CALIFORNIA TROUT

APPENDIX J: SEASONAL SHIFTS OF INVERTEBRATE DRIFT IN SPROUL CREEK (EEL RIVER WATERSHED)

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Introduction

The drift of benthic macroinvertebrates plays a key role in the lotic food web in terms of a prey base for many fish including stream-rearing salmonids (Nielsen 1992; Grossman 2014). The availability of invertebrate drift as well as the magnitude of drift flux can have direct impacts on the growth and survival of drift-feeding fish (Rosenfeld et al. 2005; Weber et al. 2014). Steelhead growth rates have been shown to decrease with decreasing drift as competition increases (Keeley 2001; Weber et al. 2014). Also, salmonid growth can be more limited by prey availability and quality than temperature (Beauchamp 2009). The thermal tolerances of salmonids, particularly juveniles, can be reduced with declines in the abundance and energy density of prey (Beauchamp 2009). Drift is a key parameter in the suitability of habitat for sensitive fish species (Hughes and Dill 1990; Weber et al. 2014). It is critical to resolve the spatial and temporal influences on drift to improve estimates from bio-energetic models (Leung et al. 2009; Naman et al. 2016).

Invertebrate drift density and composition varies significantly over time and throughout a river channel due to many abiotic and biotic factors (Naman et. al 2016). Drift can occur through passive or active processes, which vary in influence depending on flow conditions. Passive drift is due to mechanical dislodgement of invertebrates from benthic substrate and occurs fairly constantly at baseflow conditions, but it can rise dramatically in density with either increased flows or turbulence (Anderson and Lehmukhl 1968; Brittain and Eikeland 1988; Gibbins et al. 2007). Active drift is due to deliberate behaviors, representing an interplay of predation avoidance and maximizing foraging intake; this trade-off results in clear diel cycles with nocturnal peaks in streams containing drift-feeding fish such as salmonids (Allan 1978; Malmqvist and Sjostrom 1987; Hammock et al. 2012). In addition, drift composition and density change with the seasonal cycles of aquatic invertebrate communities, often peaking in the summer months in temperate systems (O'Hop and Wallace 1983). The timing of these cycles are inherently linked to the flow regime of the stream (Wallace and Webster 1996). Hydrologic alterations can have a significant impact on drift in the context of diversity and abundance (Nelson and Lieberman 2002).

For altered streams it is critical to maintain both minimum base flows as well as a flow regime similar to natural conditions to increase drift density as well as taxonomic richness (Weisburg and Burton 1993; Bunn and Arthington 2002). Constant diversions that take away a significant portion of flows can result in lower density and diversity of drifting invertebrates as the complexity of habitat decreases with decreasing flow (Rader 1999; Dewson et. al 2007). However, the effect of reduced flows has been shown in experiments to vary by taxa as drift rates can either decrease or increase with the alteration of diel drift cycles for some invertebrate species (Poff and Ward 1991). In addition, certain invertebrate functional feeding groups have been found to be more susceptible to artificially low flows such as filtering collectors and scrapers, changing the community composition (Walters and Post 2011). Therefore, it is important to examine shifts not only in overall invertebrate abundance and biomass, but also across taxonomic groups in streams with significant diversions.

The watershed of Sproul Creek has been heavily impacted by repeated clear-cutting, which was last done in the 1990's. Historically, Sproul Creek was a highly productive rearing habitat for steelhead; restoration projects aim to improve the stream's suitability for salmonids once more. As current and future development may divert streamflow, it is critical to quantify the necessary flows throughout the summer when flows are at their lowest to provide sufficient habitat for rearing steelhead. The objective of this project was to examine and quantify the variability of macroinvertebrate drift from late spring (April) to mid-summer (July) 2016 in the context of invertebrate prey availability for fish.

Methods

Sproul Creek is a tributary of the South Fork Eel River. The canopy cover over the stream is relatively young growth, varying somewhat in density along the length. Three riffles along a reach of Sproul Creek were sampled once a month from April to July 2016. At the downstream end of each riffle, a drift net with a 30cm X 60cm opening facing was placed along the stream bottom with velocity measured at the beginning the sampling period. Drift was collected for 24 hours to capture the complete diel cycle of drifting invertebrates. Samples were preserved in 70% Ethanol for laboratory analysis.

Each drift sample was split into two subsamples using a Folsom Plankton Sample Splitter. One subsample was randomly selected for identification and biomass measurements. Each selected subsample was filtered through a 5mm sieve stacked on top of a 500micron sieve to sort out inorganic and organic material. Macroinvertebrates were identified under a dissecting microscope to Family when possible. Body lengths of each individual were measured to calculate biomass through taxa-specific length-weight regressions (Benke et al. 1999; Sabo et al. 2002; Cummins et al. unpublished).

The variation of drift was compared among months in richness, biomass and abundance as well as by taxa. Linear regression models and ANOVAs were used to examine differences in drift biomass and abundance by month and origin (aquatic vs. terrestrial). While most terrestrial invertebrates can be presumed as prey for juvenile salmonids, not all aquatic invertebrates are likely consumed by salmonids (Allan et.al 2003). Therefore aquatic taxa found in the drift were compared against published studies on diet (Rader et.al 1997; White 2000; McIntosh et. al 2002; Dockham 2016) to determine the 'fish food' biomass and composition. Energy content of aquatic drift likely consumed by salmonids was calculated by using a factor of 21,790 J/g (Cummins and Wuycheck 1971).

