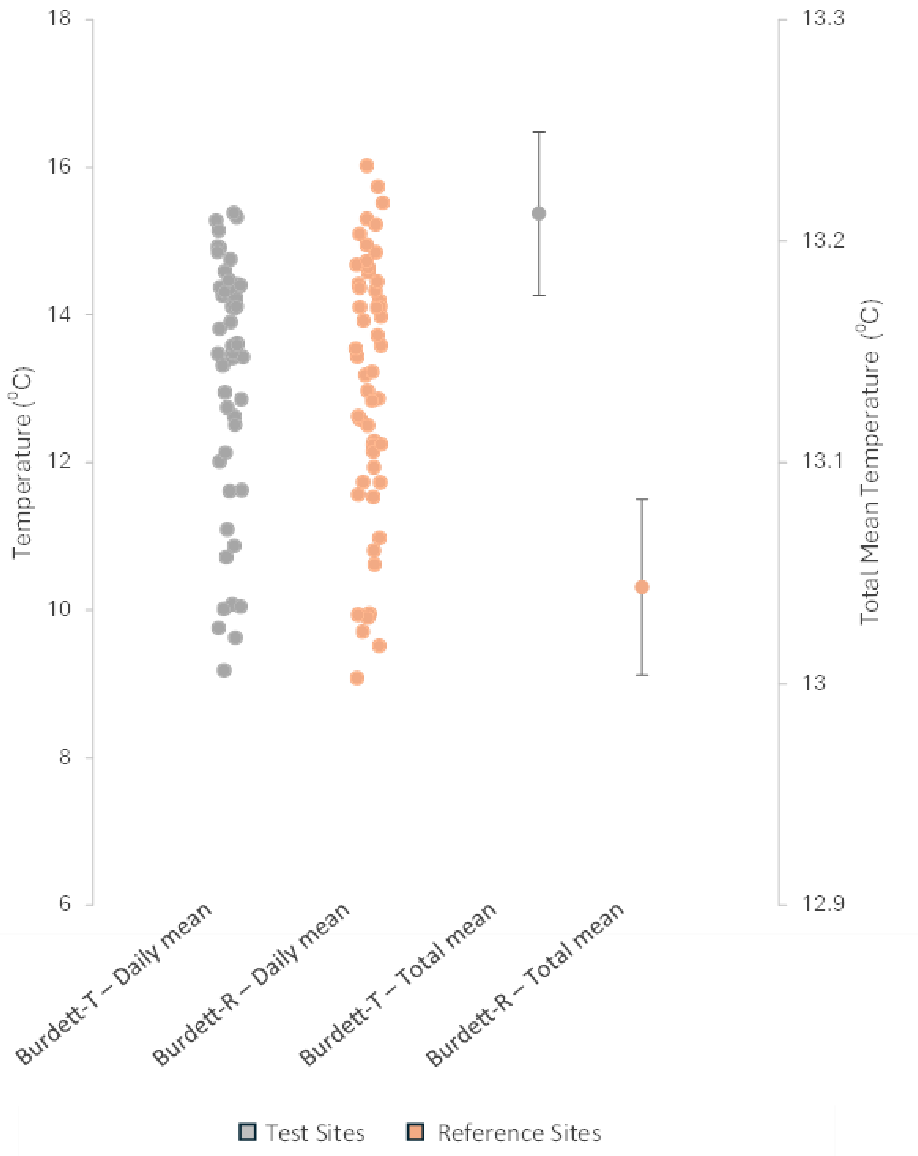
Appendix 2.1.1

Burdett Creek Daily Instream Temperatures (May 1st – June 2nd, June 9th – June 27th; n = 2,496 per site)



