INVERTEBRATE DRIFT IN NEIGHBORING PERENNIAL AND SEASONAL TRIBUTARIES OF THE SACRAMENTO RIVER

A Thesis

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by

Gina Marie Benigno

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ABSTRACT

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While seasonal floodplains are known to provide abundant food and important rearing habitat for native and anadromous fish in California, the value of other types of seasonally aquatic habitats is less well understood. The use of seasonally flowing tributaries of the Sacramento River as non-natal rearing habitat for salmonids and as spawning areas for native fish has been previously documented.

In order to evaluate food availability in Sacramento River tributaries, I compared invertebrate drift in a seasonal tributary with a neighboring perennial tributary through the duration of seasonal tributary flow, from November 2005 through June 2006. I compared drift density, taxonomic diversity, and community composition between the two tributary types.

Overall drift abundance was greater in seasonal tributary samples. Taxonomic richness in the seasonal tributary was comparable to the perennial tributary, although community composition was different between the two tributary types. Specifically, chironomid larvae and small crustaceans were abundant in seasonal tributary drift, while terrestrial invertebrates were the primary component of perennial tributary drift.

The results illustrate that seasonally flowing tributaries can provide greater prey availability to fish that use these habitats compared with perennial tributaries.

CHAPTER I

INTRODUCTION

Drying is often seen as an undesirable disturbance in river systems, but where drying is a part of a system's natural flow regime, temporary rivers can be valuable habitat for native aquatic species (Humphries & Baldwin, 2003). Enhanced productivity associated with the rewetting of seasonally aquatic habitat, as described in the Flood Pulse Concept, has been well documented for floodplain systems (Junk, Baley & Sparks, 1989; Bayley, 1995; Tockner, Malard & Ward, 2000; Junk & Wantzen, 2004). Similarly, the process of extreme wetting and drying in arid rivers has been described in terms of boom and bust periods of resource availability (Walker, Sheldon & Puckridge, 1995; Walker, Puckridge & Blanch, 1997). Native organisms that have evolved to recover rapidly from naturally occurring drought conditions are able to benefit from periods of enhanced resource availability in temporary aquatic habitats (Poff *et al*., 1997).

Rivers that periodically dry are common in regions throughout the world (Larned *et al.*, 2010), and are the dominant stream type in arid and semi-arid regions (Uys & O'Keeffe 1997). Unlike the highly variable and unpredictable flows described for arid land rivers (Walker *et al.*, 1995; Bunn *et al.*, 2006) lotic habitat in Mediterranean climate regions exhibits predictable periods of flow and drying, resulting from a predictable annual cycle of a cool wet season followed by warm dry weather (Gasith & Resh, 1999).

The unique flow regime is a defining characteristic of Mediterranean streams, and the predictable disturbance cycle plays an important role in maintaining native aquatic biodiversity (Resh *et al*., 1988; Poff *et al.*, 1997; Townsend, Scarsbrook & Dolédec, 1997). Although temporary lotic habitats have historically been overlooked by researchers in Mediterranean climate regions (Álvarez-Cobelas, Rojo & Angeler, 2005) and worldwide (Larned *et al*., 2010), they are an integral part of how river systems function.

Non-perennial streams in general have not been well defined (Walker *et al.*, 1995). There has been a wide variety of terminology used inconsistently to describe these stream types (see Uys & O'Keeffe, 1997), which may reflect an overall lack of research and understanding of these systems (Larned *et al*., 2010). The classification scheme proposed by Uys and O'Keeffe (1997) for South African temporary rivers categorizes streams primarily by the extent of drying, as the abiotic pressures and biological responses are different in streams that cease flow and maintain some surface water compared with those that dry completely. Similarly, Abell (1984) described three categories of temporary stream flow for central California foothill streams: Type I streams are ephemeral and flow only briefly after storms (I will refer to these stream as "ephemeral"); Type II streams maintain continuous flow once the water table rises, but dry completely during summer months (I will refer to this stream type as "seasonal"); and Type III streams maintain permanent pools and can resume flow prior to the rainy season, when transpiration by riparian vegetation lessons in the fall (I will refer to this stream type as "intermittent").

