Diversity, phenology, and elevational distribution of Ephemeroptera, Plecoptera, and Trichoptera in American Fork Canyon, Utah

Sarah Walker Judson
Brigham Young University, swjudson@gmail.com

C. Riley Nelson
Brigham Young University, rileynelson@byu.edu

DIVERSITY, PHENOLOGY, AND ELEVATIONAL DISTRIBUTION OF EPHEMEROPTERA, PLECOPTERA, AND TRICHOPTERA IN AMERICAN FORK CANYON, UTAH

Sarah Walker Judson[1,2] and C. Riley Nelson[1]

ABSTRACT.—Although the aquatic insect fauna of Utah and their associated adult forms are well documented taxonomically and biogeographically, little is known about seasonal and elevational patterns of aquatic insect diversity in individual Wasatch streams. We selected the American Fork River, a relatively pristine stream with little anthropogenic disturbance, as our target stream to investigate elevational distribution and seasonal phenology of adult forms of Ephemeroptera, Plecoptera, and Trichoptera (EPT). From April to October in 2003 through 2005, a total of 71 adult forms of EPT species were documented along the American Fork River. No single sampling period captured more than 30 species, and richness per sampling period averaged 8 species for all sites combined. The mid-elevational site (1862 msl) was the most species rich, with 54 species of transitional fauna captured along the elevational gradient. As such, this site is an important reference for maximum potential richness. Plecoptera emerged earlier in the year than Trichoptera, with the Plecoptera-dominated community being most rich in June, and the Trichoptera-dominated community being most rich in August. We observed 3 distinct seasonal species suites and 3 elevationally zoned community assemblages that were recurrent in their timing and location from year to year. The compiled species lists, life histories, and preliminary investigation of ecological trends provide a firm basis for further systematic studies on the ecology, water quality, and conservation of the aquatic insects of the American Fork River and similar mountain streams, particularly in the Wasatch region.

Key words: *Ephemeroptera, Plecoptera, Trichoptera, elevation, phenology, life history, Wasatch, Utah.*

RESUMEN.—Aunque la fauna de insectos acuáticos de Utah y sus formas adultas asociadas están bien documentadas taxonómica y biogeográficamente, se conoce poco sobre los patrones de distribución estacionales y altitudinales de la diversidad de insectos acuáticos en arroyos individuales de la cordillera Wasatch. Seleccionamos el Río American Fork, un arroyo relativamente prístino con poca perturbación antropogénica, como nuestro objetivo para investigar la distribución altitudinal de las formas adultas de Ephemeroptera, Plecoptera y Trichoptera (EPT), así como su fenología estacional. De abril a octubre del año 2003 al 2005, se documentó un total de 71 formas adultas de especies de EPT a lo largo del Río American Fork. No se encontraron más de 30 especies en ninguno de los períodos de muestreo, y combinando los datos de todos los sitios, el promedio de especies por período fue ocho. El sitio de elevación media (1862 msnm) fue el más rico con 54 especies constituidas por una fauna transicional entre los sitios a lo largo del gradiente de elevación, y como tal éste es un importante punto de referencia para determinar el máximo potencial de riqueza de especies. Los plecópteros aparecieron más temprano en el año que los tricópteros—la comunidad predominada por Plecoptera fue más rica en especies en junio—mientras que la comunidad predominantemente Trichoptera alcanzó su mayor riqueza en agosto. Observamos tres distintos conjuntos estacionales de especies y tres comunidades distribuidas por elevación, las cuales fueron recurrentes en su temporalidad y localización año tras año. La lista recopilada de especies, las historias de vida y la investigación preliminar de tendencias ecológicas aportan una firme base para más estudios sistemáticos y ecológicos, así como de calidad de agua y conservación de los insectos acuáticos del Río American Fork y otros arroyos semejantes a este, particularmente en la región de la cordillera Wasatch.

As with much of western North America, historical work has been done throughout Utah on the taxonomy of the aquatic groups Ephemeroptera (Edmunds 1954), Plecoptera (Gaufin et al. 1966, Baumann 1973, Baumann et al. 1977), and Trichoptera (Baumann and Unzicker 1981). However, also like much of the West, few detailed phenologies and collections of other life history data exist for the aquatic groups of this area; and none are known for the Wasatch Range or Uinta Mountains. Such biological information is an important foundation for future ecological and comparative work, but this baseline measure is lacking for Utah streams. We selected American Fork River as the representative mountain stream for a survey of Ephemeroptera,

[1]Department of Biology, Brigham Young University, 401 WIDB, Provo, UT 84602.
[2]Department of Watershed Sciences, Utah State University, 5210 Old Main Hill, Logan, UT 84322-5210. E-mail: swjudson@gmail.com
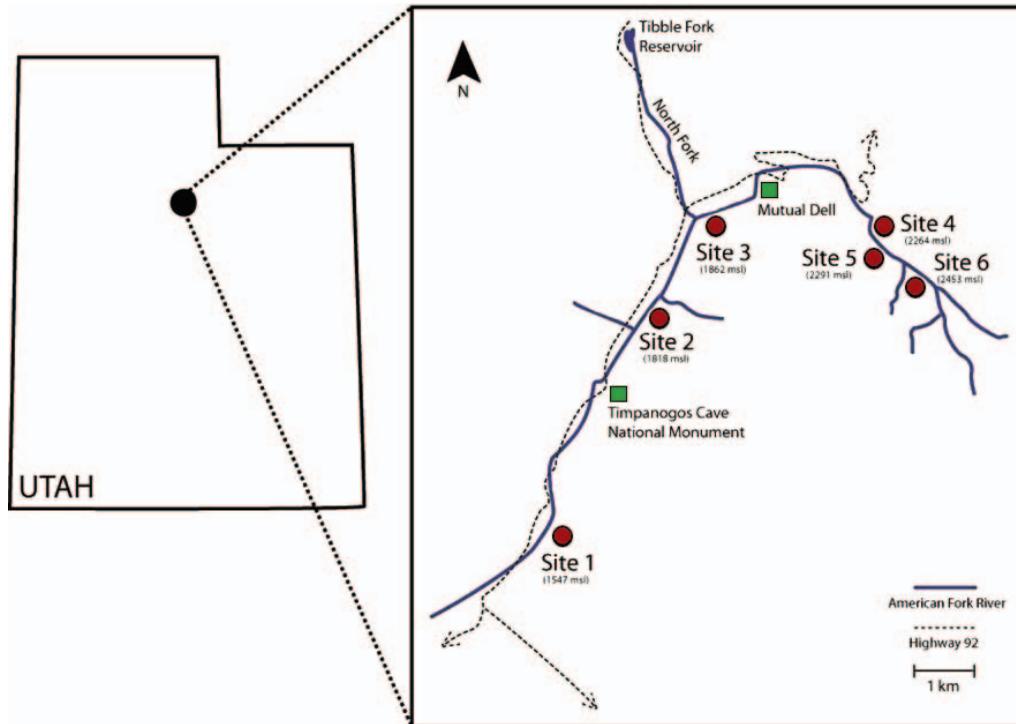
Fig. 1. Map of the American Fork River, with emphasis on the study area. The American Fork River flows generally southwest, originating at springs at the base of Mount Timpanogos and ultimately running into Utah Lake. An unstudied tributary, the North Fork, joins the river at sites 2 and 3.