Appendix 2.1.2

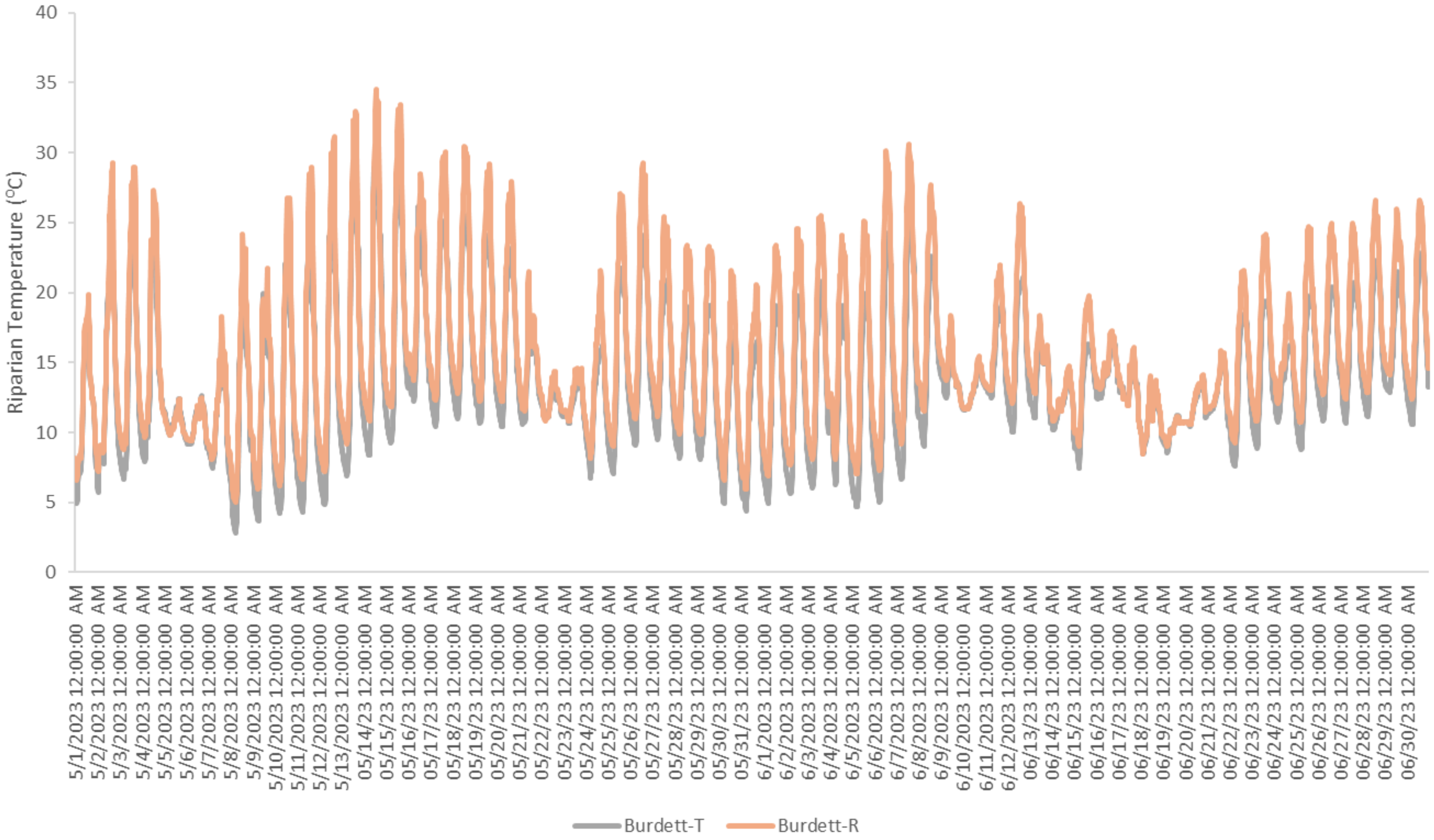
Burdett Creek Daily Mean Instream Temperatures (May 1st – June 2nd, June 9th – June 27th; n = 52 per site)



Note: Left y-axis for daily mean temperature points (n=48 per point), right y-axis for sites mean temperatures at a smaller scale

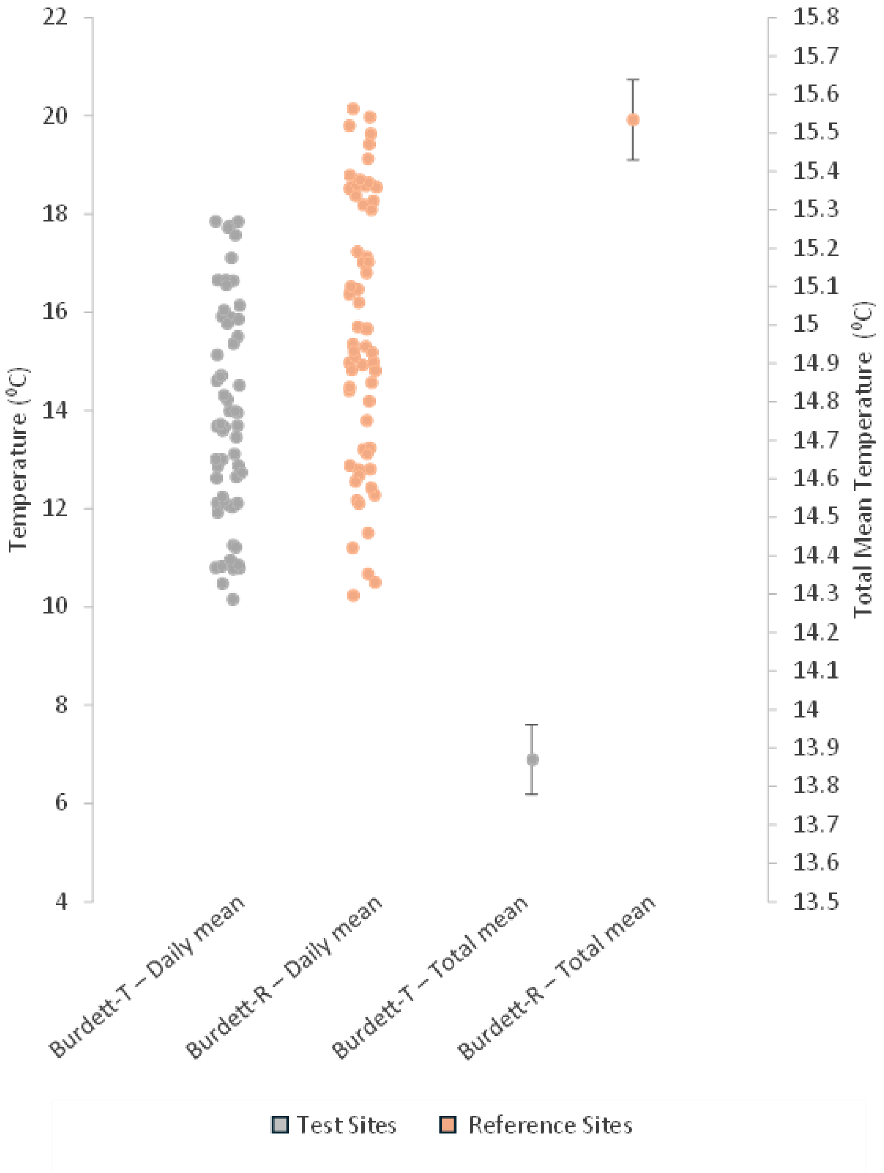
Appendix 2.2.1

Burdett Creek Daily Riparian Temperatures (May 1st - June 30th; n = 2,928 per site)



