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Post-wildfire biomonitoring of Winlaw and Trozzo Creeks: 2021-22

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The Trozzo Creek fire 2021. Photo Joel Pelletier, Castlegar News

Integrated Ecological Research

Darcie Quamme, MSc., RPBio
Integrated Ecological Research

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Post-wildfire biomonitoring of Winlaw and Trozzo Creeks: 2021-22

Abstract

Results from biomonitoring of Winlaw and Trozzo creeks in the fall of 2021 and 2022 showed that post-fire monitoring of Winlaw Creek was in reference condition at 76-and 440-days following the 2021 wildfire, respectively. Trozzo Creek was found to be divergent from reference sites at 76-days from the initiation of the fire but showed signs of recovery at 470-days post-fire.

In addition, macroinvertebrate abundance was >2-fold higher at Winlaw Creek and 5-fold greater at Trozzo Creek than most probable reference means following the wildfire. The increases in macroinvertebrate abundance observed in Winlaw and Trozzo creeks were likely due to increases in nutrients post-wildfire which remained high up to 440-days after the fire. Increases in macroinvertebrate abundances in Winlaw and Trozzo creeks at lower elevations are likely to persist while increases in nutrient export remains elevated during watershed recovery.

The community structure in Winlaw or Trozzo creeks remained similar to pre-fire conditions and reference sites following the wildfire. This is likely because the overall fire severity overall and wildfire impacts at lower elevations was moderate. In addition, riparian zones were intact following the wildfire and was accompanied by flushing of fines and a lack of channel restructuring at the macroinvertebrate sampling sites. Upper elevation reaches where there was higher burn severity, sedimentation and channel restructuring may have greater impacts to the macroinvertebrate community in those locations.

Recommendations include further monitoring of water quality and macroinvertebrates and minimizing cumulative disturbance to the watershed until post-fire hazard ratings decline.

Contents

Introduction

Integrated Ecological Research (IER) was retained by the Slocan Integral Forestry Cooperative (SIFco) in partnership with the Slocan River Streamkeeper Society (SRS) to analyze data collected from Winlaw and Trozzo Creeks. Macroinvertebrates and metadata were collected by SRS in collaboration with Living Lakes Canada using the federal Environment and Climate Change Canada (ECCC) Canadian Aquatic Biomonitoring Network (CABIN) methods for wadable streams (ECCC, 2012).

The original goal of the biomonitoring work in 2021-22 was to examine the effects of controlled fire burns on water quality and the macroinvertebrate community. However, a wildfire (Trozzo Fire N51705) occurred on July 9, 2021 within the Winlaw watershed burning 5992 ha within the Winlaw, Trozzo and Lemon creek watersheds (SNT and Sitkum Consulting 2022a and 2022b). The Trozzo Fire occurred 8 km east of Winlaw, BC and was bounded to the north by Lemon Creek and to the south by Winlaw Creek. The biomonitoring program was subsequently used to examine trends in water quality and effects on the macroinvertebrate community and ecological integrity within Winlaw and Trozzo creeks following the controlled burns that were completed and the larger impacts of a wildfire.

The impacts of wildfire include changes in hydrology (quantity and timing), increased risk of debris flow (SIFco 2023) and greater inputs of nutrients, sediment, metals, fecal contamination, ash and debris due to increased erosional processes and inputs from greater overland flow (Province of BC 2024, SNT and Sitkum Consulting 2022a, Minshall 2003). Increased burn severity from wildfire can also be associated with increased annual variation in peak flow, sediment load, organics debris, large wood debris and undercut bank structure (Arkle 2010).

The 2021 Trozzo wildfire was concentrated in the upper elevation with high burn severity ratings of 2% and 10% of the overall watershed for Winlaw and Trozzo creeks, respectively and moderate severity ratings of 12% and 30% of the overall watershed in Winlaw and Trozzo creeks, respectively. Recent landslides have occurred in high and moderate burn areas since the wildfire at upper areas in both Trozzo and Winlaw creeks (SIFco 2023, SNT and Sitkum Consulting 2022a and 2022b). The channel bed has been restructured and sediment has been deposited on the channel bed downstream of upper elevation debris flows in Trozzo Creek (SIFco 2023). However, the main channel riparian zone is intact for both Winlaw and Trozzo creeks (SNT and Sitkum Consulting 2022a and 2022b).

The overall post-fire hazards to populated areas within the Winlaw Creek watershed are low but include possible increased downstream flooding that could affect houses, Highway 6 as well as ninety-nine water licences on Winlaw Creek for domestic use, irrigation, and light industrial activity (SNT and Sitkum Consulting 2022a). Risks to Trozzo Creek are higher but are low to moderate for the overall watershed and include flooding, debris flow and blockage outwash. These factors could affect homes located in the watershed and Highway 6 as well as the thirty-eight water licences on Trozzo Creek for domestic use and irrigation. These hazards are of low to moderate risk but of high consequence if they occur. However, debris flow hazards exist in upper elevations particularly for high-intensity rain and snowmelt-caused events (SNT and Sitkum Consulting 2022a).

The identified hazards and risks (SNT and Sitkum Consulting 2022a) also affect the ecological integrity of the stream ecosystems including the macroinvertebrate community. Macroinvertebrates are often used as indicators of ecological integrity (ECCC 2017) because they integrate localized cumulative impacts, respond to a wide range of disturbances including wildfire (Minshall 2003, Minshall et al. 1989, 1997, 2001a, 2001b) and are an important part of the food web. In addition, there has been previous pre-fire monitoring of macroinvertebrates in Winlaw Creek in 2006 and 2010 for comparison and an additional 198 reference sites within the Columbia Basin for comparison to current data.

The main objectives of the analyses were as follows:

- **Identify possible impacts from wildfire within Winlaw and Trozzo Creek watersheds compared to reference sites.**
- **Examine trends of the biological communities within Winlaw and Trozzo Creeks versus reference sites over time.**
- **Assess impacts to the ecological integrity of Winlaw and Trozzo Creeks using the Columbia reference model and baseline metrics and CABIN tools.**

Methods

Field methods

Macroinvertebrates and meta-data were collected from Winlaw and Trozzo Creeks in the fall of 2021 and 2022 under the Columbia Basin Trust funding grant. In addition, SRSK previously collected samples in 2006 and 2010 (SRSK 2010) as baseline data. We use this data as a comparison to the current data.