Plecoptera, and Trichoptera (EPT) adults. American Fork River was selected primarily because it is relatively undisturbed by human modifications, as compared to the Provo River (Gray 2004) and many other Wasatch streams. Our survey is akin to other, and unfortunately sparse, phenological or altitudinal surveys from the West, including those done in Colorado (Ward 1986, DeWalt et al. 1994, Finn and Poff 2005), Montana (Sheldon 1999), and California (Bottorff and Bottorff 2007).

The focus of this survey was to define the adult EPT community structure in terms of species present and patterns of abundance and diversity over elevational and seasonal gradients, while also considering interannual variation. We documented phenology and altitudinal distribution of individual species, as measured by duration and geographical extent of flight period, to determine the species richness of EPT and to record life history information about each community member. We then assessed the contribution of each species to overall community assemblages and diversity.

According to historical investigations of seasonal faunal turnover (DeWalt et al. 1994, Bottorff and Bottorff 2007) and elevational zonation (Allan 1975, Ward 1986) in streams, we expected to see distinct community assemblages over the seasonal and elevational gradients. We were interested to discover the spatio-temporal delineations between communities and their interannual consistency in timing or location. The life history information and our preliminary investigation of community structure and turnover across elevational and seasonal gradients are intended to be a baseline for further ecological investigations and water-quality biomonitoring efforts.

Methods

Study Stream

The headwaters of the South Fork of the American Fork River originate near Scout Falls at approximately 2500 m elevation (Fig. 1). Immediately downstream is an intermittent reach that is typically dry through July and

August. The main channel reemerges with additional spring inputs near the Timpooneke Campground area (2264 msl) and remains perennial throughout the American Fork Canyon. Thus, for the purposes of our study, we treat the perennial Timpooneke site as the headwaters. From Timpooneke, there are only minor interruptions in stream flow due to small man-made culverts and a now-decommissioned hydroelectric dam that was demolished in late 2007 after our study ended. The stream is joined by the North Fork, which was not selected for our study because of its channelization, mining history, and upstream recreational reservoir. After this junction, the American Fork River continues to the mouth of the canyon (1547 msl) and then through urban areas to its outlet at Utah Lake.

Four main sites were selected at equidistant intervals along the elevational gradient of the river, from the Timpooneke springs to the canyon mouth (Fig. 1). Two additional sites above Timpooneke were included in 2005, extending the elevational gradient from the original 2264 m to 2453 m. We refer to the sampling sites in numeric order throughout this paper to indicate their relative location. Site 1 is near the canyon mouth at the lowest elevation; Site 2 is downstream from the confluence of the North and South forks; Site 3 is the first site on the South Fork; and Sites 4–6 represent the headwaters at the highest elevations (2264– 2453 msl).

Sampling and Analyses

From 2003 to 2005, we sampled the American Fork River riparian corridor for terrestrial adult forms of Ephemeroptera, Plecoptera, and Trichoptera. Each year, one Townes-style Malaise trap and 5 Lindgren funnel traps were placed at each of the 4 main sites. Traps were placed approximately 1 m from the stream bank and at least 10 m apart to maintain independence. The traps were emptied and recharged every other week, except for in 2004 when they were collected every week. Sampling was carried out from March through October, when EPT are most active in the canyon, and was continued during the 2004–2005 winter to assess the flight period of colder months. The 2 additional sites (5 and 6) were sampled only in 2005 from May through October, when the area was accessible by road.

All Ephemeroptera, Plecoptera, and Trichoptera specimens were sorted from the original bulk sample, preserved in 70% ethanol, sexed, counted, and identified using existing keys (Ross 1944, Usinger 1956, Baumann et al. 1977, Merritt et al. 2007, Ruiter 2000) or with help from taxonomic specialists (Ruiter personal communication, Wiersema personal communication, Kondratieff personal communication). All specimens, including a representative synoptic series, are deposited at the Monte L. Bean Life Science Museum, Brigham Young University, Utah.

Species abundance counts were compiled for each site and each sampling period. Totals from Malaise and Lindgren samples were combined to document the high abundances of individuals provided by the Malaise traps (presumably indicative of relative abundance in the community) yet retain the occasional rare species that appeared in Lindgren funnel samples. This information was compiled into species lists with phenological information on the first, last, and peak presence dates of each species at each site as well as elevational occurence, which indicates the distributional extent of each taxon.

Using the program Estimate S 8.0 (Colwell 2006), we computed a wide array of diversity indices and similarity comparisons. The species accumulation predictors Chao 1 (Chao), Abundance Coverage Estimator (ACE), Incidence Coverage Estimator (ICE), and raw observed species (S_{obs}) were used as the main measures of expected species richness. These selected metrics represent the full spectrum of richness predictions, from actual observed totals (S_{obs}), to those extrapolated from abundance and incidence alone (ACE and ICE respectively), to Chao, which is one of many measures that mathematically combines abundance and incidence to predict species richness according to the number of sampling events (Colwell and Coddington 1994). The Chao 1, which more heavily weights rare species, was chosen over other well-known richness predictors because of our goal to survey the entire fauna. To accomplish this goal, we needed a measure that accounted for the presence of rare species. Also, Chao 1 exhibited the best fit to preliminary data from 2003. All richness predictors generated using Estimate S—including the first- and second-order jackknife measures, Michaelis–Menten richness estimators, and other variants of the Chao index—were

TABLE 1. Detailed species information for all 71 EPT species found in American Fork Canyon, Utah. Abundance includes the total number of individuals documented for each species between 2003 and 2005 and the seasonal frequency (length of adult presence) in weeks as calculated from the number of samples in which that species occurred. The frequency is averaged across sites to account for asynchronous emergences throughout the canyon and variance in relative abundance from site to site. Since this value was computed from 2004 data, which had the best temporal resolution with sampling on a weekly basis, some species have a null value (dash) consistent with their rarity and most can be assumed to have an annual frequency of 1 or 2 when considering their values for the other parameters. Elevational distribution includes a visual depiction of altitudinal distribution across the 6 sites. Gray boxes indicate presence at the site, and black boxes indicate that the species' abundance peaks at the site. Seasonal presence (first presence, last presence, peak abundance, and peak total) includes information about length and dates of adult presence based on data from 2004 using trap end dates. If the species did not occur in 2004, data from 2005 were used. Peak total is the number of individuals present during the sampling period of peak abundance.

Taxa	Abundance		Elevational distribution	Seasonal presence			
	Individuals	Frequency	1 2 3 4 5 6	First presence	Last presence	Peak abundance	Peak total
EPHEMEROPTERA							
Ameletidae							
Ameletus sp.	14	3		30 Aug	4 Oct	4 Oct	2
Baetidae							
Baetis sp.	398	21		17 Apr	30 Oct	24 Apr	20
Callibaetis sp.	1	—		31 Jul	31 Jul	31 Jul	1
Diphetor hageni (Eaton, 1885)	70	10		3 Jul	21 Sep	31 Jul	7
Ephemerellidae							
Drunella grandis (Eaton, 1884)	43	2		21 Sep	4 Oct	21 Sep	6
Ephemerella dorothea Needham, 1908	63	2		31 Jul	21 Sep	None	1
Heptageniidae							
Cinygmula par (Eaton, 1885)	105	10		31 Jul	30 Oct	21 Sep	7
Epeorus sp.	61	10		5 Jun	21 Sep	21 Jul	6
Rhithrogena robusta Dodds, 1923	*	—		24 Jun	8 Jul	24 Jun	10
Leptophlebiidae							
Paraleptophlebia memorialis (Eaton, 1884)	40	11		19 Jun	16 Oct	16 Oct	4
PLECOPTERA							
Capniidae							
Capnia confusa Claassen, 1936	123	9		17 Apr	12 Jun	8 May	57
Capnia gracilaria Claassen, 1924	71	5		17 Apr	15 May	17 Apr	11
Capnia nana Claassen, 1924	37	7		17 Apr	5 Jun	24 Apr	7
Eucapnopsis brevicauda Claassen, 1924	306	9		17 Apr	19 Jun	1 May	86
Isocapnia hyalita Ricker, 1959	1	1		24 Apr	24 Apr	24 Apr	1
Chloroperlidae							
Alloperla severa	*	—		6 Jul	6 Jul	6 Jul	3
Paraperla frontalis (Banks, 1902)	14	3		29 May	26 Jun	None	1
Plumiperla diversa (Frison, 1935)	43	1		19 Jun	19 Jun	19 Jun	1
Suwallia pallidula (Banks, 1904)	135	9		26 Jun	21 Sep	31 Jul	22
Sweltsa borealis (Banks, 1895)	708	18		5 Jun	4 Oct	14 Aug	76
Sweltsa coloradensis (Banks, 1898)	1783	8		29 May	17 Jul	12 Jun	195

