**Title:** Catchment geology preconditions spatio-temporal heterogeneity of ecosystem functioning in forested headwater streams

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**Abstract**

Catchment geology can affect water chemistry and groundwater influence, eventually affecting macroinvertebrate communities, but its effects on stream functions such as leaf decomposition have been scarcely investigated. To understand the effects of geology on leaf decomposition, we conducted leaf litter experiments in streams with volcanic and non-volcanic substrata using fine and coarse mesh bags. Volcanic spring-fed streams showed lower temperature in summer and higher temperature in winter (with temperature difference being more pronounced later in incubation) than non-volcanic streams. Macroinvertebrate communities captured inside coarse litter bags differed in the two stream types in both seasons, mainly because of shredder communities. Shredder abundance and biomass were higher in volcanic streams in both seasons. Geology-dependent temperature influenced microbe-mediated decomposition in both seasons, with total phosphorus as an additional driver in winter. Summer temperature was associated with an overall positive effect on the abundance of shredders, which affected invertebrate-mediated decomposition, but this was not evident in winter. Shredder activity in volcanic streams compensated for temperature-dependent microbial activity resulting in an overall balance in leaf decomposition. Spring-fed systems are valuable ecosystems, particularly for cold-adapted species. Thus, understanding these understudied ecosystems will significantly aid in their appropriate conservation.

**Keywords:** leaf decomposition, shredders, spring-fed streams, temperature, invertebrates

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**Data Availability Statement**

Data are present in the Supplementary Information and available from the corresponding author upon reasonable request.

**Declarations**

**Conflict of interest**

The authors have no competing interests to declare that are relevant to the contents of this research article.

**SUPPLEMENTARY MATERIALS**

**Appendix S1.** Two types of leaf traps used in the decomposition experiment: (left) fine mesh net (257 µm × 266 µm) and (right) coarse mesh net (black part: 3.9 mm × 3.9 mm; green part: 1 cm × 1 cm). Two mesh sizes were used for coarse mesh bags to allow the entrance of bigger shredders (e.g., Limnephilidae and Tipulidae) (green part facing upstream) and, at the same time prevent the loss of leaf fragments (black part facing downstream).

**Appendix S2.** Litter bag preparation in summer (a) and winter (b).

Fallen leaves of *A. japonica* were collected along the banks of some of the study sites. Only leaves having green color greater than 50% of the whole leaf area were chosen. To approximate the initial dry weight of green leaves, 100 leaves of different sizes were used. Surface Leaf Area (SLA) was obtained by taking photos of leaves before oven-drying and processing the photos using ImageJ software. The corresponding dry weight of each of the 100 leaves was measured after oven-drying for seven days. Using multiple regression, the relationship between wet weight, SLA, and dry weight was obtained [approximate initial dry weight = -0.0044 + (1.4784 × 10-06 × SLA) + (0.2234 × Wet Weight), R2=0.82]. Similarly, using the ratio of dry weight and wet weight data, an equivalence of ~12g wet weight of green leaves was prepared to obtain approximately 3g corresponding dry weight. Green leaves were air-dried for seven days before setting in the river. In addition to green leaves, old senescent leaves collected a few years ago were also used. Using both green and senescent leaves enables adequate imitation of the existing natural condition in the river during the summer period, where green leaves reach the river laterally or longitudinally from riparian trees while senescent leaves, particularly the ones left by the winter season, are also still present.

New senescent leaves were obtained by catching freshly fallen *A. japonica* leaves in a headwater stream in the Toyohira Watershed (Latitude: 42.950166, Longitude: 141.152383). Collection nets were hung horizontally above ground for two weeks in October 2018, and leaves caught on the net were further air-dried until setting up on the 1st week of November 2018. Both old senescent (collected a few years ago) and new senescent leaves were used separately in leaf traps. Every replicate had coarse and fine mesh traps of old senescent leaves and another pair of new senescent leaves.

**Fig. S1** A total of 179 samples belonging to 15 types were measured for their carbon and nitrogen stable isotope ratios using an isotope ratio mass spectrometer coupled to an elemental analyzer (see Negishi et al. 2019 for details of sampling methods and analytical procedures of samples; carbon isotope ratios were corrected for lipid contents using methanol–chloroform method). For fish and invertebrate samples, one measurement was done on different individuals. Samples were collected in May and December 2018; several sample types were obtained from some streams only due to their relative rarity. Each dot and bar for each sample type represents the average value and standard deviations. The numbers accompanying each mean value denote sample size. Constituents in the category of primary food resources are underlined.