Table 1: Watershed characteristics and dates/locations macroinvertebrate trend monitoring sites

	Winlaw Creek	**Trozzo Creek**
Watershed characteristics		
• Local Basin Name:	Columbia	Columbia
• Eco-Region:	Columbia Mountains and Highlands	Columbia Mountains and Highlands
• Eco-zone	Montane Cordillera	Montane Cordillera
• Watershed area (km^2)[1]	40.1	28.1
• Length (km^2) [1]	9.4	9.9
• Elevation range (m) [1]	630-2080	560-66220
• Stream Order (1:50,000)		3
Macroinvertebrate sites		
• Latitude, longitude	49.605 -117.544	49.634 -117.539
• Elevation of sampling site (m)[2]	525	525
• Sampling sites: Pre-fire	NJWIN01 (Nov 07 2006) NJWIN01 (Sep 16 2010)	None
• Sampling sites: Post-fire	NJWIN01 (Sep 22 2021) NJWIN01 (Sep 21 2022)	NJTRO01 (Sep 22 2021) NJTRO01 (Oct 21 2022)

• # days from fire initiation to macroinvertebrate collection	76 days NJWIN01 (Sep 22 2021) 440 days NJWIN01 (Sep 21 2022)	76 days NJTRO01 (Sep 22 2021) 470 days NJTRO01 (Oct 21 2022)

[1]Based on watershed boundaries measured by SNT and Sitkum Consulting 2022a, [2]Field measurements by SRSK.

Macroinvertebrates were collected from riffle-run sequence by SRSK in the lower watershed using a 400 µm triangular CABIN kick net. Kick samples were collected over a 3-minute period in a travelling zig zag pattern to collect macroinvertebrates from a range of micro-habitats according to methods outlined in ECCC (2012). Meta-data were also collected at the time of sampling including measures such as reach characteristics, water quality, and substrate descriptions.

Samples were preserved and sent to a certified taxonomist for taxonomic identification at a family or genus level using standard methods and sub-sampling techniques outlined in ECCC (2020). Samples from Winlaw Creek collected in 2006 and 2010 were identified at a family level only. Data were entered in the National CABIN database by SRSK all other samples were identified to genus.

Photo 1: Macroinvertebrate collection protocol included a 3min kick-sample, Trozzo Creek, Sept 22 2021, 76 days after the wildfire. Kyle Prince from LLC shown collecting a sample here.


Winlaw Creek: substrate


Winlaw Creek: upstream


Winlaw Creek: downstream


Trozzo Creek: substrate


Trozzo Creek: upstream


Trozzo Creek: downstream

Photo 2: Winlaw and Trozzo creeks macroinvertebrate sites in 2021, 76 days after the wildfire.

Geospatial habitat variables

Predictor variables are required to implement CABIN tools including geospatial habitat variables. Each new test site requires that these predictor variables are measured and input to the CABIN database. This was completed for most fields for Winlaw Creek by the provincial government (pers com. Stephanie Strachan) in 2006. GIS measurements were completed for Trozzo Creek by Living Lakes Canada in January 2024.

Analyses

We used the CABIN BEAST assessment (Benthic Assessment of Sediment developed by Reynoldson et al. 1995) to explore how test sites from Winlaw and Trozzo Creeks compared to the “most probable reference sites” (n=13 for Winlaw and Trozzo Creeks) which belong to an assigned reference group, one of six reference groups in the Columbia Basin model.

The “most probable reference sites” were selected using CABIN tools based on predictor variables (habitat characteristics) from a subset of minimally disturbed reference sites (n=198) for the Columbia Basin model (described below). Predictor variables were selected so as to be uninfluenced by anthropogenic disturbance (Sylvestre et al. 2005,) and included: Altitude, Longitude, Bedrock Geology-Sedimentary (%), Channel Reach-%Canopy Coverage, Channel-Slope (m/m), Climate-Precipitation Oct (mm), Climate-Temperature DECmin (deg C), Hydrology Drainage area (km^2), Landcover-Grasslands (%), Landcover-Grasslands ShrubLow (%), Landcover -Water (%), Topography-Slope maximum in upper watershed (%) for the Columbia Basin model (Strachan 2020).

In addition, graphical exploration of the macroinvertebrate data from both streams was carried out and compared to raw data for all reference sites (n=198) from the Columbia Basin model and a subset of these reference sites located within the Columbia and Mountain highlands (n=107) ecozone in which Winlaw and Trozzo creeks are located.

All analyses were carried out at the family-level required for the BEAST analyses. But the family-level of taxonomy was also used because taxonomic analyses for Winlaw Creek in 2006 and 2010 pre-fire samples were only carried out at the family-level. Taxonomic analyses for all other sites were carried out to the genus-level.

Results

CABIN BEAST analysis: Tests sites versus Columbia Basin model, Group 1 reference sites

All the test sites in Winlaw and Trozzo Creeks were assigned to Group 1 references sites (n=13) in the CABIN Columbia Basin model with an error rate of 53.8% based on habitat predictor variables. Group 1 reference sites consisted of only thirteen reference sites that were typified by low stream order, steep and narrow channels with a low proportion of sedimentary rock and small substrates (Strachan 2020). Reference sites in Group 1 tend to have a low abundance with a high proportion of chironomids (Strachan 2020).

The BEAST analysis resulted in mild divergence from reference sites in 2006 and 2010 for pre-fire monitoring of Winlaw Creek. Winlaw Creek was described as in reference condition at 76- and 440-days post-fire initiation. Trozzo Creek was found to be divergent from reference sites 76-days from the initiation of the fire but showed signs of recovery at 470-days post-fire based on using the BEAST analysis tools.

Table 2: Test site assessment pre and post fire monitoring of macroinvertebrates.

Creek	Pre or Post fire monitoring	Site	# Days from fire initiation to sampling date	Overall BEAST analysis results
Winlaw	Pre-fire	NJWIN01 (Nov 07 2006)	NA	MD
Winlaw	Pre-fire	NJWIN01 (Sep 16 2010)	NA	MD
Winlaw	Post-fire	NJWIN01 (Sep 22 2021)	76	Ref
Winlaw	Post-fire	NJWIN01 (Sep 21 2022)	440	Ref
Trozzo	Post-fire	NJTRO01 (Sep 22 2021)	76	D
Trozzo	Post-fire	NJTRO01 (Oct 21 2022)	470	Ref

Ref=Similar to reference within the 95% confidence limits, MD= Mildly divergent from reference sites (between the 95 and 99% confidence limits), D=Divergent (between the 99 and 99.9% confidence limits)

Pre-fire baseline monitoring of Winlaw Creek in 2006 and 2010 suggests that Winlaw Creek had a low abundance of total macroinvertebrates like other Group 1 reference sites but in contrast had 9.7- and 4.5-times lower proportion of chironomids in 2006 and 2010, respectively (Table 3, Figures 1-3). But Winlaw Creek had 1.4- and 1.5-fold number of family taxa than Group 1 reference sites (Table 3, Figure 3, Appendix 1) in 2006 and 2010, respectively. In addition, Winlaw Creek had 1.9- and 1.7-fold higher proportion of EPT (mayflies, stoneflies and caddisflies) than Group 1 reference sites (Table 3, Appendix 1) in 2006 and 2010, respectively.

E: Ephemeroptera (mayfly). Photo by D. Quamme.

P: Plecopteran (stonefly). Photo from J. Yeow.

T: Trichopteran (Caddisfly). Photo from J. Yeow.