Results

Aquatic & Terrestrials

Overall taxonomic richness in 2016 increased from April (n=41) to June (n=54), then decreased in July (42) (Figure J-1). This trend was consistent for both aquatic and terrestrial invertebrates (Figure J- 2). June 2016 had the greatest taxa richness due potentially to peak in primary production in algae as well as in the surrounding riparian vegetation. A third of the taxa in May and June were made up of terrestrial invertebrates, while this proportion was somewhat lower in April and July (Figure J- 1).

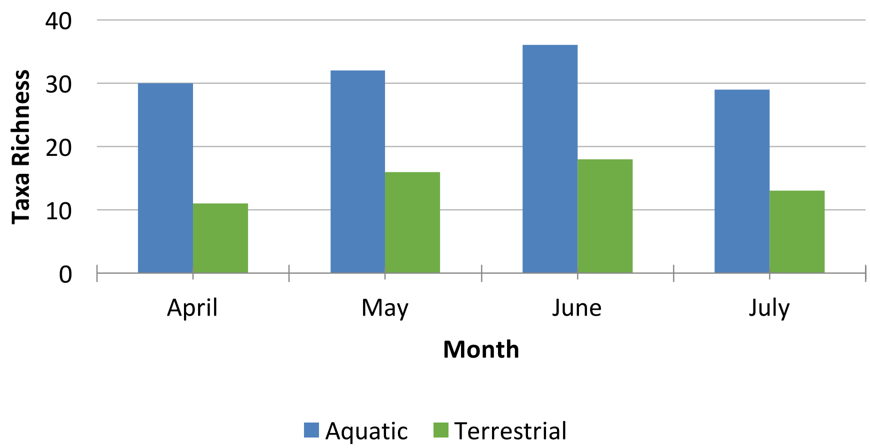

Figure J-1: Total taxonomic richness of aquatic and terrestrial invertebrates found in Sproul Creek drift samples from April-July 2016.

The concentration of invertebrate drift in terms of number of individuals appeared to have an overall positive relationship with flow, declining sharply between June and July 2016 (Table 1). The relationship between flow and biomass was weak with only a clear drop in July when flows were minimal (Table 1). The relative abundance of terrestrials was highest in April even with lower diversity and mass (Figure J-1,Table 1). Although the proportion of terrestrial invertebrate biomass was largest in June, the average biomass of aquatic invertebrates did not significantly vary among the months of April to June (Table 1, Figure J- 2).

Table J-1: Streamflow at the time of drift sampling, biomass and numerical abundance of drifting invertebrates for each month averaged across riffles. The relative proportion of terrestrial invertebrates by abundance and biomass by month.

Month (2016)	Flow (cfs)	Average Biomass (mg) aquatic + terrestrial	% Biomass Terrestrial	Average Abundance	% Abundance Terrestrial
April	23.9	287.6	17.2%	1219	10.6%
May	7.55	256.7	14.3%	1434	3.72%
June	3.23	288.2	28.2%	1089	6.61%
July	0.32	95.9	17.5%	264	7.84%

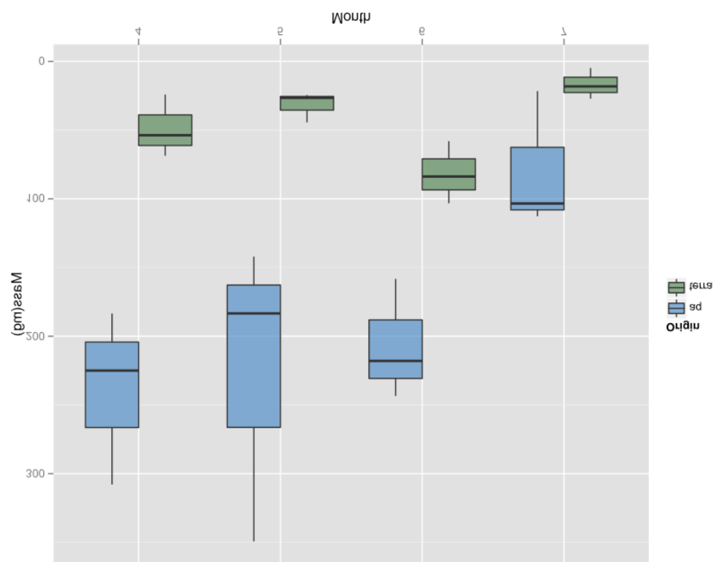

Figure J-2. The distribution of macroinvertebrate biomass in milligrams by month (April-July 2016) and by origin-aquatic (aq) or terrestrial (terra) in Sproul Creek.

July 2016 had significantly lower overall abundance and biomass than the other months at α=0.05, mostly due to a steep drop in aquatic invertebrates (p-value=0.002, Figures J- 2 and 3). The variability of total abundance declined over time, suggesting the variation between riffle habitats declined with flow (Figure J- 3).