The benefits of seasonally aquatic habitat for native fish are well described for floodplain systems. Re-wetting of floodplain habitat mobilizes an abundant supply of organic material and nutrients, which enable a pulse of productivity in newly formed aquatic habitat (Junk *et al.*, 1989). Seasonal floodplains can be critical spawning and rearing habitat for native fish (Welcomme, 1979; Sommer *et al.*, 2001; Balcome *et al.*, 2007), which are supported by more abundant invertebrate food resources available in floodplain habitat (Gladden & Smock, 1990; Benke, 2001; Schemel *et al.*, 2004). Although less commonly documented, tributaries that dry and flow seasonally are also utilized by native fish (Walther, 2009). In the arid southwestern US, they are critical habitat for endangered species (Larbe & Fausch, 2000). In the Pacific Northwest, it has been demonstrated that salmonids rearing in perennial water will move into temporary tributaries and off channel habitat when it becomes seasonally available (Erman & Hawthorne, 1976; Brown & Hartman, 1988; Wigington *et al*., 2006). In the western United States, native fish use seasonal tributary habitat for spawning in greater proportions than non-native fish (Colvin *et al.*, 2009; Walther, 2009). Chinook salmon rearing in seasonal tributaries of the Sacramento River have been shown to have increased growth rates than those found in perennial water, which may be due to warmer temperatures and greater prey availability (Limm & Marchetti, 2009).

In the highly modified Sacramento River system of Northern California, floodplain habitat is essential spawning and rearing habitat for native species. Chinook salmon rearing in floodplain habitat exhibit faster growth rates than those in perennial waters of the Sacramento River (Sommer *et al.*, 2001). Periods of extended floodplain inundation are related to strong year classes for some native species (Feyrer, Sommer &

Harrell, 2006). However, much of the historic floodplain habitat has been converted to urban and agricultural land (Nichols *et al.,* 1986), and natural flood pulses in this river system are generally muted by regulated flow releases from upstream dams (Yates *et al.*, 2008). Similar to findings documented for the large Sacramento River floodplains (Sommer *et al.*, 2001; Feyrer *et al.*, 2006), seasonally flowing small tributaries of the Sacramento River are also used primarily by native fish for spawning and rearing habitat (Walther, 2009), and higher growth rates and greater feeding success have been documented for fish rearing in these habitats (Limm & Marchetti, 2009).

My study objective is to examine and compare macroinvertebrate prey resources between seasonal and perennial tributaries. To compare prey availability, I sampled macroinvertebrate drift from two neighboring Sacramento River tributaries: one that flows perennially, and one that flows only seasonally. I chose to focus sampling on invertebrate drift, as drifting invertebrates are more susceptible to being consumed by fish (Rader, 1997). I hypothesize that invertebrate drift abundance is greater in a seasonally flowing tributary than in comparable locations in a perennially flowing tributary, similar to the patterns observed for Sacramento River floodplains (Sommer *et al.,* 2001; Benigno & Sommer, 2008). I investigate patterns in abundance, diversity, and community composition in both tributary types to further explain the differences in food web resources between perennial and seasonally flowing tributaries.

CHAPTER II

METHODS

Study Area

Sample sites were selected on two neighboring tributaries of the Sacramento River in Northern California (Figure 1). These two tributaries were chosen for