Photo 3: EPT organisms, indicators of high-water quality.

In post-fire sampling, the counts of total macroinvertebrates were 2.1 and 2.4-times greater in Winlaw Creek versus the reference mean in 2021 and 2022, respectively. However, the percentage of chironomids remained low while EPT organisms remained high (Table 3, Figures 1-3) relative to pre-fire baseline monitoring in Winlaw Creek. The percentage of EPT organisms in 2021 and 2022 was 79.8% and 69.2%, respectively in Winlaw Creek. While chironomids comprised 11.6% and 18.9% of the sample, respectively in 2021 and 2022 in Winlaw Creek. The total number of families in Winlaw Creek pre-(2006 and 2010) and post-fire (2022 and 2021) were higher than reference means (Table 3, Figure 2).

Table 3: Selected metrics for Winlaw and Trozzo creek sites and the Group 1 reference group.

Metric	NJWIN01_2006	NJWIN01_ 2010	NJWIN01_2021	NJWIN01_2022	NJTRO001_ 2021	NJTRO001_ 2022	RefMean (n=13)	Standard Error
Total Richness	22	25	25	26	24	19	16.20	1.05
Total Abundance	1362.0	422.0	3850.0	4462.5	9180.0	9140.0	1823.33	360.12
Number of EPT taxa	16	13	16	16	13	13	11.00	0.70
Number of E families	5	3.0	5	5	4.00	4.00	3.80	0.76
Number of P familes	6	5	5	5	7	6	4.73	0.35
Number of T families	5	5	6	6	2	3	2.47	0.44
%EPT	88.8	76.2	79.9	69.2	73.2	73.3	68.93	7.08
% Chironomidae	9.7	4.5	11.6	18.9	10.1	21.9	25.75	6.79
% Diptera+non-insect taxa	10.3	14.6	14.5	22.4	18.0	24.8	29.70	7.03

White indicates that the value lies between the standard error (SE) of the reference mean. Orange indicates that metrics is above the upper SE value of the reference mean and grey indicates below the lower SE value. Winlaw and Trozzo creek sites are unreplicated.

In post-fire sampling, the counts of total macroinvertebrates were 5-times greater in Trozzo Creek versus the reference mean in both 2021 and 2022. Similar trends were observed at Trozzo Creek in post-fire sampling where the percentage of chironomids was low and EPT organisms were high. Chironomids made up 10.1% and 21.9% of the sample, respectively in 2021 and 2022 Trozzo Creek. EPT organisms comprised 73.2% and 73.3% of the sample, respectively in 2021 and 2022 Trozzo Creek. The total number of families in Trozzo Creek post-fire also remained high relative to reference means (Table 3, Figure 2).

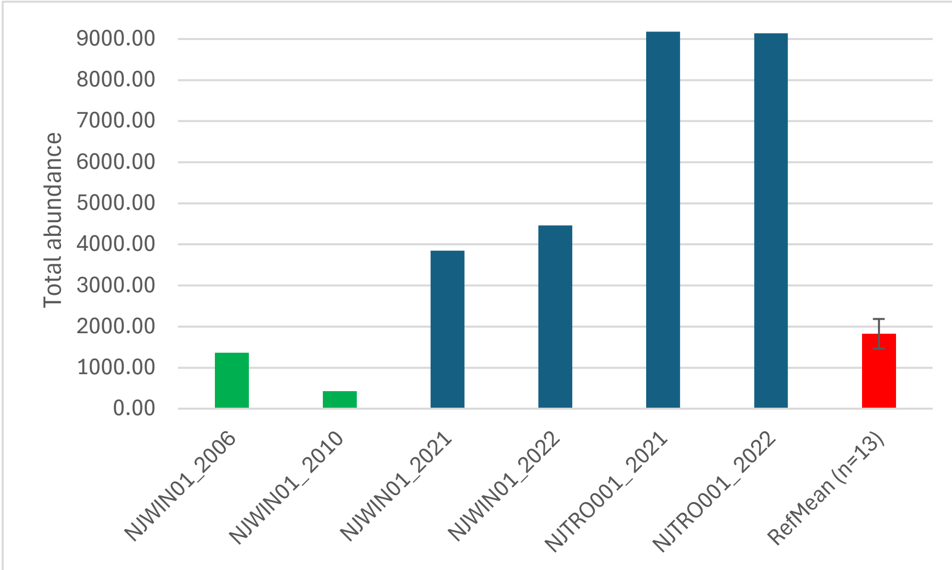

Figure 1: The abundance of total macroinvertebrates from Winlaw and Trozzo Creeks (unreplicated) versus the reference mean from Group 1 reference sites (n=13). Pre-fire baseline monitoring is indicated by green bars, post-fire monitoring by blue bars and Group 1 reference sites (n=13) are indicated by the red bar. Group 1 reference mean and standard error are indicated.

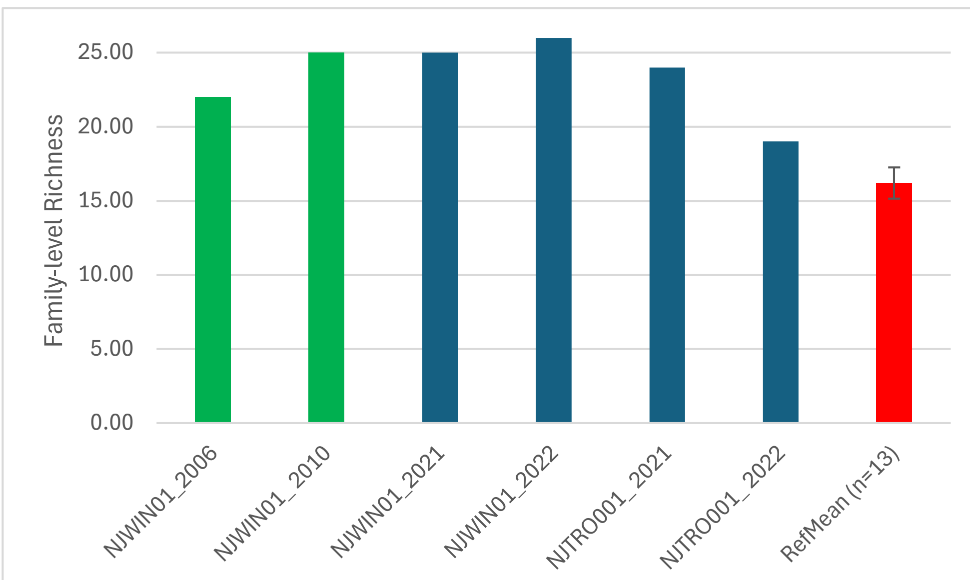

Figure 2: Family-level richness of macroinvertebrates from Winlaw and Trozzo Creeks (unreplicated) versus the reference mean from Group 1 reference sites (n=13). Pre-fire baseline monitoring is indicated by green bars, post-fire monitoring by blue bars and Group 1 reference sites (n=13) are indicated by the red bar. Group 1 reference mean and standard error are indicated.