Appendix 2.2.2

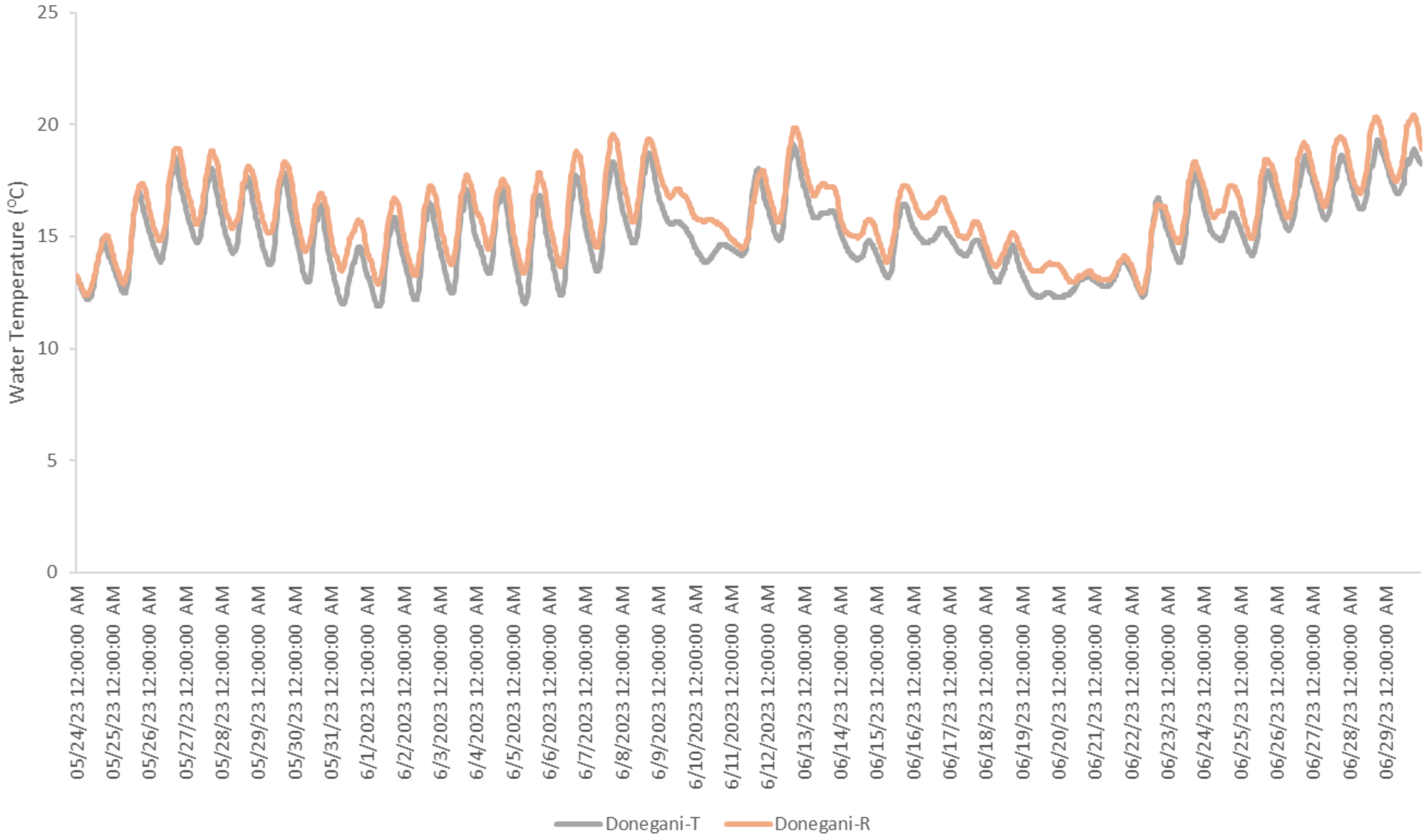
Burdett Creek Mean Riparian Temperatures (May 1st – June 30th; n = 61 per site)



Note: Left y-axis for daily mean temperature points (n=48 per point), right y-axis for sites mean temperatures at a smaller scale