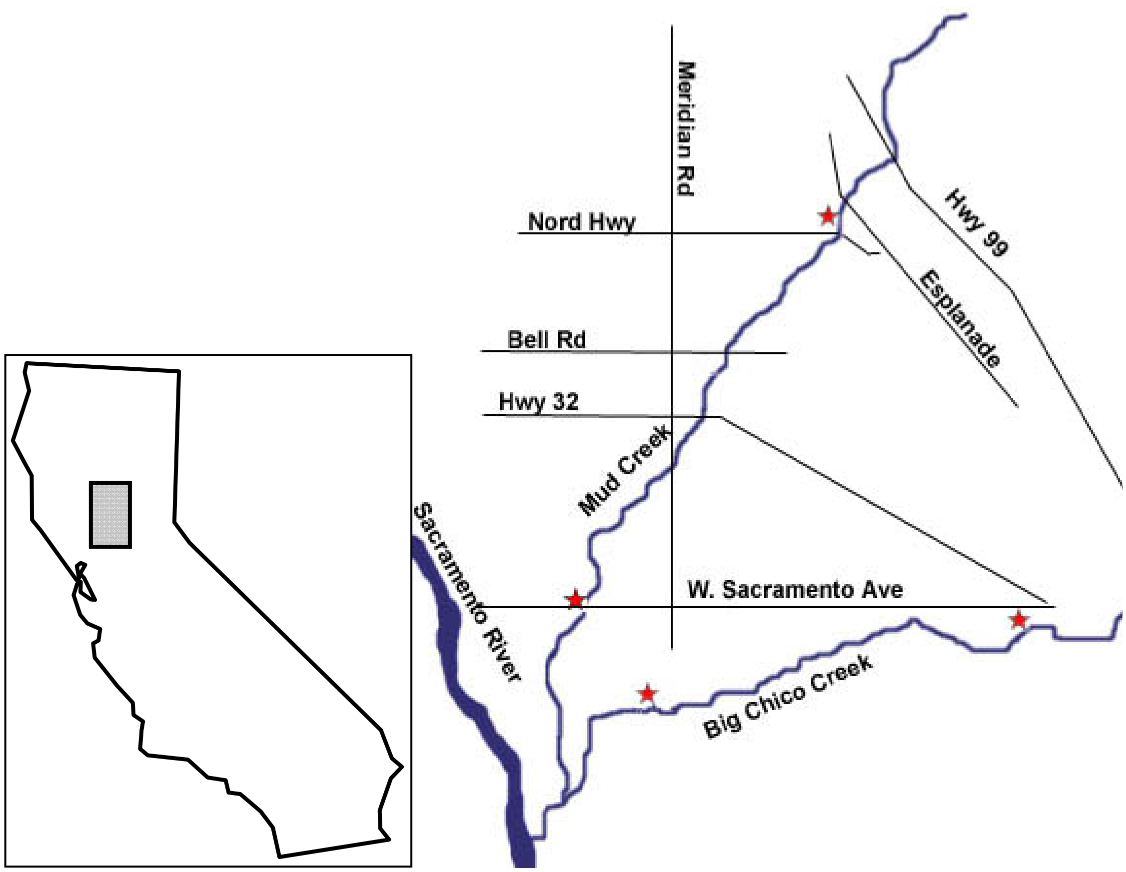

Fig. 1 Map of study site showing sample locations.

comparison because of their geographic proximity and differing flow regimes. Big Chico Creek is a perennially flowing stream and Mud Creek flows seasonally during winter and spring. Big Chico Creek is fed by numerous tributaries and springs, and flows 72 km from its origin at around 1650 m elevation to the confluence with the Sacramento River at 36 m elevation. Much of the upper watershed is located within an ecological reserve, and the lower stream reaches are within a large municipal park. Therefore, the stream habitat is relatively preserved in its natural state with intact riparian vegetation along most of its course.

Mud Creek originates as a perennial spring-fed stream at 1160 m elevation and flows 42 km to its confluence with Big Chico Creek 1 km upstream of the Sacramento River confluence. Mud Creek maintains perennial to intermittent flow in the foothills, while the lower 15-20 km of the valley floor reach dries completely in late spring and resumes flow when winter rains commence. Mud Creek typically maintains continuous surface flow for 4-6 months during winter and spring, which is typical of a Type II seasonal stream as defined by Abell (1984). A 21 m waterfall, located approximately 25 km upstream from the Sacramento River confluence, acts as an upstream barrier to fish. The upper watershed of Mud creek is fairly undisturbed and undeveloped as it is under private ownership. The valley floor reach of Mud Creek has been re-routed and straightened for flood water conveyance, with wide setback levees and periodic removal of riparian vegetation to accommodate high flows that are occasionally diverted from Big Chico Creek as flood protection for the city of Chico.

Research in other regions has demonstrated that the use of temporary tributaries by fish decreases with distance from a perennial water source (Magalhães *et* *al.*, 2007; Colvin *et al.*, 2009), so in the current study I sampled both tributary types in close proximity to the Sacramento River. Two sample sites were selected in the valley floor reach of each tributary (Figure 1). Downstream habitat sample sites were located within 3 km upstream of the confluence of the two tributaries. Stream substrate was predominantly sand at both downstream sites. Upstream sample sites were selected approximately 8 km upstream, where substrate was predominantly gravel and cobble. The elevation difference between upstream and downstream sites is less than 15 m. There were a total of four samples sites: upstream Mud Creek (UMC), downstream Mud Creek (DMC), upstream Big Chico Creek (UBC), and downstream Big Chico Creek (DBC). Because of their similar characteristics, upstream and downstream sites were paired for the two tributary types.