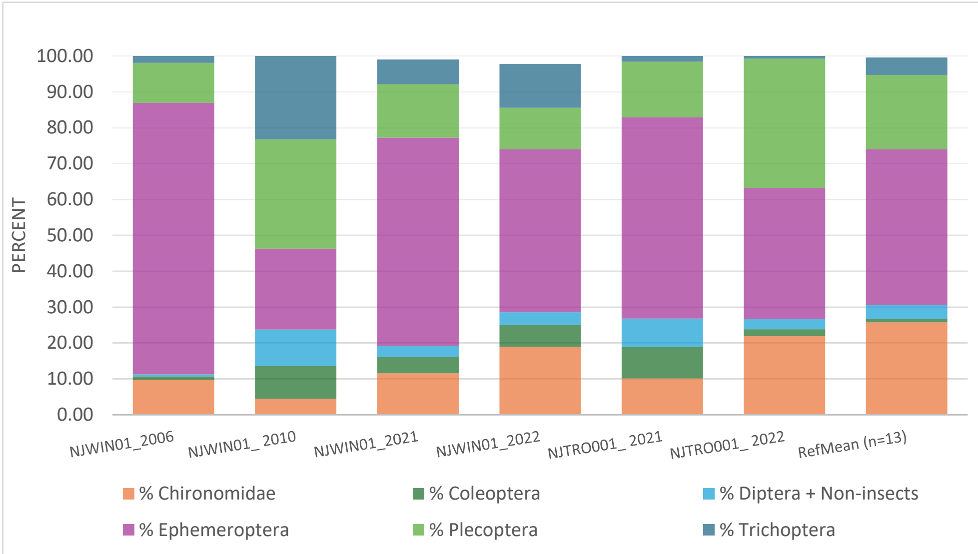

Figure 3: The percent composition of samples from Winlaw and Trozzo Creeks (unreplicated) versus the reference mean from Group 1 reference sites (n=13). Pre-fire monitoring occurred in 2006 and 2010 at Winlaw Creek. Post-fire monitoring occurred in 2021 and 2022 at Winlaw and Trozzo creeks.

Strachan (2020) recommends a cautious evaluation of comparisons to Group 1 reference sites because Group 1 has a low sample size (n=13) and thus may not be well described nor predicted. In addition, the Columbia Basin model detects decreases in taxa richness but is less successful in detecting increases in abundance with less change in taxa richness particularly for Group 1.

Because of the low sample size amongst Group 1 reference sites, Winlaw and Trozzo creeks were also compared to all reference sites within the Columbia Basin model below and to a subset of the Columbia Basin model that includes the Columbia Mountain Highlands ecoregion to further evaluate these results.

Graphical inspection of test sites versus Columbia Basin model reference sites

Winlaw and Trozzo creeks were compared to 198 reference sites within the Columbia Basin model below and to a subset of 107 reference within the Columbia Basin model that includes the Columbia Mountain Highlands ecoregion.

Family-level richness was evaluated over four years at Winlaw Creek and two years for Trozzo Creek as the count of families. Family-level richness varied from 9 to 31 families amongst 198 reference sites collected from 2007 to 2018 from all sites within the Columbia Basin Model. The median of family-level richness was 17 with and Interquartile range of 4.

Family-level richness within Winlaw and Trozzo Creeks were at or greater than the 75th percentile (19) of the reference sites for all samples collected. This indicates that family-level richness was at or higher than the normal range (50th-75th percentile or 14 to 19 families) of all sites within the Columbia Basin Model.

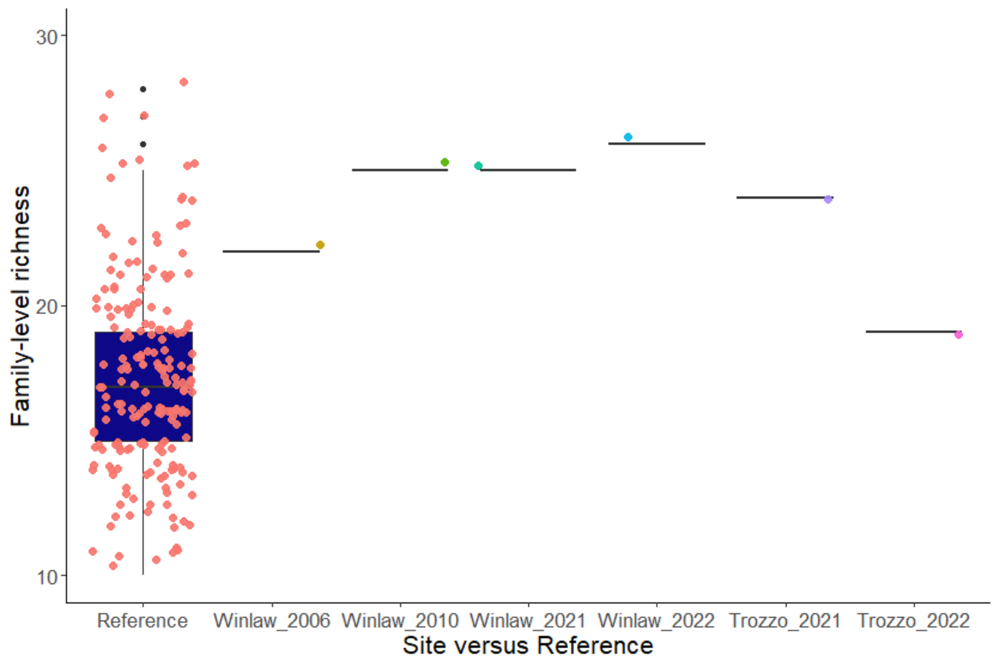

Figure 4: Macroinvertebrate family-level richness of reference sites versus Winlaw and Trozzo Creeks. Reference = 198 reference sites within the Columbia Basin Model monitored from 2003 to 2018. Winlaw and Trozzo Creeks are unreplicated for each year. Creek_Year is indicated with a horizontal line and red dot for Winlaw and Trozzo Creeks.

As a comparison, a subset of reference sites from the ECCC Columbia Mountains and Highlands Ecoregion (Ecological Stratification Working Group, 1995) in which Winlaw and Trozzo Creeks are located were also evaluated as a check on the spread of the reference sites at the ecoregion level. Family-level richness varied from 9 to 28 families amongst 107 reference sites collected from 2007 to 2018 located in the ECCC Columbia Mountains and Highlands Ecoregion. The median of family-level richness was 16 with and interquartile range of 5.

The family-level richness from all samples collected from Winlaw and Trozzo Creeks was greater than the 75^{th} percentile (19) of the reference sites. This indicates that family-level richness was at or higher than the normal range (50^{th}-75^{th} percentile or 14 to 19 families) of all sites within the Columbia Mountains and Highlands.