Reference:

Negishi, J. N., Terui, A., Nessa, B., Miura, K., Oiso, T., Sumitomo, K., ... Nakamura, F. (2019). High resilience of aquatic community to a 100-year flood in a gravel-bed river. *Landscape and Ecological Engineering*, 15, 143-154. DOI:10.1007/s11355-019-00373-y

**Fig. S2** Examples of exponential decay models developed to estimate the decomposition rate *k* of leaf litter bags. Regression model lines were described for two groups (n=50 for each stream type in each figure). 

**Fig. S3** Boxplots showing the proportion of abundance and biomass of shredders collected inside coarse litter bags from the two stream types in two seasons.



**Table S1.** General characteristics (S1.1), channel and flow characteristics (two seasons) (S1.2), and vegetation characteristics (S1.3) of each site in the two stream types. Annual mean precipitation and air temperature were determined using 1980 to 2010 data obtained from the Ministry of Land, Infrastructure, Transport, and Tourism of Japan (milt.go.jp) at the resolution of 1km x 1km. Spatial data (polygons) were delineated by catchment boundaries, and the average values were obtained using QGIS (version 3.16.12) for each catchment. Channel width was measured using a transect line set across one glide area per stream; the depth of each channel was taken at 50 cm intervals along the transect. Channel depth is reported as the average across the glide in each stream. Vegetation characteristics were defined by land-use classifications conducted based on high-resolution land-use and land cover maps with 11 thematic classes (version 21.11, Jaxa 2021). The ‘deciduous broadleaf forest’ and ‘evergreen broadleaf forest’ were defined as broadleaf forest, and ‘deciduous needleleaf forest’ and ‘evergreen needleleaf forest’ were defined as needleleaf forest. The proportion of each forest type in the catchments (%) was calculated with ArcGIS Pro (Esri, version 2.4.0).

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Type | Site | Latitude | Longitude | Elevation (m) | Volcanic Proportion of Watershed (%) | Mean Annual Precipitation (mm) | Mean Annual Air Temperature (°C) |
| Volcanic | P4 | 43.17327 | 142.603 | 382.30 | 95 | 1063.71 | 4.13 |
| P7 | 43.32317 | 142.5436 | 335.70 | 100 | 1156.53 | 3.99 |
| P11 | 43.30612 | 142.5736 | 430.10 | 100 | 1292.58 | 2.66 |
| P12 | 43.30059 | 142.5864 | 464.50 | 100 | 1258.25 | 2.83 |
| P14 | 43.2244 | 142.5927 | 377.20 | 100 | 1079.69 | 3.77 |
| Non-volcanic | P105 | 43.13824 | 142.6235 | 383.40 | 0 | 1094.74 | 3.48 |
| P106 | 43.13545 | 142.437 | 301.20 | 0 | 1107.52 | 4.41 |
| P107 | 43.12224 | 142.4 | 310.70 | 0 | 1318.54 | 4.21 |
| P108 | 43.11911 | 142.3356 | 385.60 | 0 | 1580.80 | 3.11 |
| P109 | 43.22247 | 142.4024 | 243.60 | 32 | 1088.85 | 4.82 |

**(S1.1)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Type | Site | Catchment size (km2) | Slope | Summer |  | Winter |
| Channel Width (cm) | Channel depth (cm) |  | Channel Width (cm) | Channel depth (cm) |
| Volcanic | P4 | 16.37 | 6.30 | 430 | 19.6 |  | 545 | 19.6 |
| P7 | 3.33 | 5.80 | 300 | 23.0 |  | 350 | 26.4 |
| P11 | 8.25 | 7.40 | 250 | 19.0 |  | 303 | 13.1 |
| P12 | 19.26 | 3.60 | 315 | 31.0 |  | 492 | 24.1 |
| P14 | 6.28 | 5.60 | 200 | 19.3 |  | 315 | 18.3 |
| Non-volcanic | P105 | 7.26 | 3.30 | 400 | 17.4 |  | 280 | 14.6 |
| P106 | 9.89 | 4.20 | 585 | 30.7 |  | 450 | 20.4 |
| P107 | 8.25 | 3.90 | 570 | 17.6 |  | 390 | 16.6 |
| P108 | 16.09 | 2.40 | 547 | 32.5 |  | 360 | 17.3 |
| P109 | 10.03 | 6.35 | 420 | 15.7 |  | 350 | 12.9 |

**(S1.2)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Type | Site | % Forest Cover | % Broadleaf Forest | % Needleleaf Forest |
| Volcanic | P4 | 78.39 | 55.13 | 23.26 |
| P7 | 98.38 | 71.53 | 26.85 |
| P11 | 93.29 | 71.17 | 22.11 |
| P12 | 92.02 | 74.73 | 17.29 |
| P14 | 97.13 | 79.35 | 17.78 |
| Non-volcanic | P105 | 97.40 | 70.62 | 26.78 |
| P106 | 98.57 | 75.60 | 22.97 |
| P107 | 99.25 | 89.88 | 9.37 |
| P108 | 99.27 | 90.12 | 9.15 |
| P109 | 98.81 | 83.23 | 15.58 |