Invertebrate Sampling

Drift invertebrate samples were collected from Big Chico Creek and Mud Creek during the period of seasonal flow on Mud Creek. Samples were collected monthly at two sites per evening over two consecutive days. Sampling was conducted between one half hour and three hours after sunset, during the time of peak abundance of invertebrate drift (Hauer & Lamberti, 1996). The order in which sites were sampled was determined randomly each month to avoid any potential bias associated with time of sampling. Two replicate drift invertebrate samples were collected from each site by placing a drift net (45 x 25 cm mouth, 1 m length, 350-μm mesh) into the flowing water for 15 minutes. All material collected in the nets was preserved in the field in 90% ethanol. Water velocity at the opening of each drift net was measured with a Marsh-

McBirney Flow Mate portable flow meter. Physical parameters were measured at each sample site every month. Hanna Instruments meters were used to measure temperature, pH, conductivity, and turbidity. Stream discharge was calculated using stream width, depth, and velocity measurements made at five intervals along a cross section of the stream.

In the laboratory, macroinvertebrates were sorted and identified under a dissecting microscope. Sub-sampling procedures followed an integrated fixed count and fixed area approach (King & Richardson 2002). Samples were homogenized and divided evenly into pan among a grid with 12 cells. Cells were selected randomly from the grid and sorted in their entirety until a minimum number of 500 invertebrates had been counted and a minimum of 25% of each sample was sorted. Aquatic insects were identified following Southwest Association of Freshwater Invertebrate Taxonomists Level I Standard Taxonomic Effort, which roughly corresponds to genus level identifications where possible, Chironomidae to family, and monotypic taxa identified to species (http://www.safit.org/Docs/ste_list.pdf). Higher level taxonomic resolution was used for Oligochaeta, Cladocera, Copepod, Ostracoda, and Collembola. Terrestrial invertebrates were counted and classified as terrestrial. Identifications were made using Merritt and Cummins (1996) and other appropriate taxonomic references. Non-insect invertebrates were identified using Thorp and Covich (2001) and local reference manuals. Identifications were verified by taxonomists at the California Department of Fish and Game Aquatic Bioassessment Laboratory, Chico CA.

Data Analyses

Raw data were converted to estimated abundance by dividing the total number of individuals counted by the fraction of the sample that was sorted (estimated abundance = number of invertebrates / fraction subsampled). The volume of water sampled was calculated by multiplying the water velocity measured in front of the sample net by the length of time sampled and the area of the net opening. Drift density, the number of individuals per cubic meter of water sampled, is the estimated abundance divided by the volume of water sampled. Taxonomic richness was determined as the number of unique taxa per sample. Shannon Diversity (H') calculations were made using the DIVERSE function in Primer-e v.6 software using the following equation: H' = -Sum(Pi*Ln(Pi)), where Pi=the proportion of each taxon in a sample (PRIMER-E Ltd., Plymouth, UK) (Clarke & Gorley, 2006). Terrestrial invertebrates and nondistinct taxa (damaged individuals or immature larvae not identifiable to genus) were not included in diversity estimates.

Differences in abundance, richness, and diversity metrics were analyzed using Minitab-13 (Minitab, Inc. State College, PA, USA). The two replicates per site were composited into one sample for each site and month. Because of small sample size and non-normal data distribution, non-parametric methods were used to compare these metrics between seasonal and perennial tributary types. Perennial and seasonal tributary samples were paired by habitat type (upstream or downstream) for each month, and Wilcoxon signed rank tests were used to test the null hypothesis that there is no difference between tributary types.

Non-metric multidimensional scaling (NMDS) was used to evaluate differences in community composition between streams. Non-metric multidimensional scaling is an unconstrained method of ordination that arranges sites on a two-dimensional plot with respect to the ranks of pair-wise similarities. Physical proximity of samples on the NMDS plots indicates similarity of macroinvertebrate assemblages. NMDS analyses were conducted using Primer-e v6 (PRIMER-E Ltd., Plymouth, UK) (Clarke & Gorley, 2006). Non-distinct taxa were excluded from NMDS analyses, and taxa present in only one sample were excluded from analyses to minimize the effect of rarity. Data were square-root transformed to lessen the effect of abundance. Bray-Curtis similarity scores for the transformed data were used for the following analyses: separate NMDS ordinations were conducted to compare upstream and downstream sites between creeks; one-way Analysis of Similarities (ANOSIM) was conducted to evaluate statistical differences in community structure between tributaries for upstream and downstream sites; and one-way similarity percentage (SIMPER) analysis was used to determine the taxa responsible for the greatest differences between tributaries.