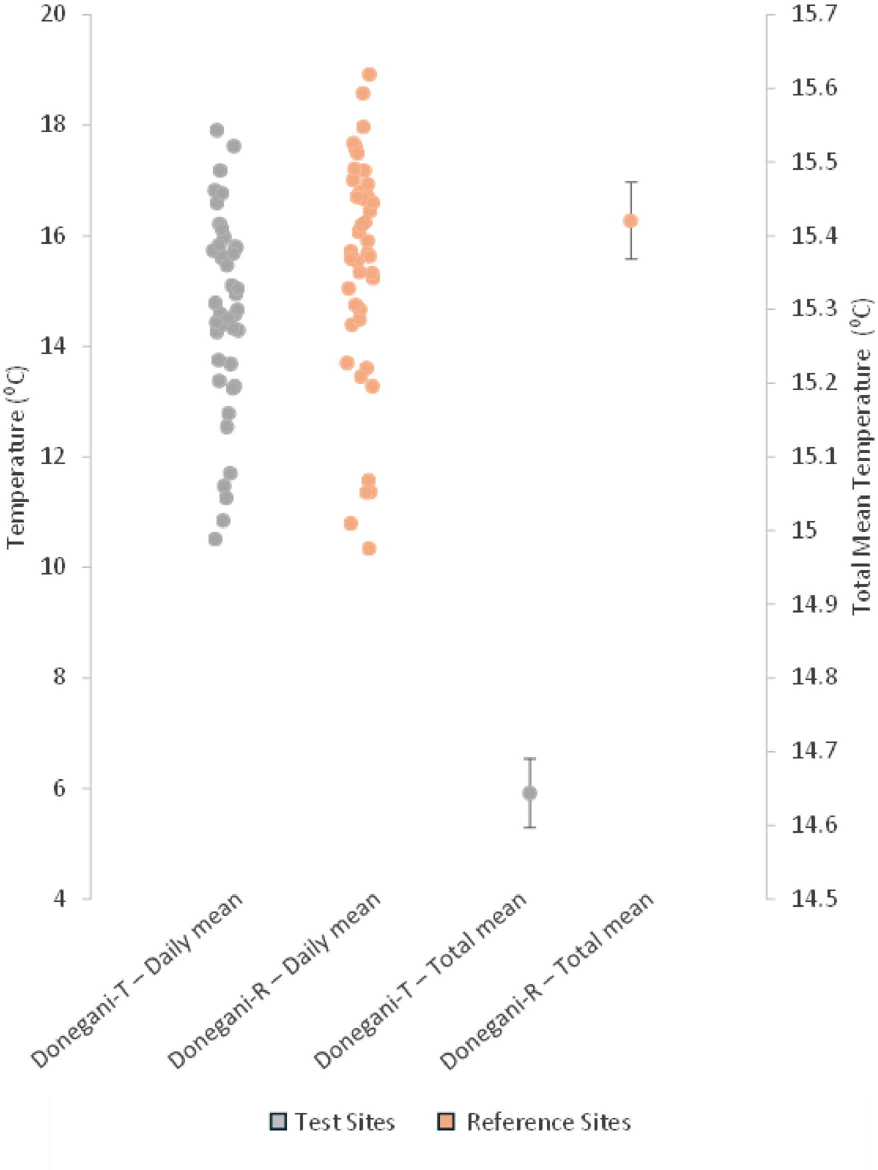
Appendix 2.3.1

Donegani Creek Daily Instream Temperatures (May 24th – June 29th; n = 2,016 per site)



Appendix 2.3.2

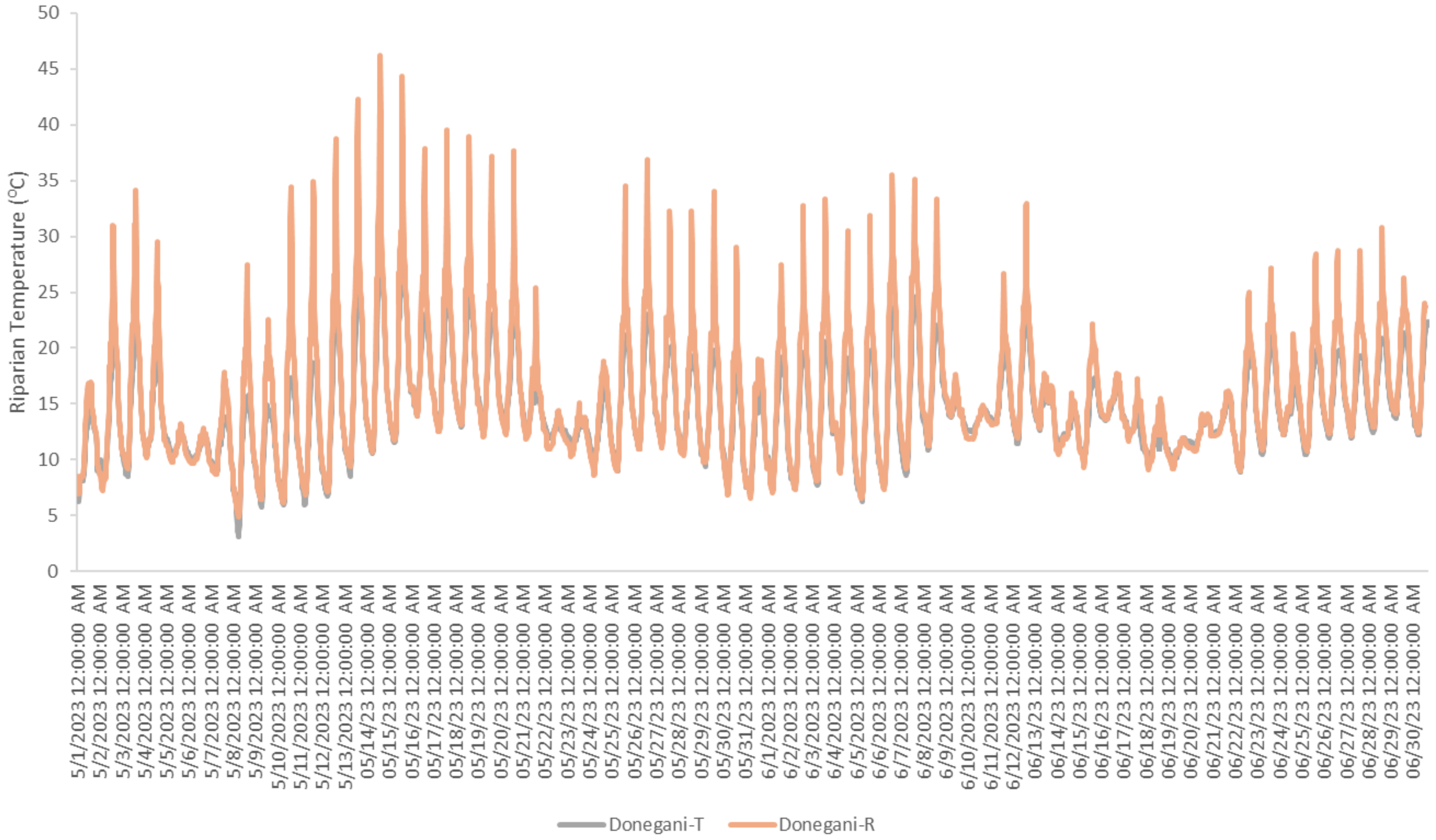
Donegani Creek Mean Instream Temperatures (May 5th – May 9th, May 23rd – June 29th; n = 42 per site)