**(S1.3)**

**Table S2.** Mean dry biomass of invertebrates collected in the study streams in summer and winter. Ethanol-preserved samples were dried in a drying oven at 60°C for >24 hours before weighing. Sample size denotes the number of individuals measured. NA indicates the absence of data because no individuals were caught.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Order | Family | Summer |  | Winter |
| Biomass (mg) | Sample size |  | Biomass (mg) | Sample size |
| Ephemeroptera | Ameletidae | 0.24 | 1 |  | 0.78 | 4 |
| Baetidae | 0.28 | 3 |  | 0.07 | 2 |
| Caenidae | 0.00 | 1 |  | 0.41 | 1 |
| Ephemerellidae | 0.50 | 8 |  | 1.33 | 5 |
| Ephemeridae | 0.93 | 4 |  | 3.03 | 2 |
| Heptageniidae | 0.33 | 3 |  | 0.19 | 3 |
| Leptophlebiidae | 0.11 | 6 |  | 0.09 | 3 |
| Plecoptera | Capniidae† | 0.01 | 4 |  | 0.32 | 22 |
| Chloroperlidae | 0.39 | 8 |  | 0.49 | 7 |
| Nemouridae† | 0.16 | 12 |  | 0.23 | 13 |
| Perlidae | 0.34 | 1 |  | NA | 1 |
| Perlodidae | 0.25 | 5 |  | 4.22 | 4 |
| Taeniopterygidae | NA | 1 |  | 0.14 | 3 |
| Trichoptera | Brachycentridae | 1.46 | 1 |  | 1.05 | 5 |
| Glossosomatidae | 0.12 | 1 |  | 0.12 | 1 |
| Hydropsychidae | 4.20 | 1 |  | 0.17 | 1 |
| Lepidostomatidae† | 0.70 | 5 |  | 0.95 | 9 |
| Limnephilidae† | 7.18 | 15 |  | 6.15 | 17 |
| Phryganeidae | NA | 1 |  | 7.14 | 3 |
| Phryganopsychidae | NA | 1 |  | 3.04 | 2 |
| Rhyacophilidae | 2.75 | 7 |  | 1.12 | 10 |
| Stenopsychidae | NA | 1 |  | 0.86 | 1 |
| Uenoidae | 11.04 | 6 |  | 0.18 | 5 |
| Diptera | Ceratopogonidae | 0.04 | 3 |  | 0.21 | 3 |
| Chironomidae | 0.25 | 7 |  | 0.03 | 3 |
| Dixidae | NA | 1 |  | 0.16 | 1 |
| Empididae | NA | 1 |  | 0.16 | 1 |
| Psychodidae | 0.15 | 1 |  | 0.15 | 4 |
| Simuliidae | 0.07 | 5 |  | 0.07 | 5 |
| Tipulidae† | 11.57 | 10 |  | 3.95 | 16 |
| Hirudinea | Hirudinea | 0.45 | 2 |  | NA | 1 |
| Odonata | Gomphidae | 32.60 | 2 |  | NA | 1 |
| Amphipoda | Gammaridae† | 0.87 | 2 |  | 1.73 | 14 |
| Annelida | Annelida | 4.14 | 4 |  | 4.14 | 1 |
| Coleoptera | Dytiscidae | 0.38 | 2 |  | 0.58 | 3 |
| Elmidae | 0.11 | 5 |  | 0.13 | 3 |
| † shredder invertebrates |

**Table S3.** General water quality parameters (S3.1) and ions/nutrients (S3.2) in the two stream types in two seasons. Temperature (°C) pertains to the average temperature for each site during the whole incubation period. Current velocity (cm/s) was taken along a transect line (set across one glide area per stream) at 50cm intervals and was integrated with cross-sectional depth (see Table S1.2) to estimate channel discharge (m3/s).