CHAPTER III

RESULTS

Stream flow in Mud Creek resumed in November, 2005, and lasted through June, 2006. Surface water runoff over the course of water year 2006 was 165% above average for this region (Gehrke *et al*., 2006), with very high levels of precipitation in late spring resulting in a longer than average period of flow in the seasonal tributary (M. Marchetti, personal communication). A total of 8 monthly samples were collected. I was unable to collect monthly samples at all samples sites; three samples were not collected from the downstream Big Chico Creek (DBC) sample site in December, March, and April when flooding prevented access. Therefore, a total of 29 samples were collected (Table 1), with only 13 sample pairs due to the missing samples.

Table 1 list of samples collected at each site. Missing samples are due to inaccessibility during flooding.

	Upstream sample sites		Downstream sample sites	
	UBC (perennial)	UMC (seasonal)	UBC (perennial)	UMC (seasonal)
November	11/29/05	11/29/05	11/29/05	11/29/05
December	12/20/05	12/19/05	**Not collected**	12/19/05
January	1/23/06	1/24/06	1/24/06	1/23/06
February	2/20/06	2/21/06	2/20/06	2/21/06
March	3/21/06	3/20/06	**Not collected**	3/20/06
April	4/18/06	4/17/06	**Not collected**	4/17/06
May	5/23/06	5/22/06	5/23/06	5/22/06
June	6/20/06	6/19/06	6/20/06	6/29/06

Water temperature ranged from 8°C to 23°C in Big Chico Creek, and from 8.5°C to 27°C in Mud Creek. The greatest temperature differences between creeks were in May and June during the drying phase, with Mud Creek warming more quickly than Big Chico Creek. Turbidity ranged from 0.6 NTU to 5.8 NTU in Big Chico Creek, and from 0.2 NTU to 26.7 NTU in Mud Creek. The greatest differences in turbidity between creeks were seen during high flow events, when Mud Creek was much more turbid than Big Chico Creek. Stream pH ranged from 7.6 to 8.5 in Big Chico Creek, and from 7.3 to 8.4 in Mud Creek, with no clear trends or differences between stream types. Conductivity ranged from less than one to 197 µs in Big Chico Creek, and from less than one to 260µs in Mud Creek. The highest conductivity for Big Chico Creek was measured during the first high flow event. Conductivity values rose in Mud Creek during spring warming and drying, but remained low in Big Chico Creek during this period. The minimum discharge measured during sampling in Big Chico Creek was 0.8 m^3/s and 0.05 m^3/s in Mud Creek. Unsafe conditions in both tributaries prevented maximum discharge measurements.

A total of 19,685 invertebrates were identified. One hundred and eleven distinct taxa were collected from the two tributaries (Table 2). Of the taxa collected, 32 were found only in Mud Creek, 27 only in Big Chico Creek, and 52 were found in both tributaries. Thirty eight taxa were represented by a single individual and were excluded from community analyses using NMDS. Taxa making up >1% of the total invertebrates collected in each tributary are shown in Table 3. Terrestrial invertebrates were the most abundant component of drift in Big Chico Creek, and were much less abundant in Mud Creek drift samples. Small crustaceans (Cladocera, Copepods, and Ostracods) were

Table 2 List of taxa collected at each site during the sampling period from November 2004-June 2005. Abundance categories given are as follows: D=dominant, present in most samples and making up >20% of the total individuals collected; A=abundant, present in more than half the samples and making up <20% of the total; C=common, present in at least half the samples and making up >5% of the total, O=occasional, present in more than one sample and making up >1% of the total, and R=rare, present is two or fewer samples and making up <1% of the total. Dashes indicate that the listed taxa was absent from all samples from that site.