Samples collected from Winlaw and Trozzo Creeks were plotted by pre or post fire status versus reference in the Columbia Mountains and Highlands for inspection purposes. Family-level richness for Winlaw Creek both pre and post fire was higher than the median (16) of 107 reference sites. This included 22 and 25 families (2006, 2010 pre-fire, respectively) and 25 and 26 families (2021 and 2022, respectively post-fire). Family-level richness for Trozzo Creek was higher than the median reference with 24 and 19 families (2021 and 2022, respectively, post-fire).

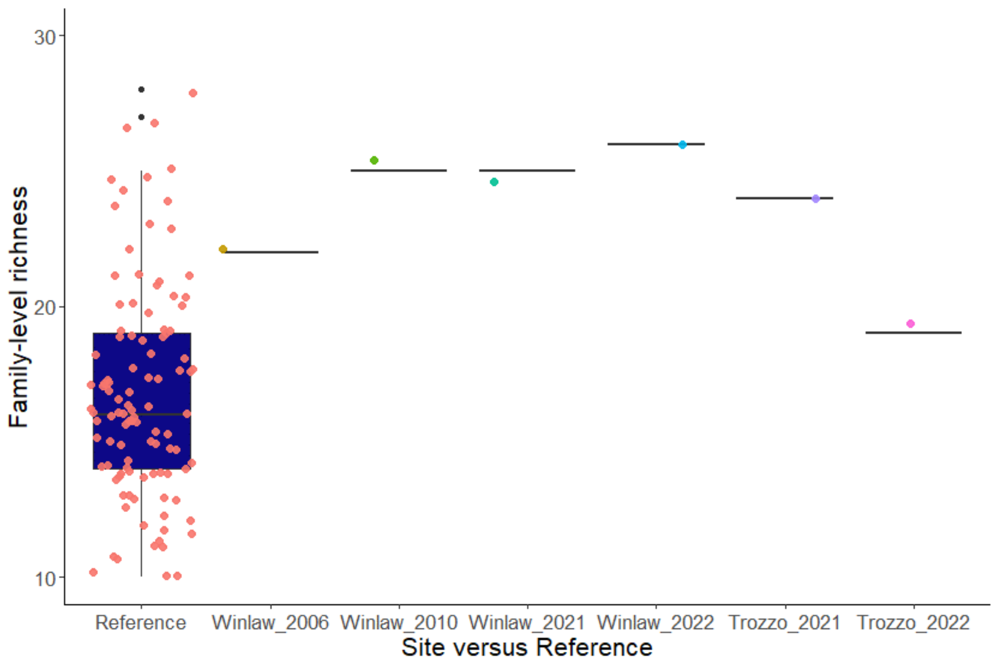

Figure 5: Macroinvertebrate family-level richness of reference sites versus Winlaw and Trozzo Creeks. Subset reference = 107 reference sites within the Columbia Mountains and Highlands ecoregion monitored from 2007 to 2018. Winlaw and Trozzo Creeks are unreplicated for each year. Creek_Year is indicated with a horizontal line and red dot for Winlaw and Trozzo Creeks. Black dots indicate outliers.

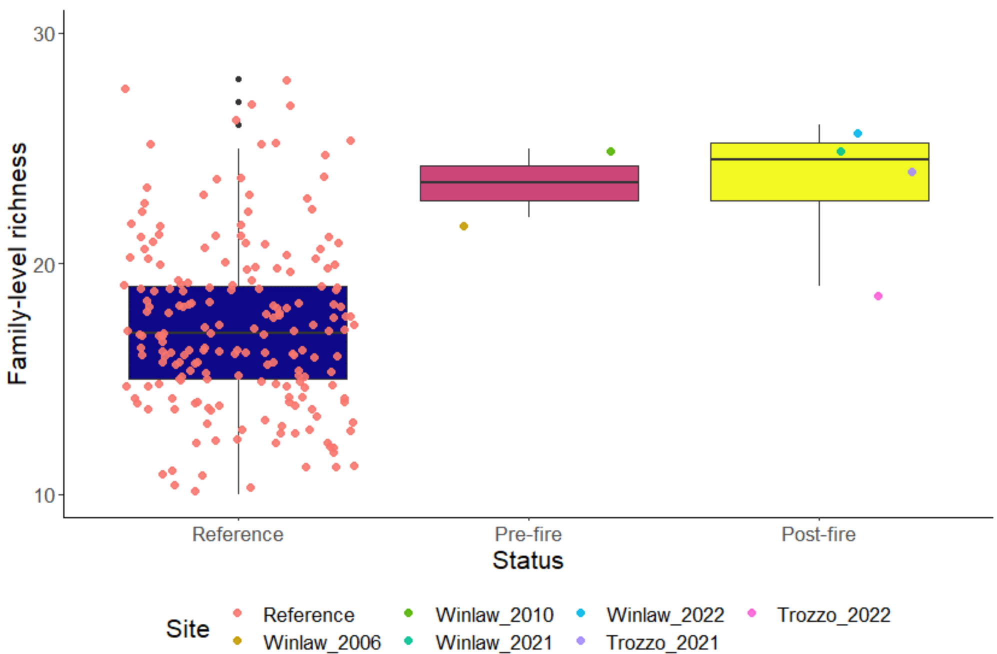

Figure 6: Family-level richness of the macroinvertebrate community of reference sites versus sampling at Winlaw and Trozzo Creeks in pre and post fire years. Reference = 198 reference sites within the Columbia Basin Model monitored from 2003 to 2018. Winlaw and Trozzo Creeks are unreplicated for each year and are pooled by pre-fire (Winlaw only) or post-fire (Winlaw and Trozzo) status for graphical inspection. Black dots indicate outlier percentiles.

The abundance of all 198 reference sites collected from 2003 to 2018 from all sites within the Columbia Basin Model was graphed versus sites from Winlaw and Trozzo Creeks. The median abundance of the 198 reference sites was 1,775 with an interquartile range of 2,643 (25^{th}-75^{th} percentiles of 774-3417).

The abundance of Winlaw Creek was within the normal range of abundance of all reference sites in 2006 (abundance = 1,345) and below the normal range in 2010 (abundance = 404). All samples within Winlaw and Trozzo Creeks following the fire were above the 75^{th} percentile and the normal range of reference sites.

In 2021 the total abundance of macroinvertebrates within Winlaw and Trozzo Creeks was 3788 and 8880, respectively while in 2022 the abundance of Winlaw and Trozzo Creeks were 3913 and 8320 respectively. This indicates that post-fire abundance was at or higher than the normal range (50^{th}-75^{th} percentile 703-2264) of all sites within the Columbia Basin Model, particularly in Trozzo Creek.

The spread of reference sites for the subset of data within the Columbia Mountains and Highlands ecoregion in which Winlaw and Trozzo Creeks are located was examined as a comparison to reference sites within the whole Columbia Basin Model. The total abundance of macroinvertebrates for each of 107 reference sites collected between 2007 and 2018 was graphed versus sites from Winlaw and Trozzo Creeks. The median abundance of the 107 reference sites was 1,326 with and interquartile range of 1,561 with a normal range (25^{th}-75^{th} percentile of 703-2264).