Note: Left y-axis for daily mean temperature points (n=48 per point), right y-axis for sites mean temperatures at a smaller scale

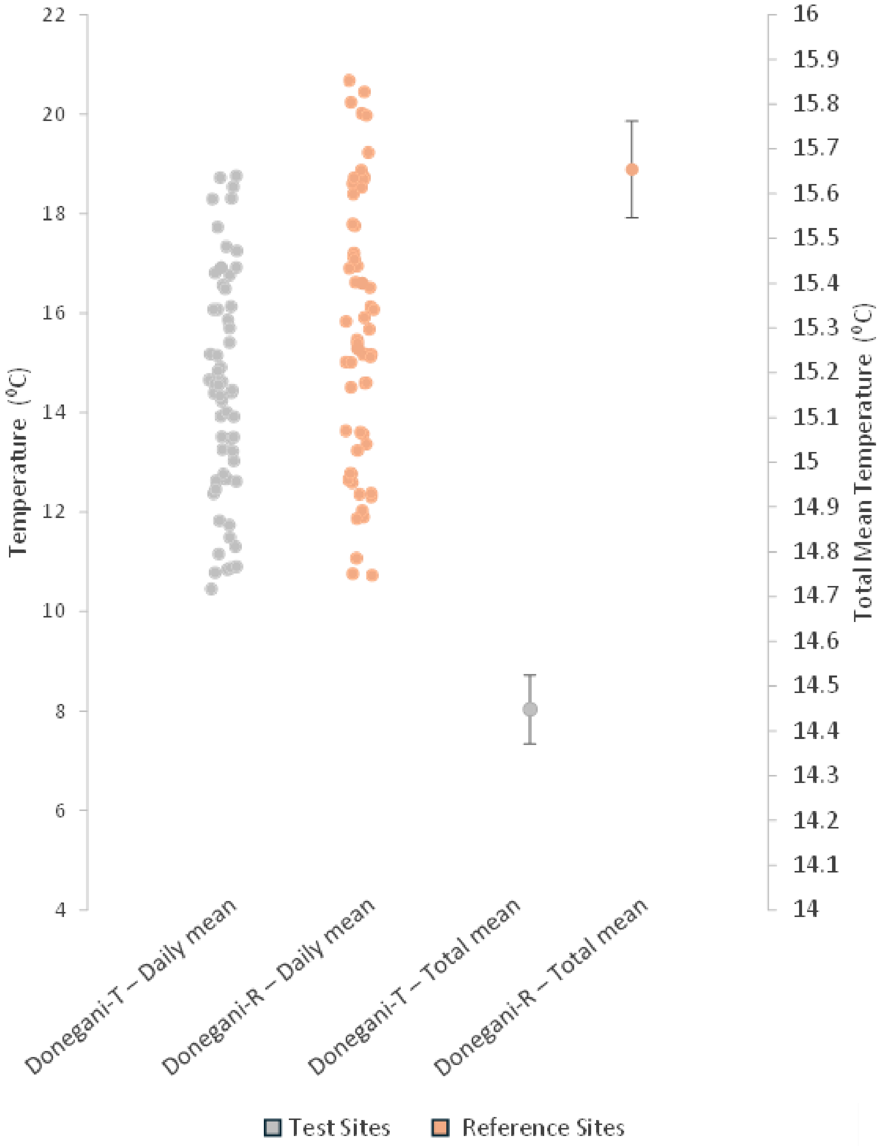
Appendix 2.4.1

Donegani Creek Daily Riparian Temperatures (May 1st - June 30th; n = 2,880 per site)