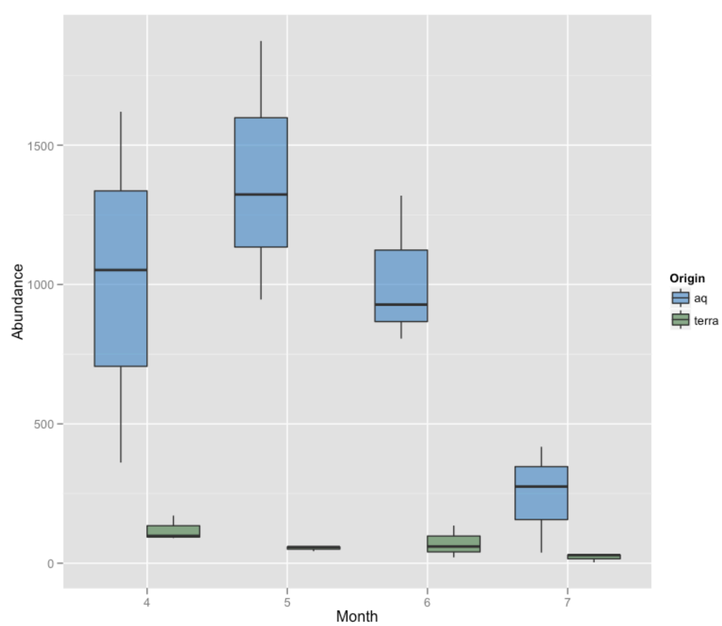

Figure J-3. The distribution of macroinvertebrate drift abundance by month and by origin-aquatic(aq) or terrestrial (terra) in Sproul Creek.

Taxonomic Composition

Table J-2. Benthic macroinvertebrate metrics based on drift samples from Sproul Creek (April-July 2016).

	April	May	June	July
Dominant Aquatic Taxa	Elmidae	Ephemerellidae	Chironomidae	Chironomidae
% Dominance	41.09%	25.82%	33.43%	31.14%
Shannon's Diversity Index	1.96	1.99	2.13	2.49
Evenness	0.59	0.59	0.62	0.76

Although total abundance and biomass of aquatic invertebrates were lowest in July, diversity in terms of richness and evenness peaked in July, due in part to the reduced dominance of a single taxonomic group (Table 2). Aquatic drift was dominated early on by the riffle beetle family, Elmidae, then by the mayfly family Ephemerellidae in May and finally in lower flow conditions, Chironomidae became more common in June and July (Table J-2, Figures J-4-7). Caddisflies representing multiple feeding groups, from scrapers (Glossomatidae) to filter collectors (Hydropyschidae) became more prevalent in the later months (Figures J-4-7). Larger predator taxa such as Sialidae and Gomphidae were rare across the months (Figures J-4-7).