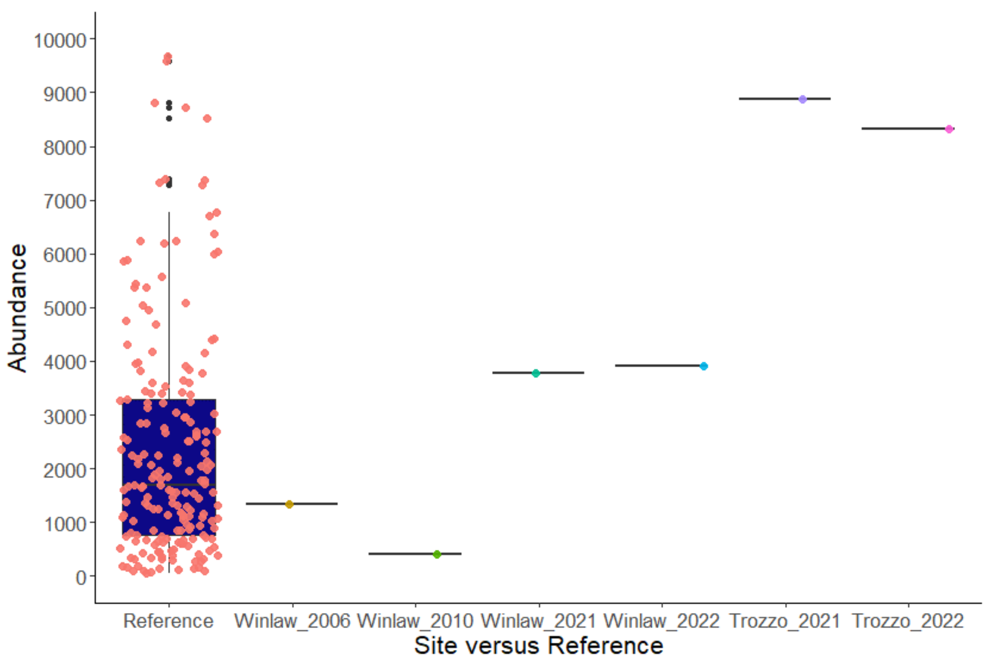

Figure 7: The abundance of macroinvertebrates at reference sites versus Winlaw and Trozzo Creeks. Reference = 198 reference sites within the Columbia Basin Model monitored from 2003 to 2018. Winlaw and Trozzo Creeks are unreplicated for each year. Creek_Year is indicated with a horizontal line and red dot for Winlaw and Trozzo Creeks. Black dots indicate outliers.

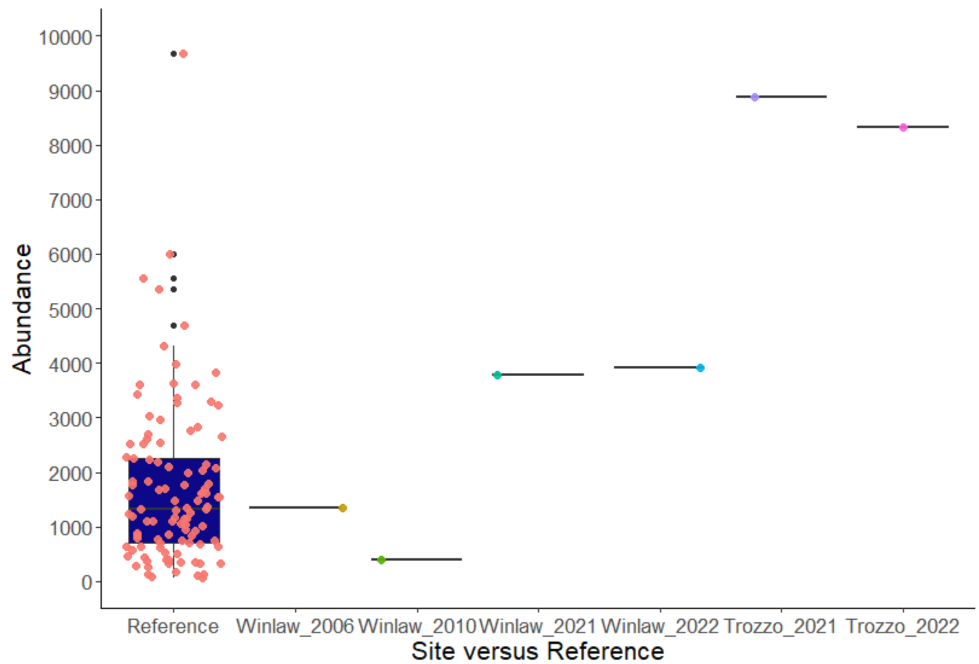

Figure 8: Macroinvertebrate abundance of reference sites versus Winlaw and Trozzo Creeks for a subset reference = 107 reference sites within the Columbia Mountains and Highlands ecoregion monitored from 2007 to 2018. Winlaw and Trozzo Creeks are unreplicated for each year. Creek_Year is indicated with a horizontal line and red dot for Winlaw and Trozzo Creeks. Black dots indicate outliers.

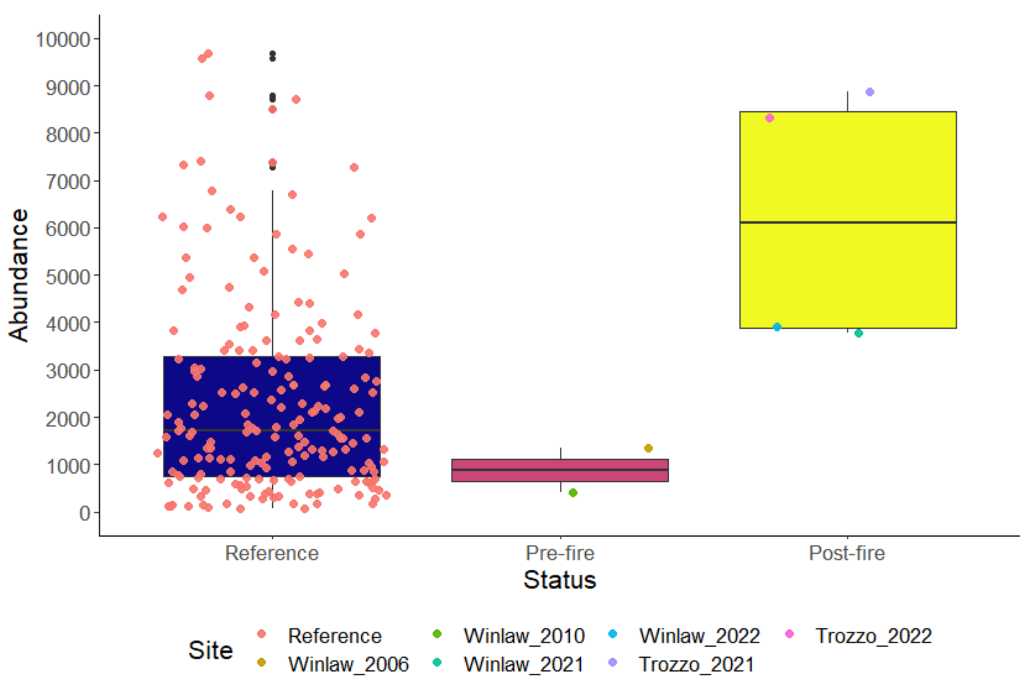

Figure 9: The abundance of macroinvertebrates at reference sites versus sampling at Winlaw and Trozzo Creeks in pre and post fire years. Reference = 198 reference sites within the Columbia Basin Model monitored from 2003 to 2018. Winlaw and Trozzo Creeks are unreplicated for each year and are pooled by pre-fire (Winlaw only) or post-fire (Winlaw and Trozzo) status for graphical inspection. Black dots indicate outliers.