*Species documented incidentally following completion of this study.

TABLE 1. Continued

Taxa	Abundance		Elevational distribution						Seasonal Presence			
	Individuals	Frequency	1	2	3	4	5	6	First presence	Last presence	Peak abundance	Peak total
Leuctridae												
Paraleuctra occidentalis (Banks, 1907)	973	14							17 Apr	17 Jul	8 May	124
Perlomyia utahensis Needham and Claassen, 1925	54	7							8 May	10 Jul	5 Jun	9
Nemouridae												
Malenka californica (Claassen, 1923)	224	6							11 Sep	30 Oct	4 Oct	22
Prostoia besametsa (Ricker; 1952)	1970	11							17 Apr	26 Jun	17 Apr	439
Zapada cinctipes (Banks, 1897)	2153	18							17 Apr	20 Aug	8 May	690
Zapada columbiana (Claassen, 1923)	728	12							17 Apr	3 Jul	8 May	262
Zapada haysi (Ricker; 1952)	653	12							17 Apr	3 Jul	8 May	128
Perlidae												
Hesperoperla pacifica (Banks, 1900)	24	2							12 Jun	19 Jun	12 Jun	6
Perlodidae												
Diura knowltoni (Frison, 1937)	2	1							22 May	22 May	22 May	1
Isoperla fulva Claassen, 1937	288	6							29 May	3 Jul	19 Jun	28
Isoperla sobria (Hagen, 1874)	86	10							29 May	4 Oct	12 Jun	12
Megarcys signata (Hagen, 1874)	50	11							12 Jun	11 Sep	12 Jun	6
Pictetiella expansa (Banks, 1920)	3	1							14 Aug	14 Aug	14 Aug	1
Skwala americana (Klapálek, 1912)	2	—							17 Apr	17 Apr	17 Apr	2
Taeniopterygidae												
Doddsia occidentalis (Banks, 1900)	2	2							24 Apr	8 May	None	1
Taenionema pallidum (Banks, 1902)	37	4							1 May	22 May	8 May	4
TRICHOPTERA												
Apatanidae												
Allomyia sp.	12								3 Jun	1 Jul	29 Jun	3
Brachycentridae												
Micrasema bactro Ross, 1938	641	11							17 Jul	25 Sep	7 Aug	99
Glossosomatidae												
Anagapetus debilis (Ross, 1938)	532	11							3 Jul	11 Sep	30 Aug	56
Glossosoma alascense Banks, 1900	33	7							5 Jun	7 Aug	24 Jul	4
Glossosoma verdona Ross, 1938	6	2							24 Apr	8 May	None	1
Hydropsychidae												
Arctopsyche grandis (Banks, 1900)	233	8							12 Jun	31 Jul	3 Jul	26
Ceratopsyche oslari (Banks, 1905)	93	10							26 Jun	11 Sep	30 Aug	9
Parapsyche elsis Milne, 1936	934	12							19 Jun	21 Sep	24 Jul	76
Hydroptilidae												
Hydroptila arctia Ross, 1938	187	12							24 Jul	15 Oct	21 Sep	46
Ochrotrichia logana (Ross, 1941)	387	9							14 Aug	30 Oct	11 Sep	97

TABLE 1. Continued

Taxa	Abundance		Elevational distribution						Seasonal Presence			
	Individuals	Frequency	1	2	3	4	5	6	First presence	Last presence	Peak abundance	Peak total
Lepidostomatidae												
Lepidostoma cascadense (Milne, 1936)	108	11							24 Jul	30 Oct	11 Sep	6
Lepidostoma pluviale (Milne, 1936)	375	11							10 Jul	21 Sep	7 Aug	37
Lepidostoma roafi (Milne, 1936)	72	5							30 Aug	16 Oct	11 Sep	6
Lepidostoma unicolor (Banks, 1911)	528	13							24 Jul	30 Oct	21 Sep	162
Limnephilidae												
Amphicosmoecus canax (Ross, 1947)	1	—							11 Sep	21 Sep	None	1
Chyranda centralis (Banks, 1900)	335	12							19 Jun	21 Sep	14 Aug	24
Dicosmoecus atripes (Hagen, 1875)	15	2							11 Sep	21 Sep	21 Sep	2
Hesperophylax occidentalis (Banks, 1908)	2	—							21 Jul	10 Sep	None	1
Homophylax flavipennis Banks, 1900	14	1							11 Sep	11 Sep	11 Sep	1
Psychoglypha ormiae (Ross, 1938)	371	4							21 Sep	30 Oct	25 Sep	11
Philopotamidae												
Dolophilodes aequalis (Banks, 1924)	480	12							17 Apr	3 Jul	1 May	62
Dolophilodes novusamericanus (Ling, 1938)	14	6							22 May	14 Aug	12 Jun	2
Wormaldia gabriella (Banks, 1930)	13	3							4 Oct	30 Oct	16 Oct	7
Rhyacophilidae												
Rhyacophila alberta Banks, 1918	349	—							10 Sep	22 Oct	22 Oct	72
Rhyacophila angelita Banks, 1911	47	6							20 Aug	16 Oct	4 Oct	9
Rhyacophila brunnea Banks, 1911	519	16							12 Jun	4 Oct	7 Aug	77
Rhyacophila coloradensis Banks, 1904	321	15							17 Apr	21 Sep	30 Aug	93
Rhyacophila harmstoni Ross, 1944	1096	10							31 Jul	16 Oct	30 Aug	66
Rhyacophila hyalinata Banks, 1905	161	6							31 Jul	21 Sep	21 Sep	66
Rhyacophila pellisa Ross, 1938	84	6							24 Jul	16 Oct	7 Aug	15
Rhyacophila vagrita Milne, 1936	37	2							21 Sep	4 Oct	21 Sep	6
Rhyacophila verrula Milne, 1936	1880	7							4 Sep	30 Oct	4 Oct	262
Uenoidae												
Neophylax splendens Denning, 1948	2	1							30 Oct	30 Oct	30 Oct	1
Neothremma alicia Dodds & Hisaw, 1925	978	13							3 Jul	4 Oct	30 Aug	85
Oligophlebodes sigma Milne, 1935	5	—							10 Sep	22 Oct	None	1

TABLE 2. Site-by-site richness and abundance statistics. Species richness for each site and all sites combined (Canyon), as well as total abundance, which considers captures in Lindgren funnels and Malaise traps from 2003 to 2005. Totals for Sites 5 and 6 only use the available information from 2005 Malaise traps and thus are likely underestimates of actual amounts. For Plecoptera and Trichoptera, "# w/ peak abund." tallies the number of species whose peak abundance occurs at the site, as visualized in the "Distribution" section of Table 1. Under "Species," the average abundance for a typical species was calculated by averaging total abundance of all species at the site during 2004. Average frequency considers the average number of samples a single random species is expected to occur in, which is also indicative of average length of adult presence. Unique species is the number of species that occur at that site only (singletons). Under "Sample," the average abundance and richness of samples is given from 2004 data as a measure of expected abundance and richness of any single random sample.