**(S3.1)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Type | Site | Summer |   | Winter |
| EC (mS/m) | pH | Temperature (°C) | Discharge (m3/s) |   | EC (mS/m) | pH | Temperature (°C) | Discharge (m3/s) |
| Volcanic | P4 | 6.75 | 6.97 | 10.86 | 0.24 |  | 7.5 | 7.38 | 4.28 | 0.27 |
| P7 | 6.88 | 6.86 | 9.1 | 0.13 |  | 8.03 | 7.44 | 6.06 | 0.3 |
| P11 | 5.81 | 6.8 | 9.77 | 0.21 |  | 6.71 | 7.38 | 4.58 | 0.26 |
| P12 | 5.9 | 7.22 | 9.44 | 0.28 |  | 6.02 | 7.32 | 4.3 | 0.73 |
| P14 | 4.78 | 6.84 | 9.83 | 0.19 |   | 6.36 | 7.22 | 5.24 | 0.18 |
| Non-volcanic | P105 | 4.25 | 6.72 | 13.63 | 0.28 |  | 6.53 | 7.3 | 4.87 | 0.15 |
| P106 | 8 | 7.12 | 15.83 | 0.52 |  | 8.24 | 7.3 | 4.01 | 0.42 |
| P107 | 7.44 | 6.89 | 16.14 | 0.6 |  | 10.3 | 7.31 | 3.63 | 0.21 |
| P108 | 11.26 | 7.39 | 15.58 | 0.63 |  | 12.71 | 7.48 | 4.2 | 0.17 |
| P109 | 6.92 | 6.92 | 14.16 | 0.12 |   | 6.41 | 7.24 | 4.34 | 0.16 |
| Abbreviation: EC, Electrical Conductivity |

**(S3.2)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Type | Site | Summer |   | Winter |
| Cl- | NO3- | SO42- | TP | TN |   | Cl- | NO3- | SO42- | TP | TN |
| Volcanic | P4 | 2.85 | 7.83 | 5.24 | 0.033 | 1.828 |  | 3.42 | 8.12 | 5.36 | 0.030 | 1.701 |
| P7 | 2.82 | 0.68 | 5.05 | 0.018 | 0.286 |  | 3.40 | 0.82 | 4.39 | 0.037 | 0.314 |
| P11 | 2.30 | 0.78 | 10.00 | 0.024 | 0.288 |  | 3.52 | 1.22 | 8.14 | 0.016 | 0.335 |
| P12 | 1.86 | 0.00 | 2.82 | 0.011 | 0.197 |  | 2.86 | 0.35 | 2.70 | 0.015 | 0.121 |
| P14 | 2.40 | 1.42 | 3.42 | 0.028 | 0.396 |  | 2.61 | 1.76 | 2.73 | 0.028 | 0.435 |
| Non-volcanic | P105 | 1.92 | 1.05 | 3.15 | 0.005 | 0.364 |  | 2.87 | 1.40 | 3.03 | 0.014 | 0.355 |
| P106 | 2.90 | 0.65 | 3.72 | 0.142 | 0.306 |  | 5.28 | 0.66 | 4.10 | 0.014 | 0.255 |
| P107 | 2.30 | 1.07 | 5.72 | 0.007 | 0.372 |  | 3.41 | 1.03 | 7.76 | 0.013 | 0.255 |
| P108 | 3.09 | 1.11 | 9.60 | 0.010 | 0.391 |   | 4.79 | 0.89 | 13.00 | 0.012 | 0.354 |
| P109 | 4.64 | 0.50 | 4.79 | 0.032 | 0.280 |  | 6.86 | 0.61 | 5.31 | 0.024 | 0.262 |
| *Note:* All measurements are in mg/L; Abbreviations: TP, total phosphorus; TN, total nitrogen |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Order/Class | Family | Volcanic |  | Non-volcanic |
| mean | SD | total | % |  | mean | SD | total | % |
| Ephemeroptera | Ameletidae | 0.0 | 0.2 | 2.0 | 0.0 |  | 0.0 | 0.1 | 1.0 | 0.0 |
| Baetidae | 0.3 | 0.8 | 15.0 | 0.4 |  | 0.0 | 0.1 | 1.0 | 0.0 |
| Caenidae | 0.0 | 0.0 | 0.0 | 0.0 |  | 0.0 | 0.1 | 1.0 | 0.0 |
| Ephemerellidae | 6.7 | 10.0 | 333.0 | 8.0 |  | 0.8 | 1.1 | 39.0 | 1.4 |