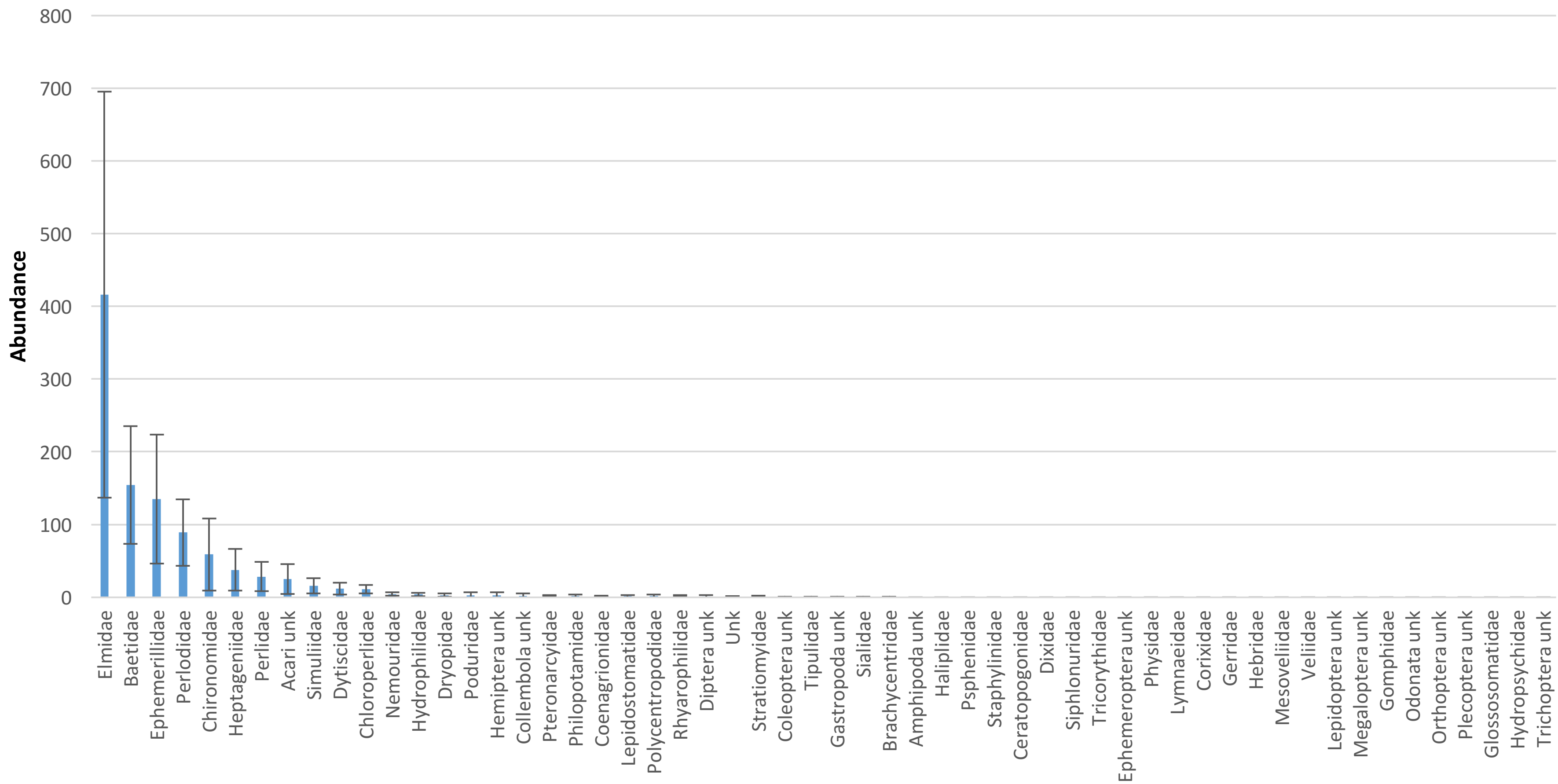

Figure J-4. The mean abundance (±1 SD) of the aquatic taxonomic groups, mostly to the family level for the month of April 2016.

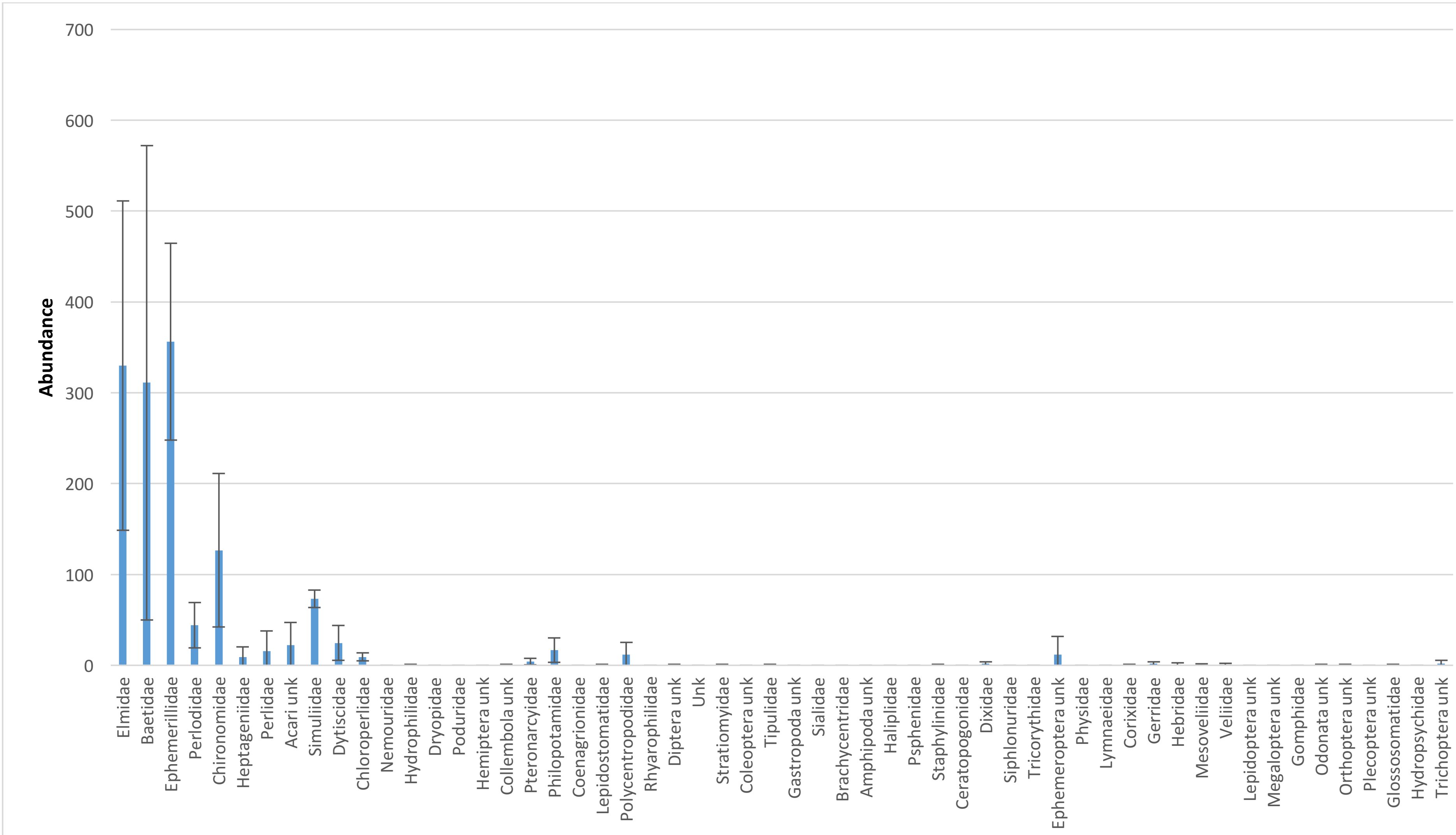

Figure J-5. The mean abundance (±1 SD) of the aquatic taxonomic groups mostly to the family level for the month of May 2016 (x-axis is the same for Figures J-4-7).