Site	Richness				Abundance				# w/ Peak abund.		Species			Sample	
	All	Pleco.	Tricho.	Ephem.	All	Pleco.	Tricho.	Ephem.	Pleco.	Tricho.	Avg. abund.	Avg. freq.	Unique	Avg. abund.	Avg. rich.
Site 1 (CM)	37	13	17	7	4557	2663	1794	100	5	8	104.50	5.87	4	72.33	7.04
Site 2 (HG)	40	17	16	7	3018	1828	1095	95	5	4	38.37	5.51	2	47.90	6.32
Site 3 (SF)	54	23	24	7	4848	3017	1705	126	11	8	49.50	4.68	5	76.95	7.44
Site 4 (Tp)	42	17	19	6	6522	2781	3634	107	6	15	120.52	6.57	4	127.77	7.68
Site 5 (IM)[a]	27	10	14	3	546	57	483	6			20.22	2.11	1	60.66	6.33
Site 6 (ScF)[a]	18	7	9	2	1165	349	550	266			64.72	2.50	0	129.44	5.11
Canyon	71	26	35	10	20,656	10,695	9261	700							

[a]Data from 2005 only

used to construct species accumulation curves and to determine the minimum and maximum predicted richness of the EPT community. The MacArthur and Shannon diversity indices were used to quantitatively summarize species richness, abundance, and evenness. All analyses were run using the default settings of Estimate S; however, in order to compute the diversity indices, the "Compute Diversity Stats" option under the diversity computation menu was selected.

To assess similarities between sites and samples, nonmetric multidimensional scaling (NMDS), similarity percentages (SIMPER), and analysis of similarities (ANOSIM) analyses were conducted using Primer 6 (Clarke and Gorley 2006). A square-root-transformed Bray–Curtis similarity matrix was used in comparisons. Factors including month, prescribed seasonal community (described below), and site were entered as variables to code and explain similarity. Analyses were run on the cumulative data set as well as by order and by year. Here, we emphasize the 2004 data set for seasonal analysis because of that year's weekly sampling, contrasted with the every-other-week sampling in other years. For elevational analysis, the 2005 data set is represented here because of its inclusion of Sites 5 and 6, which were not sampled in other years.

The Bray–Curtis similarity matrix supporting Primer analyses was also used to delineate seasonal communities. The seasonal groupings were determined by similarity thresholds or significant drops in similarity between otherwise highly similar groups. A seasonal community was characterized by a sequential grouping of at least 3 consecutive samples with Bray–Curtis similarity values of 0.55 to 0.8 (no values over 0.8 occurred) immediately followed by a sample with 0.25 or lower similarity to the previous samples. We set these criteria upon investigation of similar data sets, and they are currently under further development as an analytical technique for seasonal community delineation.

RESULTS

Of the 252 samples from all sites and all years, 245 had at least one EPT individual present. A large number of Trichoptera (11,003 specimens), Plecoptera (10,402 specimens), and Ephemeroptera (731 specimens) individuals
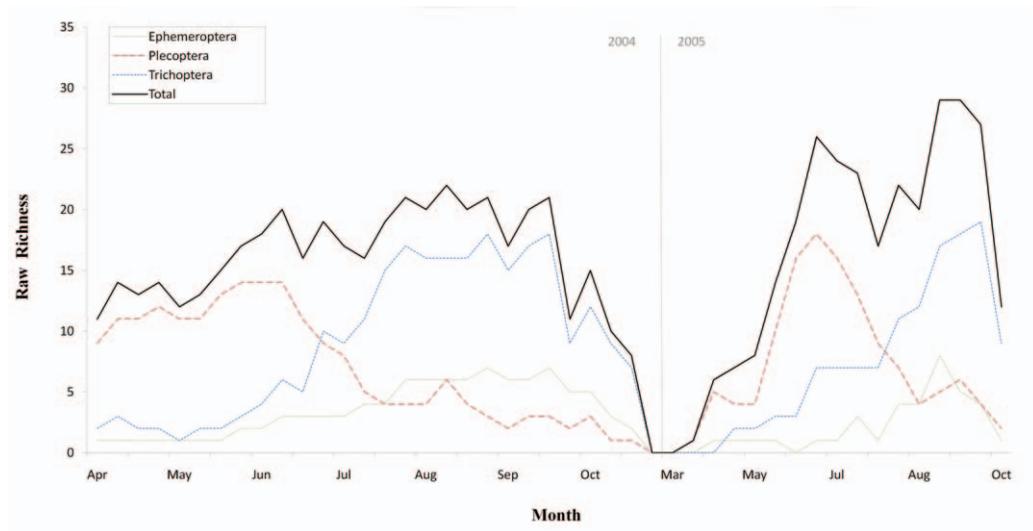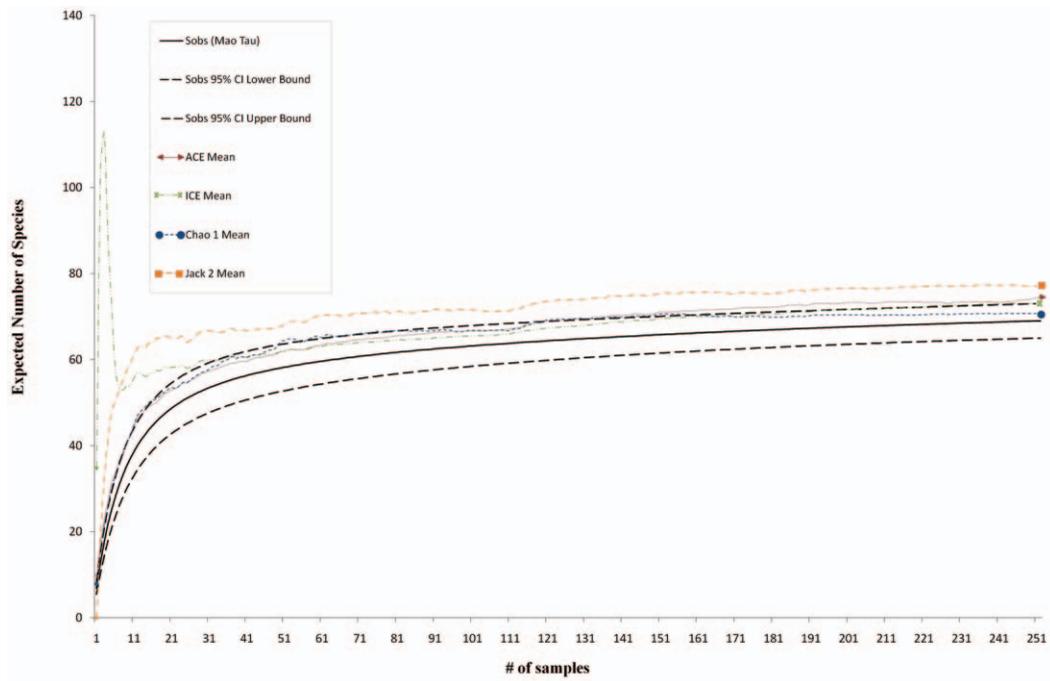
Fig. 2. EPT richness over time, 2004–2005.