			Downstream		Upstream	
			BC	MC	BC	MC
Cnidaria						
	Hydrozoa	*Hydra* sp.	–	R	–	–
Nemertea						
	Enopla	*Prostoma* sp.	–	R	–	–
Mollusca						
	Bivalvia	*Corbicula* sp.	R	–	R	–
	Gastropoda	Lymnaeidae	–	–	–	R
		Physa sp.	–	C	R	C
		Planorbidae	–	C	R	R
		Ferrissia	–	–	R	–
Annelida						
	Oligochaeta		O	C	C	C
Arthropoda (non-insect)						
	Arachnida	Acari (immature)	–	–	R	–
		Arrenurus sp.	–	–	–	O
		*Wandesia*sp.	–	–	R	–
		*Atractides*sp.	R	O	R	R
		Hygrobates sp.	–	O	O	R
		*Lebertia*sp.	R	R	R	–
		Mideopsis sp.	–	O	O	O
		Sperchon sp.	C	O	C	O
		Sperchonopsis sp.	–	–	R	–
		Torrenticola sp.	R	–	O	R
	Branchiopoda	Cladocera	R	D	–	C
	Maxillopoda	Copepoda	O	D	O	C
	Ostracoda		R	A	O	C
	Malacostraca	Amphipoda (immature)	–	O	R	–
		Hyalella sp.	–	O	R	–
		Crangonyx sp.	–	O	–	–
		Cambaridae	–	–	O	–
	Collembola		C	A	C	C
Insecta						
	Ephemeroptera	Ephemeroptera (immature)	–	–	R	–
		Ameletus sp.	R	R	O	O
		Baetidae (immature)	R	R	O	R
		Acentrella sp.	–	–	R	–
		Acentrella insignificans	–	–	O	–
		Acentrella turbida	–	–	R	–
		Baetis sp.	–	R	R	–
		Baetis tricaudatus	C	C	A	D
		Callibaetis sp.	R	O	–	C
		Centroptilum sp.	–	O	O	O
		Fallceon quilleri	–	O	O	C
		Caenis latipennis	–	O	R	O
		Ephemerellidae (immature)	O	O	O	C
		Caudatella sp.	R	–	O	–
		Drunella coloradensis	–	R	O	O
		Ephemerella sp.	C	O	C	C
		Serratella sp.	–	–	R	O
		Serratella teresa	–	–	–	R
		Serratella tibialis	–	–	–	R
		Heptageniidae (immature)	–	O	O	O
		Epeorus sp.	–	O	O	O
		Heptagenia sp.	–	–	–	R
		Ironodes sp.	–	–	R	–
		Rhithrogena sp.	R	–	R	O
		Tricorythodes sp.	R	R	O	O
		*Paraleptophlebia*sp.	–	–	R	O

Table 2 (Continued)

			Downstream		Upstream	
			BC	MC	BC	MC
Insecta (continued)	Odonata	Coenagrionidae (immature)	–	C	–	O
		Argia sp.	R	R	O	O
		Enallagma sp.	–	R	–	–
		Anisoptera (immature)	–	R	R	–
		Libellulidae / Cordulidae (immature)	–	–	–	R
	Plecoptera	Plecoptera (immature)	–	–	R	–
		Capniidae	R	R	C	O
		Taeniopterygidae	–	–	R	–
		Suwallia sp.	–	–	–	R
		Sweltsa sp.	–	–	R	R
		Perlodidae (immature)	–	–	R	O
		Isoperla sp.	–	–	O	O
		Pteronarcys sp.	R	–	O	–
	Hemiptera	*Belostoma* sp.	–	R	–	–
		Corixidae (immature)	R	O	–	R
		Corisella sp.	–	–	–	R
		Hesperocorixa sp.	–	R	–	–
		Sigara sp.	O	O	–	R
		Trichocorixa sp.	–	–	R	–
	Megaloptera	Corydalidae	–	R	–	R
	Trichoptera	Trichoptera (immature)	R	–	R	R
		Glossosoma sp.	–	–	O	–
		Hydroptilidae	–	–	–	R
		Hydroptila sp.	R	O	O	–
		Rhyacophila sp.	–	–	O	–
		Hydropsychidae	R	–	O	R
		*Cheumatopsyche*sp.	–	–	O	R
		Hydropsyche sp.	O	–	C	O
		Chimarra sp.	–	–	R	–
		Polycentropus sp.	–	–	–	R
		Tinodes sp.	–	–	–	R
		Amiocentrus aspilus	–	–	R	–
		Brachycentrus sp.	–	–	O	–
		Eobrachycentrus sp.	–	–	–	R
		Micrasema sp.	R	O	O	O
		Lepidostoma sp.	R	–	O	–
		Leptoceridae (immature)	–	R	O	O
		Nectopsyche sp.	–	–	R	–
		Ylodes sp.	–	–	–	R
		Gumaga sp.	–	–	R	R
		Neophylax sp.	–	–	–	R
	Lepidoptera	*Petrophila* sp.	R	–	O	–
	Coleoptera	Dytiscidae (immature)	–	O	–	R
		Laccophilus sp	R	–	–	R
		Hydroporinae	–	–	–	R
		Liodessus obscurellus	A	C	C	C
		Hydroporus sp.	R	R	–	R
		Sanfilippodytes sp.	–	R	R	R
		Stictotarsus sp.	–	–	R	O
		Agabus sp.	–	O	–	O
		Thermonectus sp.	–	R	–	–
		Haliplus sp.	–	R	–	–
		Microcylloepus sp.	–	–	O	O
		Narpus sp.	–	–	–	R
		Optioservus sp.	R	R	C	O
		Ordobrevia sp.	R	–	–	–
		Rhizelmis sp.	–	–	R	–
		Zaitzevia sp.	R	–	R	O
		Hydraena sp.	–	R	–	R
		Ochthebius sp.	–	–	R	–
		Hydrophilidae (immature)	R	R	C	R
		Cymbiodyta sp.	–	R	–	R
		Tropisternus sp.	R	–	–	R