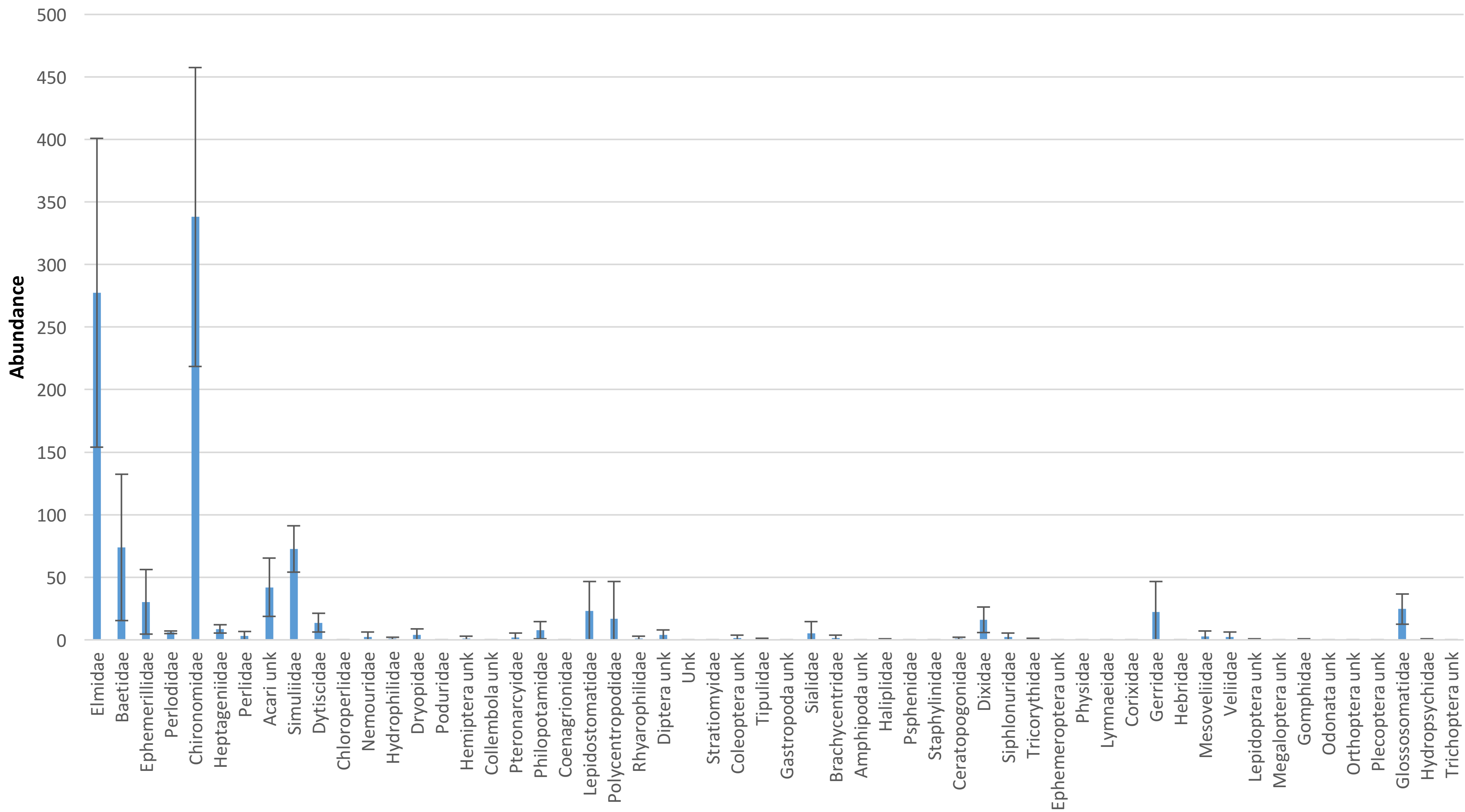

Figure J-6. The mean abundance (±1 SD) of the aquatic taxonomic groups, mostly to the family level for the month of June 2016 (x-axis is the same for FiguresJ- 4-7).