Discussion

The impacts of wildfire on stream macroinvertebrates depend on local watershed characteristics including factors such as vegetation, geology, soils, water quality and interacting with burn severity (Coble et al. 2023, Arkle et al. 2010) and climate variables (Cooper et al. 2021, Rugenski and Minshall, 2014). Some studies show that increases in peak flows and sediment can depress macroinvertebrate populations or decrease richness (Katos 2013) and that these effects may be related to the level of disturbance following a fire and impacts to macroinvertebrate habitat (Buckingham et al. 2015). Arkle et al. (2010) observed increased annual variability in macroinvertebrate communities following wildfire due to an interaction between fire severity, peak flows and fluctuating habitat conditions for macroinvertebrates.

The CABIN BEAST analysis resulted in a mild divergence from reference sites in 2006 and 2010 for pre-fire monitoring of Winlaw Creek and reference condition for sampling carried out at 76-and 440-days from the initiation of the wildfire in 2021 and 2022, respectively. Trozzo Creek was found to be divergent from reference sites 76-days from the initiation of the fire but showed signs of recovery at 470-days post-fire.

Graphical inspection of the macroinvertebrate data suggests that the macroinvertebrate community increased in abundance at both Winlaw and Trozzo creeks following the wildfire with less change in the richness or composition of the macroinvertebrate community accounting for some of the CABIN BEAST results above. In addition, the number of EPT families, an indicator of high-water quality, in Winlaw and Trozzo creeks was higher than reference means both before and after the Trozzo Creek wildfire.

Increases in macroinvertebrate abundance observed in the fall of 2021 and 2022 in Winlaw and Trozzo creeks are likely due to an enrichment effect from increases in nutrients post-wildfire which remained high up to two years after the fire. Fall monitoring of total nitrogen levels in Winlaw Creek post-fire were 31.7- and 1.8-times in 2021 and 2022, respectively relative to pre-fire monitoring in 2020. Total nitrogen levels in Trozzo Creek post-fire were 2.7- and 2.0-times in the fall of 2021 and 2022, respectively relative to fall pre-fire monitoring in 2020. Monitoring of fall total phosphorus levels in Winlaw Creek post-fire were 80.9- and 1.2-times in 2021 and 2022, respectively relative to pre-fire monitoring in 2020. Total phosphorus levels in Trozzo Creek post-fire were 5.1- and 1.2-times fall pre-fire monitoring in 2020 in the fall of 2021 and 2022, respectively.

Past work has also shown that macroinvertebrate community structure and abundance can be affected by changes to stream water quality including export of nutrients (Cooper et al. 2021), metals, sediment (Katos 2013) and increases in temperature (Gleaves 2017, Oliver et al. 2012, Minshall et al. 1989) or changes to channel morphology following a wildfire. But the abundance, density or biomass of macroinvertebrates can increase after a fire through the export of nutrients and bottom-up drivers such as increases in periphyton and microbial activity that provide food for macroinvertebrates (Gleaves 2017, Roome et al. 2011, Minshall 2003).

A recent study by Coble et al. 2023 identified positive correlations between fire severity and decreased overstory riparian vegetation, increased light, dissolved organic concentrations and macroinvertebrate densities. In contrast in this study, negative relationships were quantified between fire severity and canopy cover, large woody diameter, macroinvertebrate diversity and fish densities. In this study, low winter rainfall was thought to ameliorate sediment and woody debris delivery resulting in non-significant impacts of these variables.

Macroinvertebrate community structure can also be negatively impacted by wildfire through the loss of sensitive species and a predominance of species adapted to disturbance (Katos 2013, Minshall et al. 2001a and 2001b, Minshall et al. 1997, Rugenski and Minshall, 2014). However, these types of changes are usually associated with more intense burns and crown fires greater than 50% of the catchment (Minshall 2003). In contrast, the Trozzo wildfire burned 14% of Winlaw Creek and 37% of Trozzo Creek catchments when moderate and high burn severity areas are totalled and possibly why we did not see a loss of sensitive taxa including EPT organisms.

The community structure of macroinvertebrates in Winlaw or Trozzo creeks remained similar to pre-fire and reference sites following the fire. In part, this is likely because the fire severity overall and at lower elevations was moderate with riparian zones still intact and was accompanied by flushing of fines and a lack of channel restructuring at the monitoring sites. In contrast, upper elevation reaches where there was higher burn severity, sedimentation and channel restructuring due to debris flow (SiCo 2023) may have greater impacts to the macroinvertebrate community in those locations but were not monitored. Higher burn severities in upper elevations of Winlaw or Trozzo creeks could be detrimental to macroinvertebrate communities or increase the annual variability in macroinvertebrate communities at upper elevation sites. Interactions between fire severity, peak flows and dynamics in sediment, large woody debris, riparian cover and organic debris which decreases the stability of habitat quality for macroinvertebrates (Arkle et al 2010).

Long-term effects on the macroinvertebrate community have been found to be correlated with the persistence of fire impacts to hydrology (Coble et al 2023, Rugenski and Minshall 2014, Minshall 2003), channel alteration (Minshall 2003), stream water quality (Martens et al. 2019) and habitat quality (Arkle et al. 2010) particularly in watersheds that have other cumulative disturbances (Minshall 2003) or salvage logging (Martens et al. 2019).

Increases in macroinvertebrate abundances in Winlaw and Trozzo creeks at lower elevations are likely to persist while increases in nutrient export remains elevated. In the future, a return to baseline of both nutrient concentration and abundance of macroinvertebrates could be a signal that the watershed is recovering particularly if other indicators of watershed recovery also return to baseline and hazard ratings decline.

Recommendations

1. Continue water quality and quantity monitoring and biomonitoring into the future until post-fire hazard ratings decline.
2. Minimize cumulative disturbance to the watershed while the catchments are in recovery.
3. Consider further monitoring in upper elevation reaches where there is channel restructuring, sedimentation and greater impacts from wildfire on the stream channel.
4. Increase baseline pre-fire monitoring in local streams at higher risk to wildfire impacts to better evaluate and communicate post-fire impacts to community members in the event of a future wildfire.