| Ephemeridae | 0.0 | 0.1 | 1.0 | 0.0 |  | 0.3 | 0.7 | 15.0 | 0.5 |
| Heptageniidae | 0.1 | 0.3 | 6.0 | 0.1 |  | 0.0 | 0.2 | 2.0 | 0.1 |
| Leptophlebiidae | 9.4 | 9.7 | 472.0 | 11.3 |  | 0.1 | 0.4 | 5.0 | 0.2 |
| Plecoptera | Capniidae† | 0.1 | 0.4 | 6.0 | 0.1 |  | 0.2 | 1.3 | 9.0 | 0.3 |
| Chloroperlidae | 1.8 | 3.2 | 92.0 | 2.2 |  | 0.8 | 2.4 | 40.0 | 1.4 |
| Nemouridae† | 11.0 | 15.4 | 548.0 | 13.1 |  | 3.2 | 6.3 | 159.0 | 5.6 |
| Perlidae | 0.0 | 0.1 | 1.0 | 0.0 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Perlodidae | 6.7 | 9.5 | 333.0 | 8.0 |  | 1.1 | 2.5 | 55.0 | 1.9 |
| Taeniopterygidae | 0.0 | 0.0 | 0.0 | 0.0 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Trichoptera | Brachycentridae | 0.0 | 0.1 | 1.0 | 0.0 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Glossosomatidae | 0.0 | 0.3 | 2.0 | 0.0 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Hydropsychidae | 0.0 | 0.0 | 0.0 | 0.0 |  | 0.0 | 0.2 | 2.0 | 0.1 |
| Lepidostomatidae† | 2.3 | 5.1 | 113.0 | 2.7 |  | 0.7 | 2.1 | 36.0 | 1.3 |
| Limnephilidae† | 0.9 | 1.6 | 47.0 | 1.1 |  | 0.7 | 1.3 | 35.0 | 1.2 |
| Phryganeidae | 0.0 | 0.0 | 0.0 | 0.0 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Phryganopsychidae | 0.0 | 0.0 | 0.0 | 0.0 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Rhyacophilidae | 1.6 | 2.0 | 80.0 | 1.9 |  | 0.2 | 0.4 | 9.0 | 0.3 |
| Stenopsychidae | 0.0 | 0.0 | 0.0 | 0.0 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Uenoidae | 0.5 | 1.1 | 25.0 | 0.6 |  | 0.4 | 1.1 | 18.0 | 0.6 |
| Diptera | Ceratopogonidae | 0.2 | 0.5 | 12.0 | 0.3 |  | 0.2 | 0.5 | 10.0 | 0.4 |
| Chironomidae | 37.4 | 73.1 | 1872.0 | 44.9 |  | 46.3 | 63.1 | 2313.0 | 81.3 |
| Dixidae | 0.0 | 0.0 | 0.0 | 0.0 |  | 0.0 | 0.1 | 1.0 | 0.0 |
| Empididae | 0.0 | 0.0 | 0.0 | 0.0 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Psychodidae | 0.2 | 0.7 | 10.0 | 0.2 |  | 0.0 | 0.1 | 1.0 | 0.0 |
| Simuliidae | 0.5 | 2.0 | 23.0 | 0.6 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Tipulidae† | 1.8 | 2.4 | 88.0 | 2.1 |  | 1.3 | 1.8 | 63.0 | 2.2 |
| Coleoptera | Dytiscidae | 0.0 | 0.1 | 1.0 | 0.0 |  | 0.0 | 0.1 | 1.0 | 0.0 |
| Elmidae | 1.2 | 2.4 | 58.0 | 1.4 |  | 0.1 | 0.4 | 7.0 | 0.2 |
| Amphipoda | Gammaridae† | 0.3 | 1.2 | 16.0 | 0.4 |  | 0.1 | 0.6 | 4.0 | 0.1 |
| Annelida |  | 0.2 | 0.5 | 8.0 | 0.2 |  | 0.3 | 0.8 | 15.0 | 0.5 |
| Hirudinea |  | 0.1 | 0.4 | 4.0 | 0.1 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Odonata | Gomphidae | 0.0 | 0.0 | 0.0 | 0.0 |  | 0.0 | 0.2 | 2.0 | 0.1 |
| All taxa together |  | 2.31 |  |  |  |  | 1.58 |  |  |  |
| † shredder invertebrates |