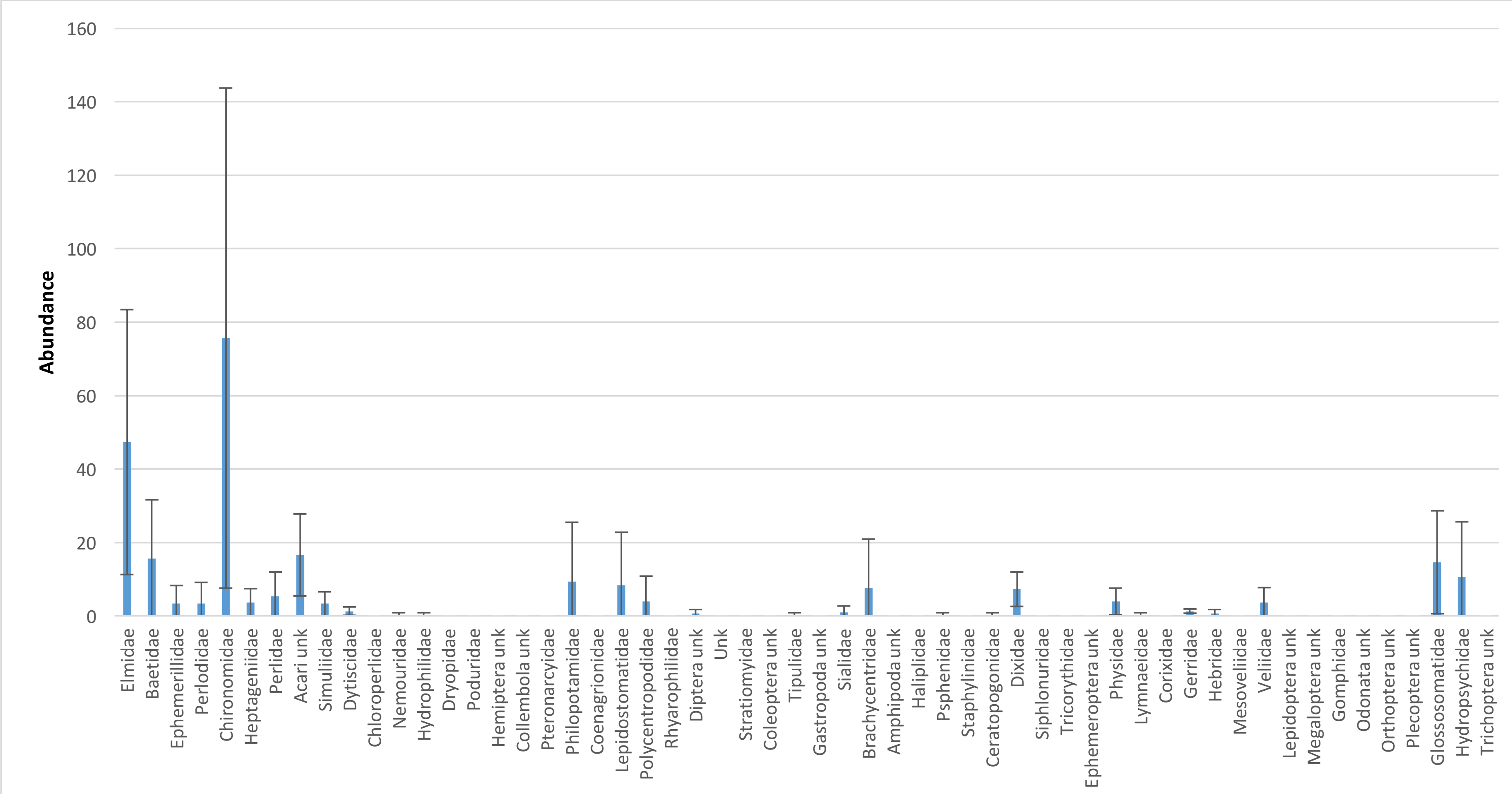

Figure J-7. The mean abundance (±1 SD) of the aquatic taxonomic groups, mostly to the family level for the month of July 2016 (x-axis is the same for Figures J-4-7).

Terrestrial macroinvertebrates in the drift samples were predominantly adult flies (Diptera) from April to June with bees and wasps (Hymenoptera) becoming more common in July (Figure J-8). Most major orders across the months were winged with the exception of Hemiptera, which had mostly wingless individuals (Figure J-8). The only major order with an aquatic life stage was Ephemeroptera (Figure J-8). These individuals along with a few Plecoptera and Trichoptera in the later months were all newly emerged adults.