5. Include the evaluation the impacts of wildfire on macroinvertebrates more broadly in BC to incorporate a greater number of streams and replicate findings in comparison to Winlaw and Trozzo creeks using publicly open data from the CABIN database.
6. Collaborate with other community groups carrying out post-fire water quality, hydrological and CABIN monitoring to compare results.
7. In the future consider integrating the current and past biomonitoring from Lemon Creek in the analyses also affected by the Trozzo fire.
8. Carry out analyses at the genus level for current data (traditional taxonomy) where it exists. Time restrictions prevented this analysis in the current report.
9. Investigate use of tolerant and sensitive categories of macroinvertebrates finetuned for impacts from disturbance from resource development (sedimentation, erosion, nutrient increases) described in Strachan (2020).
10. Explore the use of multivariate methods to examine clustering macroinvertebrate data and environmental variables. Time restrictions prevented further analyses.
11. Incorporate genomic eDNA from the STREAM (Sequencing The Rivers for Environmental Assessment and Monitoring) carried out for Winlaw Creek (2021 and 2022) and Trozzo Creek (2021 only). Availability of the data prevented this analysis; however, this data will be available in the future. The metrics from the eDNA monitoring could be used to confirm traditional taxonomy metrics and strengthen results and can be carried out at a lower taxonomic level (genus or taxa free biodiversity levels).

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Appendix 1: Metrics from test sites versus reference sites

Metric	NJWIN01_2006	NJWIN01_2010	NJWIN01_2021	NJWIN01_2022	NJTRO001_2021	NJTRO001_2022	RefMean (n=13)	StdDev	SE	SE_Upper	SE_Lower
% Chironomidae	9.74	4.46	11.55	18.91	10.14	21.88	25.75	24.49	6.79	32.54	18.96
% Coleoptera	0.97	9.16	4.62	6.09	8.78	1.92	0.96	2.03	0.56	1.52	0.40
% Diptera + Non-insects	10.26	14.60	14.52	22.44	18.02	24.76	29.70	25.36	7.03	36.73	22.67
% Ephemeroptera	75.69	22.52	58.09	45.51	56.08	36.54	43.30	22.66	6.28	49.59	37.02
% Plecoptera	11.15	30.45	14.85	11.54	15.54	36.06	20.75	13.11	3.64	24.39	17.11
% Trichoptera	1.93	23.27	6.93	12.18	1.58	0.72	4.88	6.81	1.89	6.77	2.99
% Ephemeroptera that are Baetidae	82.81	26.37	30.68	56.34	0.40	9.21	43.33	23.03	6.39	49.72	36.94
% EPT Individuals	88.77	76.24	79.87	69.23	73.20	73.32	68.93	25.52	7.08	76.01	61.86
% Filterers		1.42	0.32	0.28			0.61		0.00	0.61	0.61
% Gatherers	24.89	43.13	42.21	38.10	43.57	45.73	49.98	20.31	5.63	55.62	44.35
% Predators	11.97	38.39	19.81	23.81	15.90	22.76	31.89	22.54	6.25	38.14	25.64
% Scrapers	78.56	39.81	57.47	53.22	58.82	31.73	41.53	21.95	6.09	47.62	35.44
% Odonata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
% of 2 dominant taxa	72.42	28.71	49.50	44.55	61.94	44.95	59.14	16.72	4.64	63.78	54.50
% of 5 dominant taxa	91.30	57.92	77.56	72.76	86.71	82.93	83.38	8.13	2.25	85.63	81.13
% of dominant taxa	62.68	14.85	31.68	25.64	49.55	23.08	41.73	17.70	4.91	46.64	36.83
% Tribe Tanyatarisini									0.00	0.00	0.00
% Trichoptera that are Hydropsychida	3.85	19.15	23.81	5.26	0.00	0.00	14.67	24.20	6.71	21.38	7.96
Chironomidae taxa (genus level only)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	1.00	1.00
Coleoptera taxa	1.00	1.00	1.00	1.00	1.00	1.00	0.30	0.53	0.15	0.45	0.15
Diptera taxa	5.00	7.00	4.00	3.00	5.00	2.00	3.13	1.17	0.32	3.46	2.81
Ephemeroptera taxa	5.00	3.00	5.00	5.00	4.00	4.00	3.80	0.76	0.21	4.01	3.59
EPT Individuals (Sum)	1194.00	308.00	3025.00	2700.00	6500.00	6100.00	1328.89	1129.58	313.29	1642.18	1015.60
EPT taxa (no)	16.00	13.00	16.00	16.00	13.00	13.00	11.00	2.53	0.70	11.70	10.30
Hilsenhoff Family index (Mid-Atlantic)	3.74	3.24	3.78	3.91	4.46	2.81	3.75	0.98	0.27	4.02	3.48
Hilsenhoff Family index (North-West)	3.74	3.24	3.78	3.91	4.46	2.81	3.75	0.87	0.24	4.00	3.51
Intolerant taxa			1.00				1.00		0.00	1.00	1.00
Long-lived taxa	2.00	2.00	4.00	3.00	5.00	3.00	2.90	1.52	0.42	3.32	2.48
No. Clinger Taxa	16.00	15.00	34.00	29.00	26.00	22.00	16.97	5.37	1.49	18.45	15.48
No. EPT individuals/Chironomids+EPT Individuals	0.90	0.94	0.87	0.79	0.88	0.77	0.73	0.26	0.07	0.80	0.65
Odonata taxa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pielou's Evenness	0.47	0.84	0.70	0.71	0.58	0.70	0.65	0.15	0.04	0.69	0.61
Plecoptera taxa	6.00	5.00	5.00	5.00	7.00	6.00	4.73	1.26	0.35	5.08	4.38
Shannon-Wiener Diversity	1.45	2.71	2.26	2.33	1.84	2.06	1.82	0.47	0.13	1.95	1.69
Simpson's Diversity	0.58	0.91	0.83	0.86	0.72	0.84	0.73	0.16	0.05	0.78	0.69
Simpson's Evenness	0.11	0.46	0.24	0.27	0.15	0.32	0.29	0.11	0.03	0.32	0.26
Tolerant individuals (%)					0.65		0.61		0.00	0.61	0.61
Total Abundance	1362.00	422.00	3850.00	4462.50	9180.00	9140.00	1823.33	1298.44	360.12	2183.45	1463.21
Total No. of Taxa	22.00	25.00	25.00	26.00	24.00	19.00	16.20	3.78	1.05	17.25	15.15
Trichoptera taxa	5.00	5.00	6.00	6.00	2.00	3.00	2.47	1.57	0.44	2.90	2.03

Test sites are unreplicated, RefMean=mean of 13 Group 1 reference sites with SD and SE in following columns. Metrics were calculated at the family-level.