Appendix 2.4.2

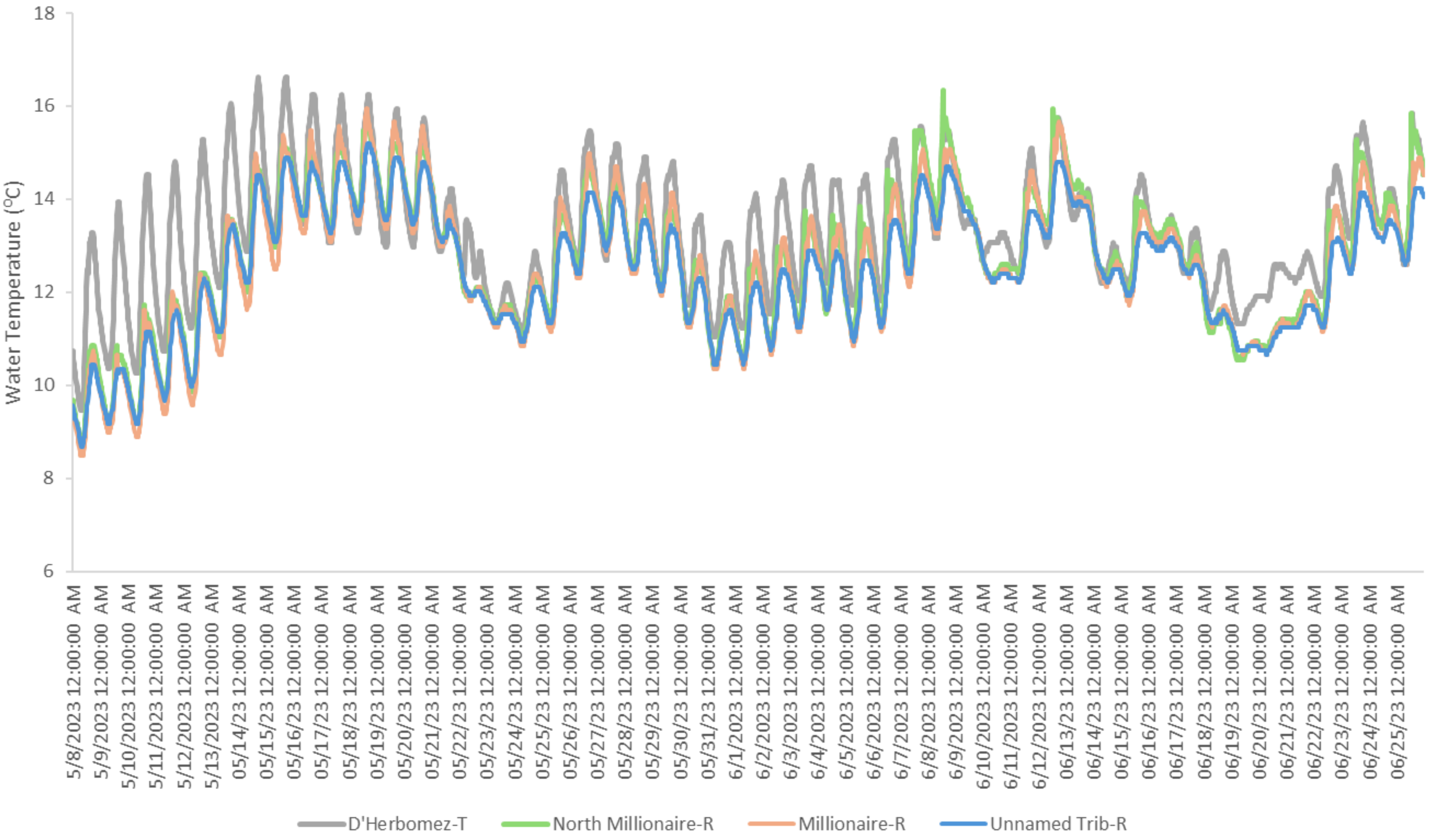
Donegani Creek Mean Riparian Temperatures (May 1st – June 29th; n = 60 per site)



Note: Left y-axis for daily mean temperature points (n=48 per point), right y-axis for sites mean temperatures at a smaller scale