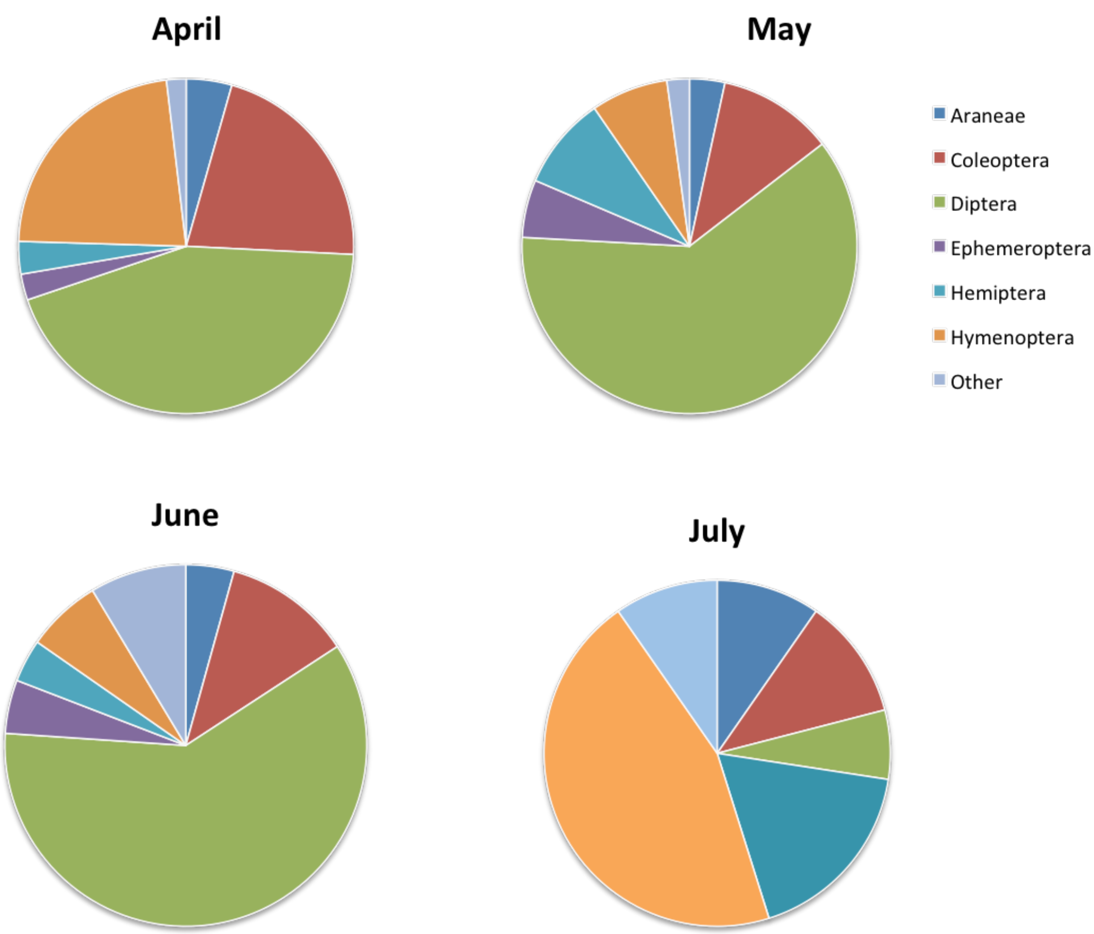

Figure J-8. The relative abundances of major terrestrial invertebrate orders by month from top left to bottom right.

Salmonid Prey Availability

When all aquatic taxonomic groups that had been previously found in the diet of salmon were included as prey, May 2016 had the greatest available proportion of drift (93%) while July had the lowest (78%) (Figure J-9). This excluded water mites or Hydrachnids, Hemipterans, Hydropyschids and Gastropods. The variability in available drift mostly declined over the months (Figure J-9).

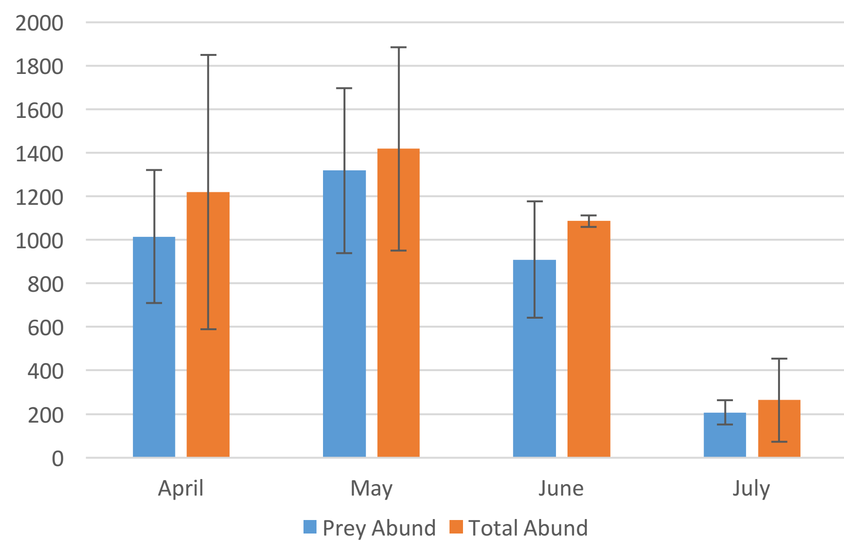

Figure J-9: Average abundance of salmonid prey taxa versus total abundance by month (April-July 2016) in Sproul Creek.

As an estimate of preferred aquatic prey, only taxonomic groups that were found commonly and/or in multiple studies were considered. For the common prey taxa, June 2016 had the highest proportion of preferred prey (76.4%), while May (64%) had the lowest (Figure J-10). The reversal of May is due to the exclusion of families like Ephemerellidae and multiple Plecoptera families that were common in drift samples.