**Table S4.** Abundance of invertebrates (number of individuals in each leaf litter bag) collected during the study in summer (S4.1) and winter (S4.2), and biomass (mg) of invertebrates in summer (S4.3) and winter (S4.4). SD denotes the standard deviation of the mean.

**(S4.1)**

**(S4.2)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Order/Class | Family | Volcanic |  | Non-volcanic |
| mean | SD | total | % |  | mean | SD | total | % |
| Ephemeroptera | Ameletidae | 1.1 | 1.9 | 55.0 | 0.8 |  | 1.6 | 3.5 | 81.0 | 1.7 |
| Baetidae | 1.6 | 2.4 | 81.0 | 1.1 |  | 1.3 | 3.1 | 67.0 | 1.4 |
| Caenidae | 0.2 | 1.3 | 9.0 | 0.1 |  | 0.0 | 0.1 | 1.0 | 0.0 |
| Ephemerellidae | 20.5 | 25.2 | 1027.0 | 14.2 |  | 2.5 | 4.0 | 126.0 | 2.7 |
| Ephemeridae | 0.0 | 0.1 | 1.0 | 0.0 |  | 0.0 | 0.1 | 1.0 | 0.0 |
| Heptageniidae | 0.7 | 1.1 | 35.0 | 0.5 |  | 0.6 | 1.2 | 30.0 | 0.6 |
| Leptophlebiidae | 9.1 | 9.6 | 456.0 | 6.3 |  | 3.3 | 5.7 | 165.0 | 3.5 |
| Plecoptera | Capniidae† | 10.3 | 9.4 | 517.0 | 7.1 |  | 18.8 | 18.9 | 939.0 | 20.1 |
| Chloroperlidae | 2.7 | 4.0 | 136.0 | 1.9 |  | 1.5 | 4.4 | 75.0 | 1.6 |
| Nemouridae† | 5.1 | 5.8 | 257.0 | 3.5 |  | 8.7 | 10.7 | 437.0 | 9.3 |
| Perlidae | 0.0 | 0.0 | 0.0 | 0.0 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Perlodidae | 5.0 | 6.0 | 251.0 | 3.5 |  | 0.7 | 1.3 | 37.0 | 0.8 |
| Taeniopterygidae | 0.0 | 0.2 | 2.0 | 0.0 |  | 1.1 | 3.8 | 56.0 | 1.2 |
| Trichoptera | Brachycentridae | 1.8 | 5.2 | 90.0 | 1.2 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Glossosomatidae | 0.0 | 0.1 | 1.0 | 0.0 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Hydropsychidae | 0.0 | 0.1 | 1.0 | 0.0 |  | 0.1 | 0.2 | 3.0 | 0.1 |
| Lepidostomatidae† | 21.9 | 36.6 | 1095.0 | 15.1 |  | 6.9 | 8.0 | 343.0 | 7.3 |
| Limnephilidae† | 3.5 | 7.4 | 173.0 | 2.4 |  | 0.6 | 1.2 | 32.0 | 0.7 |
| Phryganeidae | 0.1 | 0.2 | 3.0 | 0.0 |  | 0.1 | 0.5 | 7.0 | 0.1 |
| Phryganopsychidae | 0.0 | 0.0 | 0.0 | 0.0 |  | 0.0 | 0.1 | 1.0 | 0.0 |
| Rhyacophilidae | 0.9 | 1.1 | 45.0 | 0.6 |  | 0.0 | 0.2 | 2.0 | 0.0 |
| Stenopsychidae | 0.0 | 0.1 | 1.0 | 0.0 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Uenoidae | 0.4 | 2.5 | 22.0 | 0.3 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Diptera | Ceratopogonidae | 0.1 | 0.4 | 5.0 | 0.1 |  | 0.1 | 0.3 | 5.0 | 0.1 |
| Chironomidae | 55.9 | 53.1 | 2797.0 | 38.6 |  | 43.6 | 71.4 | 2182.0 | 46.6 |
| Dixidae | 0.0 | 0.0 | 0.0 | 0.0 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Empididae | 0.0 | 0.0 | 0.0 | 0.0 |  | 0.0 | 0.1 | 1.0 | 0.0 |
| Psychodidae | 0.2 | 0.5 | 12.0 | 0.2 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Simuliidae | 0.4 | 1.3 | 18.0 | 0.2 |  | 1.1 | 3.3 | 53.0 | 1.1 |
| Tipulidae† | 1.2 | 1.7 | 61.0 | 0.8 |  | 0.3 | 0.8 | 17.0 | 0.4 |
| Coleoptera | Dytiscidae | 0.0 | 0.1 | 1.0 | 0.0 |  | 0.2 | 0.7 | 10.0 | 0.2 |
| Elmidae | 1.1 | 1.5 | 53.0 | 0.7 |  | 0.0 | 0.1 | 1.0 | 0.0 |
| Amphipoda | Gammaridae† | 0.8 | 2.3 | 40.0 | 0.6 |  | 0.1 | 0.4 | 5.0 | 0.1 |
| Annelida |  | 0.0 | 0.0 | 0.0 | 0.0 |  | 0.1 | 0.4 | 3.0 | 0.1 |
| Hirudinea |  | 0.0 | 0.0 | 0.0 | 0.0 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| Odonata | Gomphidae | 0 | 0 | 0 | 0 |  | 0.0 | 0.0 | 0.0 | 0.0 |
| All taxa together  |  | 4.0 |  |  |  |  | 2.6 |  |  |  |
| † shredder invertebrates |