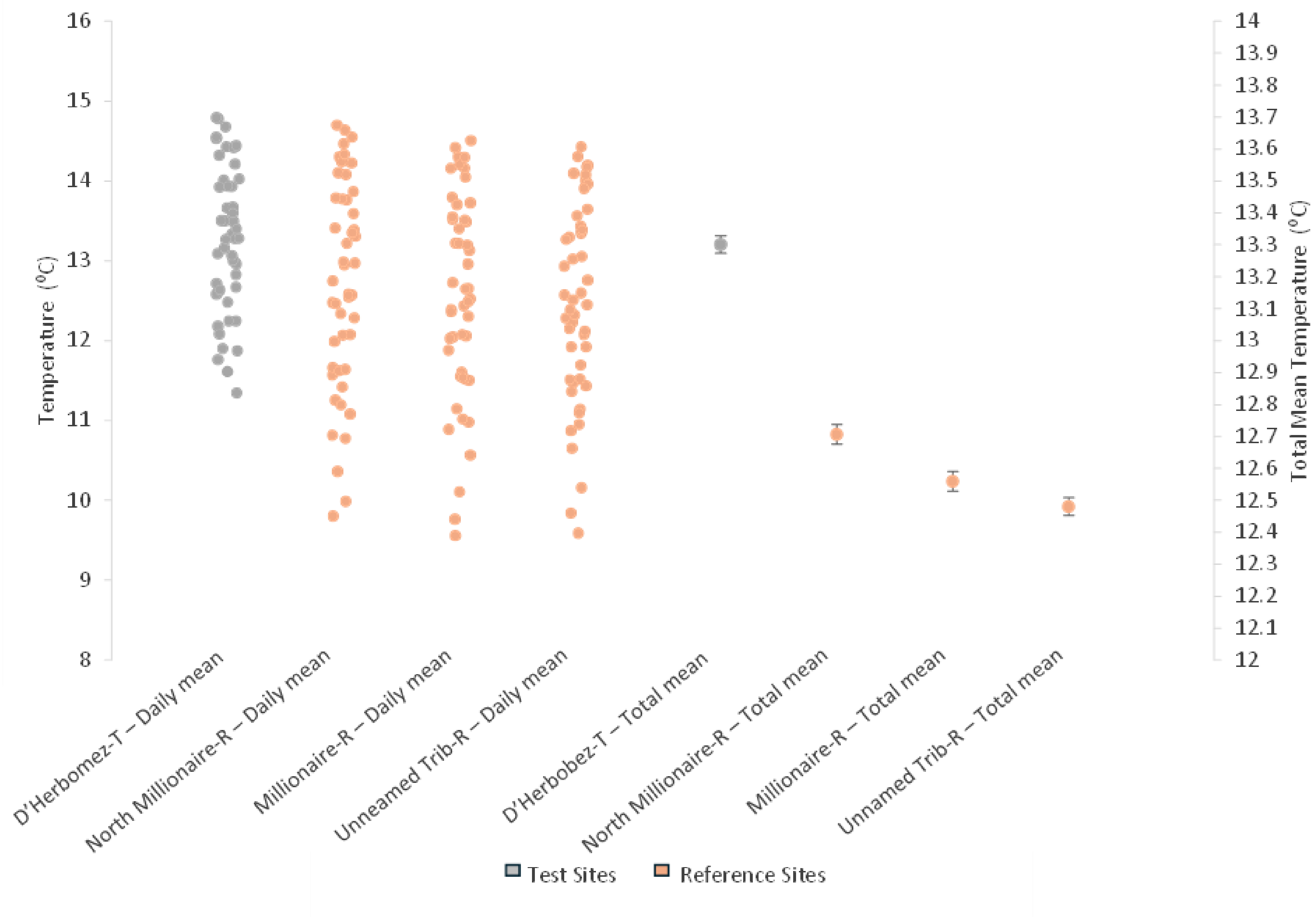
Appendix 2.5.1

D’Herbomez Creek and Millionaire Watershed Daily Instream Temperatures (May 8th – June 25th, n= 2,544 per site)



Appendix 2.5.2

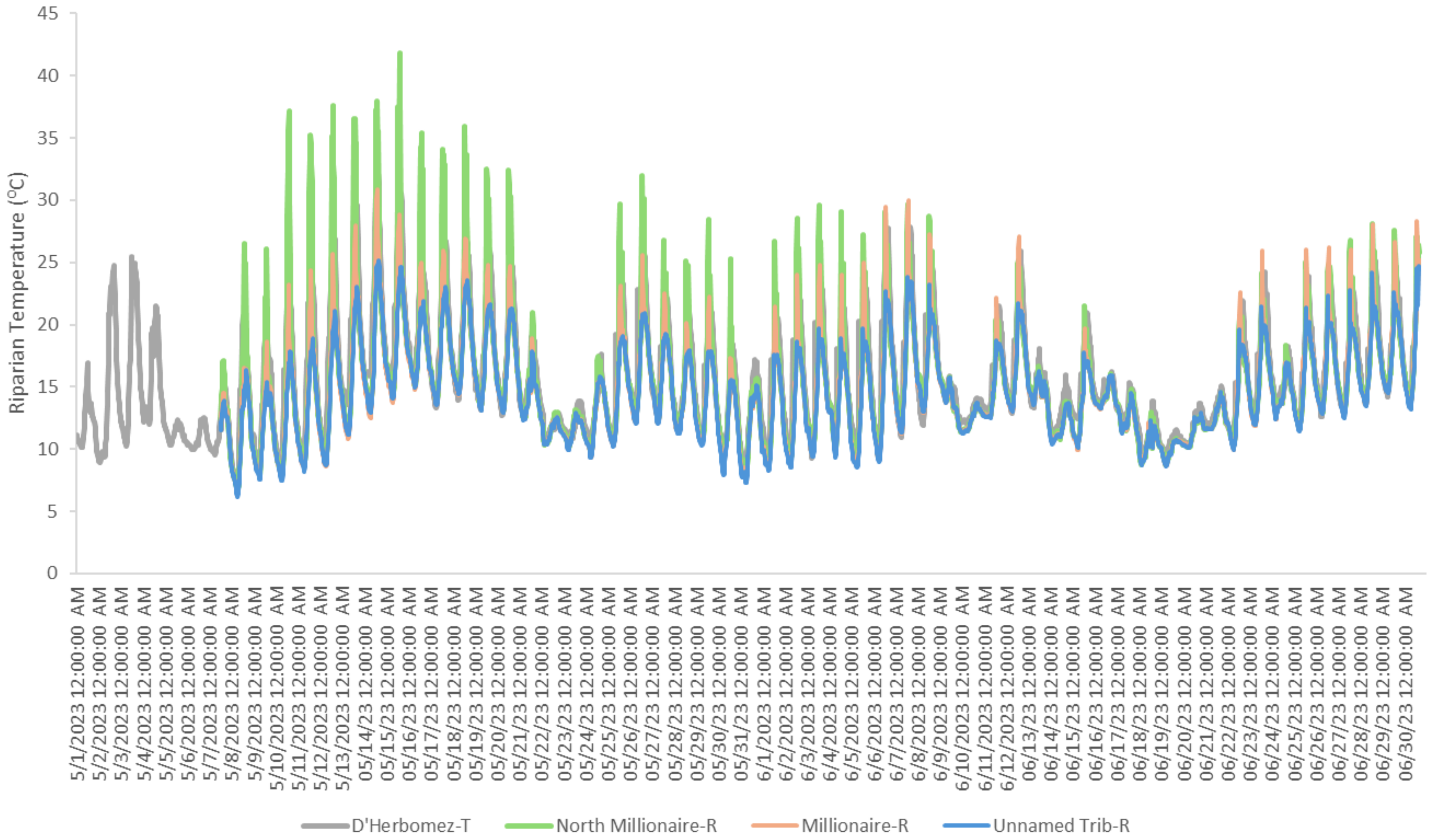
D'herbomez Creek and Millionaire Watershed Mean Instream Temperatures (May 8th – June 24th; n = 53 per site)