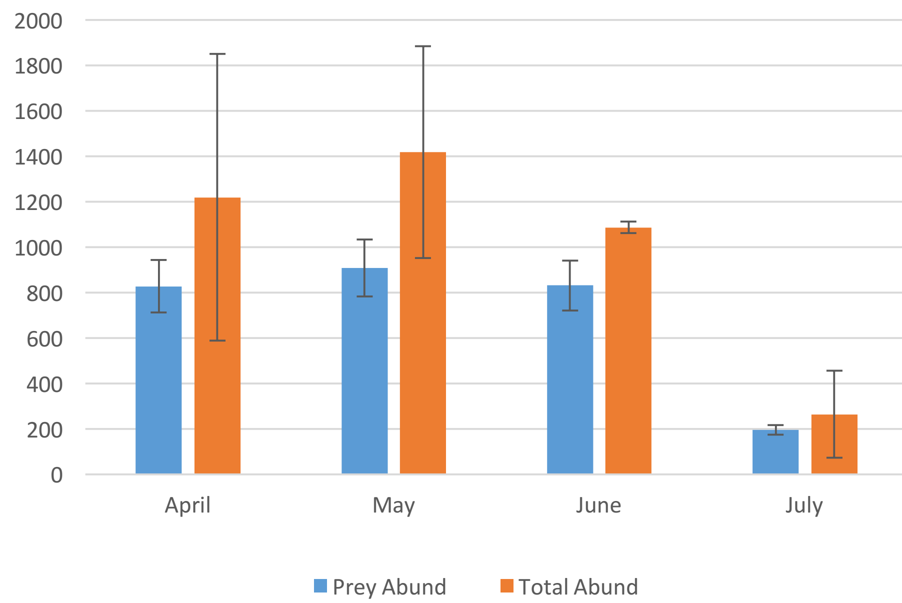

Figure J-10: Average abundance of common salmonid prey taxa versus total abundance by month (April-July 2016).

A conservative estimate of aquatic energy content available to drift-feeding fish suggests June 2016 had the greatest energy content while July has the lowest (Table 3). Therefore prey availability does not appear to correlate with overall abundance, but rather depends on total biomass as well as diversity.

Table J-3. The average biomass in milligrams of preferred aquatic invertebrate prey and energy content in Joules by month (April-July 2016) in Sproul Creek.

Month (2016)	**Biomass (mg)**	**Energy Content (J)**
April	195.2	4253.2
May	164.4	3581.7
June	220.3	4800.9
July	70.96	1546.1

Discussion

Taxonomic richness in Sproul Creek was not significantly reduced until flows dropped to less than two percent of April flows, indicating only extreme stress may cause sensitive taxa to drop out (Rader 1999). While evenness and Shannon diversity index suggest the lowest flow had the highest diversity it should be noted that with only ~25% of abundance compared to previous samples, consistency in abundance was inherently more likely. The Shannon diversity index has been shown to be limited in distinguishing environmental trends, especially at coarser taxonomic levels and without a known sample volume and should always been taken in context with other stream quality measurements (Hughes 1978). In addition, the time of year likely had a strong influence on the taxa richness of the drift as the life cycles of aquatic macroinvertebrate taxa vary within a season (Cowell and Carew 1976; Rader 1999). Terrestrial invertebrate inputs, which can make up a significant portion of salmonid diet, increased into the summer as expected with the peak of primary production (Kawaguchi and Nakano 2001). Therefore, only under severe loss of habitat area with declining flows does diversity become notably reduced.

Similarly, the magnitude of drift in terms of biomass and abundance appeared to be only affected by declining flow when flows dropped to their lowest level in July. In low-order streams, the relationship of velocity and drift can be relatively weak with the short lengths of habitats and the homogenization due to turbulence (Leung et al. 2009). Lowering flows to some extent may actually cause increases in drift rates of certain taxa as long as habitat area is not greatly reduced (Poff and Ward 1991). Macroinvertebrate families such as Chironomidae and Simuliidae as well as some Baetidae species have been shown to increase in drift density under experimentally reduced flows (Poff and Ward 1991); these trends were observed to some degree in Sproul Creek. Baetidae and Ephemerellidae increased in abundance between April and May as flows dropped from by two thirds. The reduced abundance of these mayfly taxa in the later months may likely be due in part to the timing of peak emergence, which cycles throughout much of the year (Brittain and Eikeland 1988). Dipteran larvae like chironomids became more prevalent in the later months with the lowest flows, as they prefer more slow water conditions (Poff and Ward 1991). Therefore, changes in composition and density over the spring and summer is likely due to behavioral changes at the moderate scale and abiotic shifts at the high and low extremes.

Prey availability for summer-rearing salmonids is generally linked to the seasonality of the preferred taxa and could be impacted by diversions during summer low flows. The overall biomass and energy content of macroinvertebrate prey increased into the summer as flows continued to drop with a rise in chironomids and several Trichoptera families. However, the change in flow from June into July crossed a threshold where habitat area was significantly reduced, likely impacting many taxa. Further study of drift at this critical period should be conducted at greater sampling frequency to more adequately capture this flow threshold. Sampling at multiple intervals in the diel cycle could demonstrate the periodicity of macroinvertebrate drift, indicating key periods of movement. While terrestrial inputs did not significantly vary with flow, they play a key role as summer prey for salmonids (Kawaguchi and Nakano 2001). Restoration and protection of the riparian vegetation will ensure this subsidy remains stable. Diversions on Sproul Creek are most likely to alter prey for drift-feeding fish in these summer months. Stopping allocations even for only certain times of day such as at dusk could improve the survival of drifting aquatic invertebrates (Benstead et al. 1999).

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