**(S4.3)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Order/Class | Family | Volcanic |  | Non-volcanic |
| mean | SD | total | % |  | mean | SD | total | % |
| Ephemeroptera | Ameletidae | 0.01 | 0.05 | 0.47 | 0.02 |  | 0.00 | 0.03 | 0.24 | 0.01 |
| Baetidae | 0.08 | 0.22 | 4.18 | 0.15 |  | 0.01 | 0.04 | 0.28 | 0.01 |
| Caenidae | 0.00 | 0.00 | 0.00 | 0.00 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Ephemerellidae | 3.34 | 5.01 | 167.13 | 5.84 |  | 0.39 | 0.57 | 19.57 | 0.97 |
| Ephemeridae | 0.02 | 0.13 | 0.93 | 0.03 |  | 0.28 | 0.66 | 13.96 | 0.69 |
| Heptageniidae | 0.04 | 0.11 | 1.95 | 0.07 |  | 0.01 | 0.06 | 0.65 | 0.03 |
| Leptophlebiidae | 1.06 | 1.08 | 52.86 | 1.85 |  | 0.01 | 0.04 | 0.56 | 0.03 |
| Plecoptera | Capniidae† | 0.00 | 0.00 | 0.04 | 0.00 |  | 0.00 | 0.01 | 0.06 | 0.00 |
| Chloroperlidae | 0.72 | 1.25 | 36.24 | 1.27 |  | 0.32 | 0.96 | 15.76 | 0.78 |
| Nemouridae† | 1.73 | 2.43 | 86.36 | 3.02 |  | 0.50 | 1.00 | 25.06 | 1.25 |
| Perlidae | 0.01 | 0.05 | 0.34 | 0.01 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Perlodidae | 1.68 | 2.40 | 84.23 | 2.94 |  | 0.28 | 0.63 | 13.91 | 0.69 |
| Taeniopterygidae | 0.00 | 0.00 | 0.00 | 0.00 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Trichoptera | Brachycentridae | 0.03 | 0.21 | 1.46 | 0.05 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Glossosomatidae | 0.00 | 0.03 | 0.24 | 0.01 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Hydropsychidae | 0.00 | 0.00 | 0.00 | 0.00 |  | 0.17 | 0.83 | 8.40 | 0.42 |
| Lepidostomatidae† | 1.57 | 3.54 | 78.56 | 2.75 |  | 0.50 | 1.43 | 25.03 | 1.25 |
| Limnephilidae† | 6.75 | 11.18 | 337.48 | 11.79 |  | 5.03 | 9.32 | 251.31 | 12.50 |
| Phryganeidae | 0.00 | 0.00 | 0.00 | 0.00 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Phryganopsychidae | 0.00 | 0.00 | 0.00 | 0.00 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Rhyacophilidae | 3.90 | 5.42 | 194.80 | 6.81 |  | 0.11 | 0.53 | 5.57 | 0.28 |
| Stenopsychidae | 0.00 | 0.00 | 0.00 | 0.00 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Uenoidae | 5.52 | 11.64 | 275.88 | 9.64 |  | 3.97 | 11.96 | 198.63 | 9.88 |
| Diptera | Ceratopogonidae | 0.01 | 0.02 | 0.52 | 0.02 |  | 0.01 | 0.02 | 0.44 | 0.02 |
| Chironomidae | 9.21 | 17.99 | 460.67 | 16.10 |  | 11.38 | 15.53 | 569.20 | 28.32 |
| Dixidae | 0.00 | 0.00 | 0.00 | 0.00 |  | 0.00 | 0.02 | 0.16 | 0.01 |
| Empididae | 0.00 | 0.00 | 0.00 | 0.00 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Psychodidae | 0.03 | 0.10 | 1.51 | 0.05 |  | 0.00 | 0.02 | 0.15 | 0.01 |
| Simuliidae | 0.03 | 0.14 | 1.64 | 0.06 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Tipulidae† | 20.37 | 27.32 | 1018.44 | 35.59 |  | 14.58 | 20.49 | 729.11 | 36.27 |
| Coleoptera | Dytiscidae | 0.01 | 0.05 | 0.38 | 0.01 |  | 0.01 | 0.05 | 0.38 | 0.02 |
| Elmidae | 0.13 | 0.26 | 6.39 | 0.22 |  | 0.02 | 0.04 | 0.77 | 0.04 |
| Amphipoda | Gammaridae† | 0.28 | 1.00 | 13.87 | 0.48 |  | 0.07 | 0.49 | 3.47 | 0.17 |
| Annelida |  | 0.66 | 1.94 | 33.15 | 1.16 |  | 1.24 | 3.16 | 62.16 | 3.09 |
| Hirudinea |  | 0.04 | 0.20 | 1.81 | 0.06 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Odonata | Gomphidae | 0.00 | 0.00 | 0.00 | 0.00 |  | 1.30 | 6.45 | 65.19 | 3.24 |
| All taxa together  |  | 1.59 |  |  |  |  | 1.12 |  |  |  |