Note: Left y-axis for daily mean temperature points (n=48 per point), right y-axis for sites mean temperatures at a smaller scale

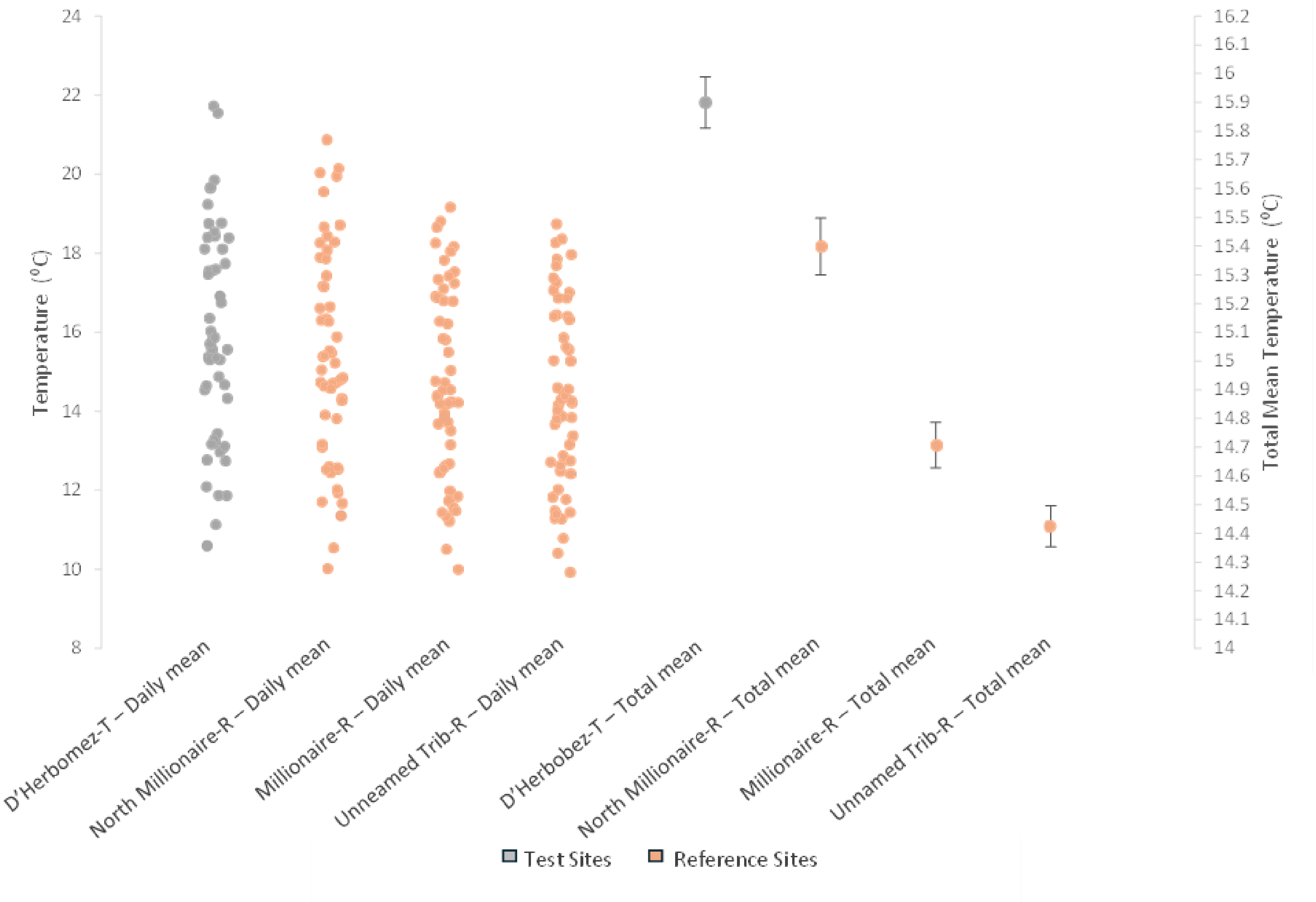
Appendix 2.6.1

D'Herbomez Creek and Millionaire Watershed Daily Riparian Temperatures (May 1st - June 30th; n = 2,544 per site)



Appendix 2.6.2

D'Herbomez Creek and Millionaire Watershed Mean Riparian Temperatures (May 8th - June 29th; n = 53 per site)



Note: Left y-axis for daily mean temperature points (n=48 per point), right y-axis for sites mean temperatures at a smaller scale