Fig. 3. Species accumulation curve, all sites (1–6), all years (2003–2005). The bold, solid line represents the observed species (S_{obs}) and the bold, dashed lines represent the corresponding 95% confidence bounds, indicating observed and expected number of species, respectively. Note how the curve reaches an asymptote around 72 species for all indices.

TABLE 3. Comparison of acutal and predicted species richness. Sobs = observed species (raw richness), Chao = Chao 1 richness estimator, S–W = Shannon–Weiner index ($S' = E^\wedge H'$; $H' = -\sum(p_i)(\ln p_i)$), MacA = MacArthur index ($1/D = 1/\sum p_i^2$).

	2003				2004				2005				2005[a]				Overall			
Site	Sobs	Chao	S–W	MacA	Sobs	Chao	S–W	MacA	Sobs	Chao	S–W	MacA	Sobs	Chao	S–W	MacA	Sobs	Chao	S–W	MacA
Site 1	23	23.8	13.20	10.14	32	34	10.07	5.71	25	27.5	7.92	4.75	18	24	8.76	5.86	37	39.5	13.33	7.80
Site 2	29	31.5	9.87	4.75	35	42	15.64	11.68	31	33	7.32	3.68	22	23.5	5.93	3.37	40	41	16.28	11.31
Site 3	31	37	7.85	3.79	47	54	14.15	7.66	48	49.7	17.46	10.54	39	46	14.01	8.28	53	58	17.81	10.39
Site 4	27	29.5	8.08	4.89	33	33.6	11.82	9.34	36	38	11.25	7.11	31	33.5	9.87	6.79	41	46	13.60	9.72
Site 5													27	30	4.85	2.37				
Site 6													18	25.5	6.11	4.89				
Canyon[b]	56	65	21.12	13.18	63	66.8	24.53	16.16	60	61	21.12	13.22	54	56.5	21.12	15.62	69	70.7	27.11	18.96

[a]Calculations normalized to the shorter sampling season at Sites 5 and 6.
[b]All sites combined.

were collected, and Malaise sampling averaged 225 EPT individuals per sample. A total of 71 species (Tables 1, 2; Fig. 2) were documented in American Fork Canyon during our survey. No more than 30 species were documented during any single sampling period (Fig. 2), and an average of 8 species were captured at all sites and traps combined per sampling period.

Species accumulation curves for all predictors (Fig. 3) approach an asymptote of about 72 species, with a maximum estimate of 77 species from the second-order jackknife richness estimator. These results suggest a near saturation of possible species with our efforts and a potential for only 5–6 additional species. This maximum projected richness is realistic for the canyon as a whole because we found 2 species (*Alloperla severa* and *Rhithrogena robusta*) in 2007 while hand collecting at our standard study sites, and we documented 2 additional species (*Amphinemura banksi* and *Oligophlebodes minutus*) while collecting on the North Fork above Tibble Fork Reservoir. Thus, the higher estimates of 74 and 77 species given by the first- and second-order jackknife estimates are considered reflective of whole-canyon diversity, including areas such as the North Fork that were not sampled at all. The Chao 1 richness estimator correlated most closely with actual observed species (S_{obs}) (Table 3) and is considered the best predictor of species richness for American Fork Canyon due to its theoretical underpinnings that mathematically weight rare species.

The species accumulation curve (Fig. 3), based on the Chao 1 richness estimator, is $y = 9.1487 \ln(x) + 23.83$ ($R^2 = 0.8982$). The rate of species addition with more samples slows greatly after 86 samples and meets the number of observed species near 152 samples, demonstrating that our efforts in sampling with 245 samples was reflective of the actual community present. With 2004 as a model for heavy sampling in a single year at multiple sites, species accumulation curves predicted a maximum of 68 species when the number of observed species was 63. With Site 3 as a model for heavy sampling at one site over multiple years, a maximum of 67 species is projected from the 59 actually collected. These predictions demonstrate the importance of using multiple years and multiple sites to document all species in the area, because the maximum projected and actual numbers of
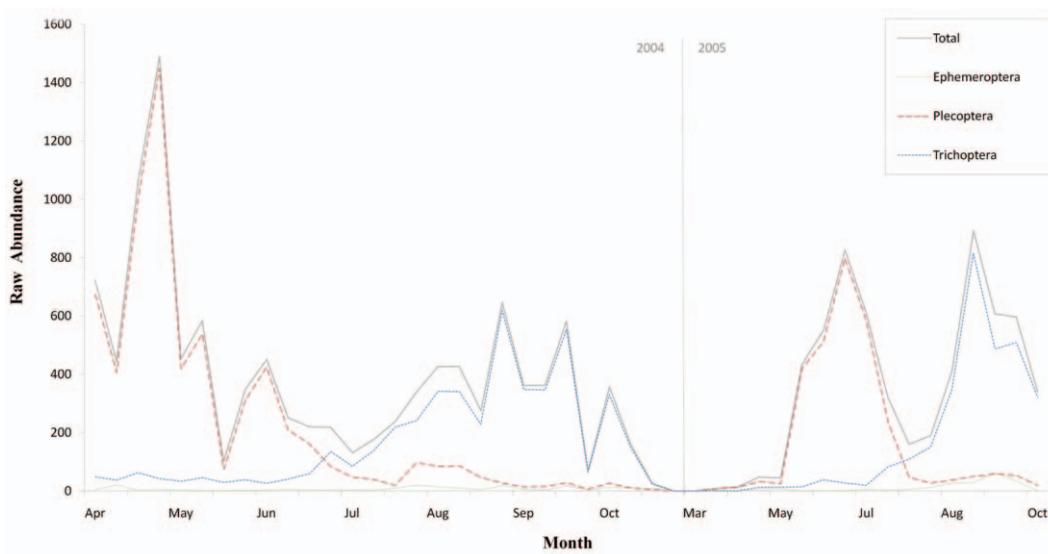
Fig. 4. EPT abundance over time, 2004–2005.

species during an individual year or at a single site are below the observed 71 species from all samples over all 3 years and 4 main sites.

There were 35 documented Trichoptera species, 26 Plecoptera species, and between 10 and 13 Ephemeroptera species (*Baetis* and *Epeorus* subimagoes were unresolvable to species level; Table 1). Within the Trichoptera, there were 10 families and 22 genera. An undescribed species in the genus *Allomyia* was collected at Site 5 in 2005 and is currently being examined to determine its position in this already problematic species complex in which the males are highly similar but the females noticeably distinct (Ruiter personal communication). We consider this undescribed species to be a new species based on the female morphology and preliminary DNA analysis (Ruiter personal communication). The genus *Rhyacophila* was the most species rich, with 9 species, 8 of which overlap at Site 3 and have little temporal segregation. The most genus-rich family was Limnephilidae, most of which were only collected from high-elevation sites, namely Site 4. Plecoptera comprised 7 families and 20 genera. The richest plecopteran genera were *Zapada* and *Capnia*, both with 3 species each. The Perlodidae family had the most species within Plecoptera (6 total), but all were from different genera and most had relatively low abundances.

Ephemeroptera are expected to be more speciose than observed because of extremely low capture rates.