| † shredder invertebrates |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Order/Class | Family | Volcanic |  | Non-volcanic |
| mean | SD | total | % |  | mean | SD | total | % |
| Ephemeroptera | Ameletidae | 0.86 | 1.51 | 42.93 | 0.78 |  | 1.26 | 2.74 | 63.23 | 3.91 |
| Baetidae | 0.11 | 0.16 | 5.44 | 0.10 |  | 0.09 | 0.21 | 4.50 | 0.28 |
| Caenidae | 0.07 | 0.52 | 3.69 | 0.07 |  | 0.01 | 0.06 | 0.41 | 0.03 |
| Ephemerellidae | 27.39 | 33.63 | 1369.33 | 24.75 |  | 3.36 | 5.36 | 168.00 | 10.38 |
| Ephemeridae | 0.06 | 0.43 | 3.03 | 0.05 |  | 0.06 | 0.43 | 3.03 | 0.19 |
| Heptageniidae | 0.14 | 0.22 | 6.76 | 0.12 |  | 0.12 | 0.24 | 5.80 | 0.36 |
| Leptophlebiidae | 0.82 | 0.86 | 40.79 | 0.74 |  | 0.30 | 0.51 | 14.76 | 0.91 |
| Plecoptera | Capniidae† | 3.33 | 3.04 | 166.61 | 3.01 |  | 6.05 | 6.08 | 302.61 | 18.70 |
| Chloroperlidae | 1.33 | 1.93 | 66.46 | 1.20 |  | 0.73 | 2.14 | 36.65 | 2.27 |
| Nemouridae† | 1.20 | 1.35 | 60.17 | 1.09 |  | 2.05 | 2.51 | 102.31 | 6.32 |
| Perlidae | 0.00 | 0.00 | 0.00 | 0.00 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Perlodidae | 21.18 | 25.46 | 1058.76 | 19.14 |  | 3.12 | 5.31 | 156.07 | 9.65 |
| Taeniopterygidae | 0.01 | 0.03 | 0.27 | 0.00 |  | 0.15 | 0.52 | 7.69 | 0.48 |
| Trichoptera | Brachycentridae | 1.90 | 5.54 | 94.92 | 1.72 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Glossosomatidae | 0.00 | 0.02 | 0.12 | 0.00 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Hydropsychidae | 0.00 | 0.02 | 0.17 | 0.00 |  | 0.01 | 0.04 | 0.50 | 0.03 |
| Lepidostomatidae† | 20.89 | 34.91 | 1044.51 | 18.88 |  | 6.54 | 7.59 | 327.18 | 20.22 |
| Limnephilidae† | 21.27 | 45.43 | 1063.36 | 19.22 |  | 3.93 | 7.32 | 196.69 | 12.16 |
| Phryganeidae | 0.43 | 1.71 | 21.41 | 0.39 |  | 1.00 | 3.23 | 49.97 | 3.09 |
| Phryganopsychidae | 0.00 | 0.00 | 0.00 | 0.00 |  | 0.06 | 0.43 | 3.04 | 0.19 |
| Rhyacophilidae | 1.20 | 1.60 | 60.05 | 1.09 |  | 0.01 | 0.07 | 0.66 | 0.04 |
| Stenopsychidae | 0.02 | 0.12 | 0.86 | 0.02 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Uenoidae | 0.08 | 0.47 | 4.05 | 0.07 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Diptera | Ceratopogonidae | 0.02 | 0.08 | 1.05 | 0.02 |  | 0.02 | 0.06 | 1.05 | 0.06 |
| Chironomidae | 1.93 | 1.84 | 96.71 | 1.75 |  | 1.51 | 2.47 | 75.45 | 4.66 |
| Dixidae | 0.00 | 0.00 | 0.00 | 0.00 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Empididae | 0.00 | 0.00 | 0.00 | 0.00 |  | 0.00 | 0.02 | 0.16 | 0.01 |
| Psychodidae | 0.04 | 0.08 | 1.81 | 0.03 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Simuliidae | 0.03 | 0.10 | 1.34 | 0.02 |  | 0.08 | 0.25 | 3.94 | 0.24 |
| Tipulidae† | 4.81 | 6.87 | 240.71 | 4.35 |  | 1.34 | 3.15 | 67.08 | 4.15 |
| Coleoptera | Dytiscidae | 0.01 | 0.08 | 0.58 | 0.01 |  | 0.12 | 0.39 | 5.83 | 0.36 |
| Elmidae | 0.14 | 0.20 | 7.04 | 0.13 |  | 0.00 | 0.02 | 0.13 | 0.01 |
| Amphipoda | Gammaridae† | 1.39 | 4.07 | 69.29 | 1.25 |  | 0.17 | 0.72 | 8.66 | 0.54 |
| Annelida |  | 0.00 | 0.00 | 0.00 | 0.00 |  | 0.25 | 1.76 | 12.43 | 0.77 |
| Hirudinea |  | 0.00 | 0.00 | 0.00 | 0.00 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| Odonata | Gomphidae | 0.00 | 0.00 | 0.00 | 0.00 |  | 0.00 | 0.00 | 0.00 | 0.00 |
| All taxa together  |  | 3.07 |  |  |  |  | 0.90 |  |  |  |
| † shredder invertebrates |

**(S4.4)**