Peak abundances calculated by taxonomic order and totaled across time (Fig. 4) indicated a May–June peak for Plecoptera, a September peak for Trichoptera, and no clear peak for Ephemeroptera. The most abundant trichopteran species were *Rhyacophila verrula, Neothremma alicia,* and *Rhyacophila harmstoni*—all with total counts >1000 individuals. *Zapada cinctipes, Prostoia besametsa,* and *Sweltsa coloradensis* were the most abundant Plecopterans—with counts >1000 individuals. *Cinygmula par* and *Diphetor hageni* were the most abundant ephemeropteran species, with total counts <100 individuals. *Baetis* sp. was also highly abundant relative to other Ephemeroptera but was not considered to be the most abundant mayfly, as it likely includes 2 species that were indistinguishable in the subimago stage.

We compiled average abundances of each species, peak abundance dates, frequency of occurrence, and dates of adult presence for all species (Table 1). These life history observations are based on information from 2004, when sampling was performed weekly. We also compiled additional species treatments including type localities, geographic range, known ecology, and documented seasonality of emergence for each species in American Fork
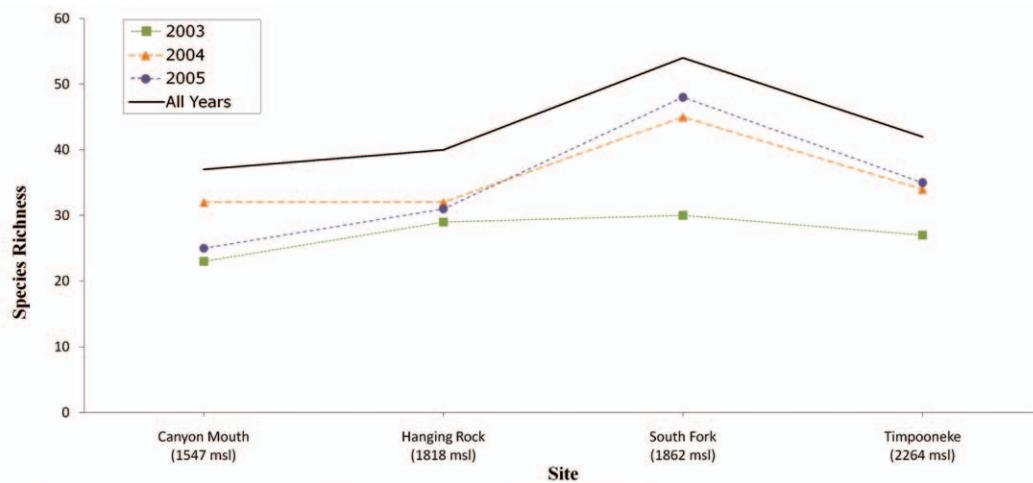
Fig. 5. Elevational richness trends. All years are represented separately with the total number of species that occur at each site. Richness consistently peaks at South Fork (Site 3), as does the number of unique species (Table 2).

Canyon from 2003 to 2005, coupled with adult phenology and elevation distribution comparisons between American Fork Canyon and the Rocky Mountains (Walker [now Judson] 2008).

Bray–Curtis similarities between sites along the elevational gradient show a 44% baseline similarity over the whole canyon. Fifteen ubiquitous species, including all 5 Nemouridae stoneflies, that occur at the 4 main sites contribute to this baseline similarity. When Sites 5 and 6 are also considered in 2005, this similarity drops to 19% due to the greater elevational change, the shorter sampling period, and the use of only Malaise traps.

The community composition of species distributed across elevations remained fairly constant between years, with more than 80% of the same species appearing at their respective sites. In all years, raw species richness based on presence and absence peaked at the mid-elevational site (Fig. 5; Tables 2, 3), Site 3, with a total of 54 species (E:7, P:23, T:24). Site 4 had 42 species, followed by Site 2 with 40 and Site 1 with 37. The highest number of unique species (Table 2) was also at Site 3, with 5 species occurring only at that site (*Amphicosmoecus canax, Doddsia occidentalis, Glossosoma verdona, Isocapnia hyalita,* and *Pictetiella expansa*). Site 2 had the lowest number of unique species, with only 2 (*Neophylax splendens, Paraperla frontalis*). Rarefaction by the site with the minimum total abundance showed the same trends of richness and unique species.

Altitudinal zonation was well defined, with a significant difference ($P < 0.008$) between low elevation (Sites 1 and 2) and high elevation (Sites 4, 5, and 6), with Site 3 as a transition community (Fig. 6). The NMDS plot by elevation (Fig. 6) had low 2-D stress (0.01), as did the plot for seasonal communities (Fig. 7). According to SIMPER, the major species contributing to low-elevation communities are *Lepidostoma pluviale* (14.32%), *Malenka californica* (13.95%), *Arctopsyche grandis* (13.73%), *Suwallia pallidula* (13.04%), and *Sweltsa coloradensis* (9.86%). For high elevations, *Neothremma alicia* (17.98%), *Sweltsa borealis* (14.88%), *Chyrandra centralis* (14.86%), *Rhyacophila harmstoni* (14.28%), and *Paraleuctra occidentalis* (10.19%) are the main contributing species. These same species that contributed to the community composition of low- and high-elevation sites, with the addition of *Rhyacophila verrula,* were also important in distinguishing low- and high-elevation sites from one another, with percent contributions to dissimilarity ranging from 6.45% to 4.03%. Many species from both altitudinal zones are present at Site 3 in the middle elevation.

Across the temporal gradient, 3 prominent seasonal species suites occurred consistently from year to year (Fig. 7). These groupings, as determined by abrupt decreases in Bray-Curtis similarity between consecutive samples, are supported by significant *P* values ($P = 0.001$) in ANOSIM analysis and by months within these groupings that were not significantly different from one another. From April to May, the winter
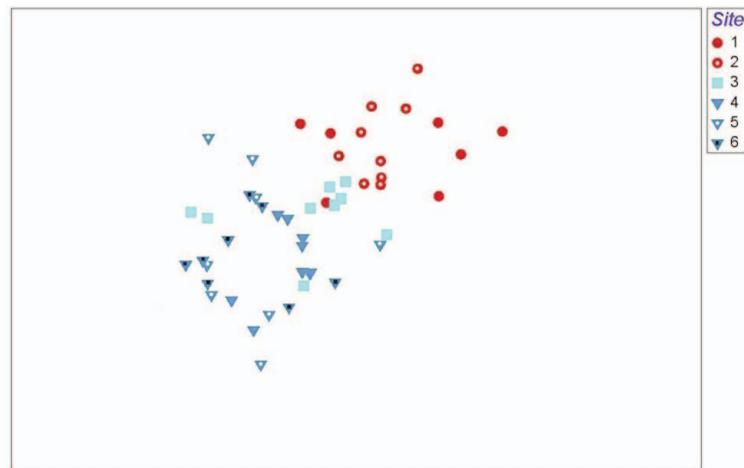
Fig. 6. NMDS plot by site. These plots from 2005 samples illustrate the elevational segregation of EPT communities. The sites are coded by elevational groupings with sites 1 and 2 designated as low elevation, site 3 as transitional, and sites 4–6 as high elevation. This coding was based on groupings apparent in the NMDS coded by site, which showed site 2 interspersed within site 1 and sites 4, 5, and 6 mixed together without distinct clustering by site. Samples from 2005 alone were selected for this ordination because of the addition of sites 5 and 6 which were absent in 2004, although 2004 shows similar trends.

community of adults was dominated by nemourid and capniid stoneflies (Table 1), particularly *Zapada cinctipes* (SIMPER % contribution: 52.66%) and *Prostoia besametsa* (20.71%), along with *Dolophilodes aequalis* (9.41%) as the caddisfly representative. The spring community is represented from late May until early July. Dominant members of the community were *Sweltsa coloradensis* (37.48%) and other Chloroperlidae, perlodid stoneflies (especially *Isoperla fulva* [10.72%]), and again *Dolophilodes aequalis* (8.78%). Beginning in late July or early August, the summer community is dominated by a number of caddisflies including *Rhyacophila brunnea* (20.17%), *Micrasema bactro* (17.18%), and *Lepidostoma pluviale* (12.37%), along with various limnephilid species and *Sweltsa borealis* and *Malenka californica* as the Plecoptera representatives. The summer community was most variable from year to year— sometimes more heavily composed of the diverse *Rhyacophila* species. Some variation occurs in annual phenology of these seasonal communities, but most are centered around dates in April ("Winter" community), June ("Spring" community), and August ("Summer" community). There seems to be no unique or consistent "Fall" community, though a few caddisflies and one stonefly (*Pictetiella expansa*) emerge exclusively during this time (Table 1).

Periods with low Bray–Curtis similarities and no consistent contributing species in SIMPER were termed transitional, with "Transition Sp-Sum" and "Transition Fall" groupings (Fig. 7). These samples are not seasonal communities as defined in this study, but transitional assemblages with high species turnover between each consecutive sample, as indicated by Bray–Curtis pairwise similarities of <0.55 between sequential samples or failure to meet our seasonal community delineation criteria.

Discussion

The riparian corridor of American Fork Canyon supports a rich EPT fauna, with a total of 71 species documented during our study. The formation of an asymptote in the species accumulation curves demonstrates that we captured the majority of potential species. Site 3 had the highest number of species (54 total)—a number equivalent to the average number of species sampled in any single year along the American Fork River. Additionally, this system has large faunal turnover throughout the season and as one moves up the elevational gradient. This turnover is most evident in the maximum of 30 species and average of 8 species documented in any single sampling period, which is only a small fraction of the total richness.
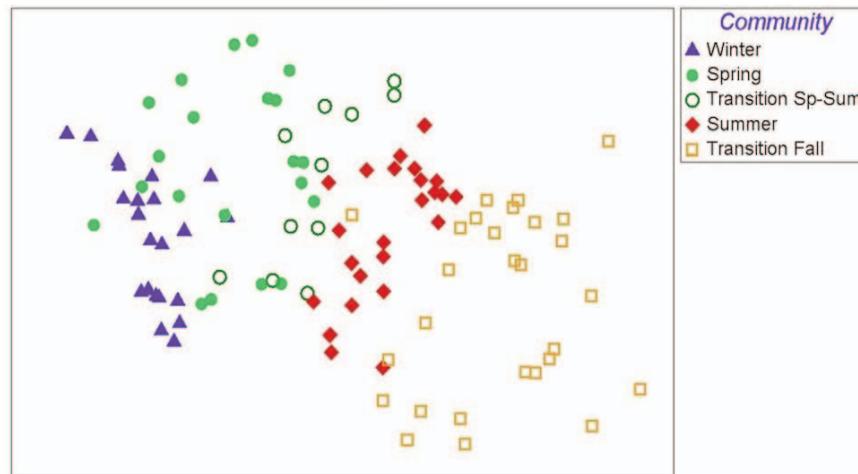
Fig. 7. NMDS plot by observed seasonal community. This plot, generated from 2004 samples, illustrates the temporal segregation of EPT communities. The sites are coded by the seasonal groupings of winter, spring, and summer along with transitional times. Samples from 2004 alone were selected for this ordination because of the weekly sampling, which was reduced to every other week in 2005 (although 2005 shows similar trends).

Along the elevational gradient, we clearly observed elevationally zoned communities (Fig. 6), as are frequently noted in stream insect communities (Allan 1975, Ward 1986). Additionally, we observed a gradual increase in number of species, with peak richness at Site 3 (Fig. 5), the mid-elevational site, followed by a decrease at Site 4. Interestingly, Site 3, just meters above the confluence of the North and South Forks, had surprisingly high richness in comparison to its neighboring site (Fig. 5, Table 2), located just 2 km downstream, at a comparable elevation, and with a superficially similar habitat. We did not assess the potential causes of this drastic change in our study, but we suspect one cause may be habitat degradation of the North Fork in areas upstream from the confluence. The North Fork is channelized, noticeably silty, and historically polluted by mine tailings—all factors that could influence past and current habitat suitability. Site 2 also has greater anthropogenic disturbance, as it is a popular camping and fishing area. Changes in stream order may also have an effect, but stream-order increases of small magnitude have not been shown to greatly affect community turnover (Minshall and Robinson 1998). Further study is needed to investigate this unanticipated, abrupt difference in richness and community composition. We suggest a comparison of multiple sites above and below the confluence of these forks

that would quantify physical and chemical habitat characteristics, assess anthropogenic disturbance history, and continue measurement of the EPT richness of both nymphs and adults.

Each year of our study, we observed 3 seasonal communities: "Winter," "Spring," and "Summer" (Fig. 7). The "Winter" and "Spring" communities were composed largely of Plecoptera, while the "Summer" community was composed almost exclusively of Trichoptera. In mountain streams, Trichoptera are known to emerge later in the season than other taxa (DeWalt et al. 1994), and we therefore anticipated a distinct Trichoptera-dominated seasonal community. However, within the Plecoptera-dominated community, we expected a gradual community transition (Figs. 2, 4), rather than 2 distinct seasonal communities with relatively abrupt turnovers. The 2 observed seasonal Plecopteran communities are supported by the known biology of the main contributors to these seasonal communities, namely Nemouridae and Capniidae of the "Winter" community. These species are known to emerge while streams are still largely inundated with ice. A comparison of the adult and nymph seasonal community composition and turnover rates could further elucidate these seasonal transitions. At a deeper level, such comparisons could examine the ecological and evolutionary

underpinnings of seasonal community succession of species with both an aquatic and terrestrial life stage. This succession can drive niche partitioning (Hildrew and Edington 1979, Smith et al. 2000) and life history strategies (Verberk et al. 2008) in unique ways.

We encourage the use of these species lists, distributions, and phenologies to inform biomonitoring (Barbour et al. 1999) of local water quality. Although this study was based on adult forms, the community structure of the terrestrial adults reflects the current or preceding aquatic community and reveals a number of species that are difficult to distinguish as nymphs. The use of adult taxa amplifies the species information available because adult forms are more easily resolved to species and can be correlated with immature forms to yield more specific information regarding stream quality (Lenat and Resh 2001). For example, we documented 9 distinct species of *Rhyacophila* as adults that in the past, we had classified as 2 or 3 species groups by using larvae.

Our documentation of changes in the faunal community along seasonal and elevational gradients also identifies the importance of having multiple sampling sites and dates to properly assess richness and water quality. Based on our observations of seasonal species suites (Fig. 7) and elevational zonation (Fig. 6), we recommend sampling the American Fork River near sites 1, 3, and 4 in May, late June, and mid-August to accurately monitor species richness. If sampling ability is severely limited, as is often the case due to funding and time constraints, we suggest using Site 3, the consistently most species-rich location, as a sentinel site. Specifically, we suggest sampling during June to capture stonefly diversity and August to document the caddisfly community. It is unclear how accurately Ephemeroptera would be represented in these suggested sampling regimes because of lack of abundant adult data, but we expect that collecting throughout these periods would sufficiently account for mayflies, as their abundance and apparent diversity was noted in aquatic samples taken in 2007. We anticipate that sampling with this proposed temporal and elevational strategy could also effectively document diversity and spatiotemporal variability in other Wasatch and Uinta streams.

This initial species survey of the EPT community is an important basis for the conservation of riparian habitats in American Fork Canyon and comparable streams along the Wasatch Range. The taxa lists we compiled document rare species, some of which were thought to be extirpated in Utah (Baumann and Ruiter 2008) and may not be captured in the future by less comprehensive evaluations. This study provides biodiversity and life history information that may otherwise be lost if human impacts continue to increase and regional richness decreases with the degradation of nearby watersheds such as has been noted with the Provo River. The compiled life history information (Table 1) represents current patterns of phenology, distribution, and community assemblage. This information will be helpful in developing further hypotheses about ecology, community structuring, and life history strategies. These baseline phenologies and distributions are an important foundation for future comparisons of seasonal or distributional shifts attributable to climate (Sheldon 2007) or other environmental changes, as well as for investigation of macroecological elevational patterns (Colwell et al. 2004, Bankhead et al. 2009). We hope future decisions can be influenced by this information to improve stream management, water-quality biomonitoring, and ecosystem preservation.

LITERATURE CITED

ALLAN, J.D. 1975. Faunal turnover and longitudinal zonation in an alpine stream. Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie 19:1646–1652.

BANKHEAD, E., S.W. JUDSON, AND C.R. NELSON. 2009. Comparison of Diptera: Empididae to Ephemeroptera, Plecoptera, and Trichoptera along an elevational gradient [poster]. Utah Conference on Undergraduate Research, Salt Lake City, UT.

BARBOUR, M.T., J. GERRITSEN, B.D. SNYDER, AND J.B. STRIBLING. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish. 2nd edition. EPA 841-B-99-002, U.S. Environmental Protection Agency, Office of Water, Washington, DC.

BAUMANN, R.W. 1973. Studies on Utah stoneflies (Plecoptera). Great Basin Naturalist 33:91–108.

BAUMANN, R.W., A.R. GAUFIN, AND R.F. SURDICK. 1977. The stoneflies (Plecoptera) of the Rocky Mountains. American Entomological Society, Philadelphia, PA. 208 pp.

BAUMANN, R.W., AND D.E. RUITER. 2008. Notes on the apparent loss of Trichoptera species from Utah. Abstract #503, North American Benthological Society 56th Annual Meeting, Salt Lake City, UT. Available from: http://nabs.confex.com/nabs/2008/techprogram/P3134.HTM

BAUMANN, R.W., AND J.D. UNZICKER. 1981. Preliminary checklist of Utah caddisflies (Trichoptera). Encyclia 58:25–29.

BOTTORFF, R.L., AND L.D. BOTTORFF. 2007. Phenology and diversity of adult stoneflies (Plecoptera) of a small coastal stream, California. Illiesia 3:1–9.

CLARKE K.R., AND R.N. GORLEY. 2006. PRIMER: multivariate statistics for ecologists. Version 6. PRIMER-E Ltd., 3 Meadow View, Lutton, Ivybridge PL21 9RH, United Kingdom. Available from: http://www.zen87707.zen.co.uk/primer-e/primer.htm

COLWELL, R.K. 2006. Estimate S: statistical estimation of species richness and shared species from samples. Version 8.0. Available from: http://viceroy.eeb.uconn.edu/estimates

COLWELL, R.K., AND J.A. CODDINGTON. 1994. Estimating terrestrial biodiversity through extrapolation. Philosophical Transactions: Biological Sciences 345:101–118.

COLWELL, R.K., C. RAHBEK, AND N.J. GOTELLI. 2004. The mid-domain effect and species richness patterns: what have we learned so far? American Naturalist 163:E1–E23.

DEWALT, R.E., K.W. STEWART, S.R. MOULTON, AND J.H. KENNEDY. 1994. Summer emergence of mayflies, stoneflies, and caddisflies from a Colorado mountain stream. Southwestern Naturalist 39:249–256.

EDMUNDS, G.F. 1954. The mayflies of Utah. Utah Academy of Sciences, Arts and Letters, Proceedings 31:64–66.

FINN, D.S., AND N.L. POFF. 2005. Variability and convergence in benthic communities along the longitudinal gradients of four physically similar Rocky Mountain streams. Freshwater Biology 50:243–261.

GAUFIN, A.R., A.V. NEBEKER, AND J. SESSIONS. 1966. The stoneflies (Plecoptera) of Utah. University of Utah Biological Series 14:1–89.

GRAY, L. 2004. Changes in water quality and macroinvertebrate communities resulting from urban stormflows in the Provo River, Utah, USA. Hydrobiologia. 518:33–46.

HILDREW, A.G., AND J.M. EDINGTON. 1979. Factors facilitating the coexistence of hydropsychid caddis larvae (Trichoptera) in the same river system. Journal of Animal Ecology 48:557–576.

LENAT, D.R., AND V.H. RESH. 2001. Taxonomy and stream ecology: the benefits of genus- and species-level identifications. Journal of the North American Benthological Society 20:287–298.

MERRITT, R.W., K.W. CUMMINS, AND M.B. BERG, EDITORS. 2007. An introduction to the aquatic insects of North America. 4th edition. Kendall-Hunt Publishing Company, Dubuque, IA.

MINSHALL, G.W., AND C.T. ROBINSON. 1998. Macroinvertebrate community structure in relation to measures of lotic habitat heterogeneity. Archiv für Hydrobiologie 141:129–151.

ROSS, H.H. 1944. The caddis flies, or Trichoptera, of Illinois. Natural History and Survey Division, IL. 326 pp.

RUITER, D.E. 2000. The generic key to the adult occellate Limnephiloidea of the western hemisphere (Insecta: Trichoptera). Ohio Biological Survey, Ohio State University, Columbus, OH.

SHELDON, A.L. 1999. Emergence patterns of large stoneflies (Plecoptera: Pteronarcys, Calineuria, Hesperoperla) in a Montana river. Great Basin Naturalist 59:169–174.

_____. 2007. Upward bound? Possible climate-induced shifts of stoneflies in Great Smoky Mountains National Park. Abstract #242, North American Benthological Society 55th Annual Meeting, Columbia, SC. Available from: http://www.benthos.org/Other-Publications/NABStracts/2007/242.aspx

SMITH, C., M. GOOD, J.F. MURPHY, P.S. GILLER, AND J. O'HALLORAN. 2000. Life-history patterns and spatial and temporal overlap in an assemblage of lotic Plecoptera in the Araglin Catchment Study Area, Ireland. Archiv für Hydrobiologie 150:117–132.

TERBORGH, J. 1971. Distribution on environmental gradients: theory and a preliminary interpretation of distributional patterns in the avifauna of the Cordillera Vilcabamba, Peru. Ecology 52:23–40.

USINGER, R.L., EDITOR. 1956. Aquatic insects of California. University of California Press, Berkeley, CA.

VERBERK, W.C.E., H. SIEPEL, AND H. ESSELINK. 2008. Life-history strategies in freshwater macroinvertebrates. Freshwater Biology 53:1722–1738.

WALKER, S. 2008. Altitudinal and seasonal survey of Ephemeroptera, Plecoptera, and Trichoptera in American Fork Canyon, Utah. Undergraduate honors thesis, Brigham Young University, Provo, UT.

WARD, J.V. 1986. Altitudinal zonation in a Rocky Mountain stream. Archive für Hydrobiologie Supplement 74:133–199.