Table 2 (Continued)

			Downstream		Upstream	
			BC	MC	BC	MC
Insecta (continued)	Diptera	Tipulidae	R	–	R	R
		Blepharicera sp.	–	–	R	–
		Psychodidae (pupae)	–	–	R	–
		Psychoda sp.	R	–	O	–
		Pericoma/Telmatoscopus sp.	–	–	R	–
		Ceratopogonidae	–	R	R	O
		Chaoborus sp.	–	R	–	–
		Chironomidae	D	D	D	D
		Culicidae (immature)	–	–	–	R
		Culex sp.	–	–	R	–
		Culiseta sp.	–	–	–	R
		Dixa sp.	–	–	–	R
		Dixella sp.	–	–	–	R
		Simulium sp.	A	C	A	A
		Empididae (pupae)	–	R	R	R
		Clinocera sp.	–	–	–	R
		Neoplasta sp.	R	–	O	R
		Sciomyzidae	–	R	–	–
		Ephydridae	–	–	–	R
		Muscidae	–	R	–	–

Table 3 Taxa comprising >1% of all invertebrates collected from each tributary

Big Chico Creek		Mud Creek	
terrestrial	37.9	Chironomidae	21.5
Chironomidae	32.6	Cladocera	17.9
Baetis	6.8	Copepoda	10.2
Liodessus obscurellus	4.2	Baetis	8.4
Simulium	3.1	Physa	7.8
Sperchon	2.7	terrestrial	6.5
Oligochaeta	1.3	Simulium	4.2
Capniidae	1.1	Fallceon quilleri	4.0
Collembola	1.0	Ostracoda	3.4
Ephemerella	0.9	Collembola	2.4
		Liodessus obscurellus	1.5
		Oligochaeta	1.2
		Callibaetis	1.2

abundant in Mud Creek and not in Big Chico Creek. Chironomidae larvae and pupae were an abundant component of the drift in both stream types over the sampling period.

Taxonomic richness and Shannon diversity values are shown in Figures 2 and 3, respectively. Taxonomic richness and Shannon diversity values were not significantly different between the two stream types on a month-to-month comparison (Wilcoxon signed rank test, $p = 0.075$ and $p = 0.727$ respectively), but cumulative taxonomic richness over the study period for each site begin to reveal differences between stream types (Figure 2). Drift densities are shown in Figure 4. Drift density was significantly greater in the seasonal tributary than in the perennial tributary (Wilcoxon signed rank test, $p = 0.003$). Bootstrapping estimates of the mean and 95% confidence interval of perennial tributary drift density is 9.6 (3.2, 17.3) invertebrates/m^3 of flow, and seasonal tributary drift density is 24.1 (13.1, 38.9) invertebrates/m^3 of flow.

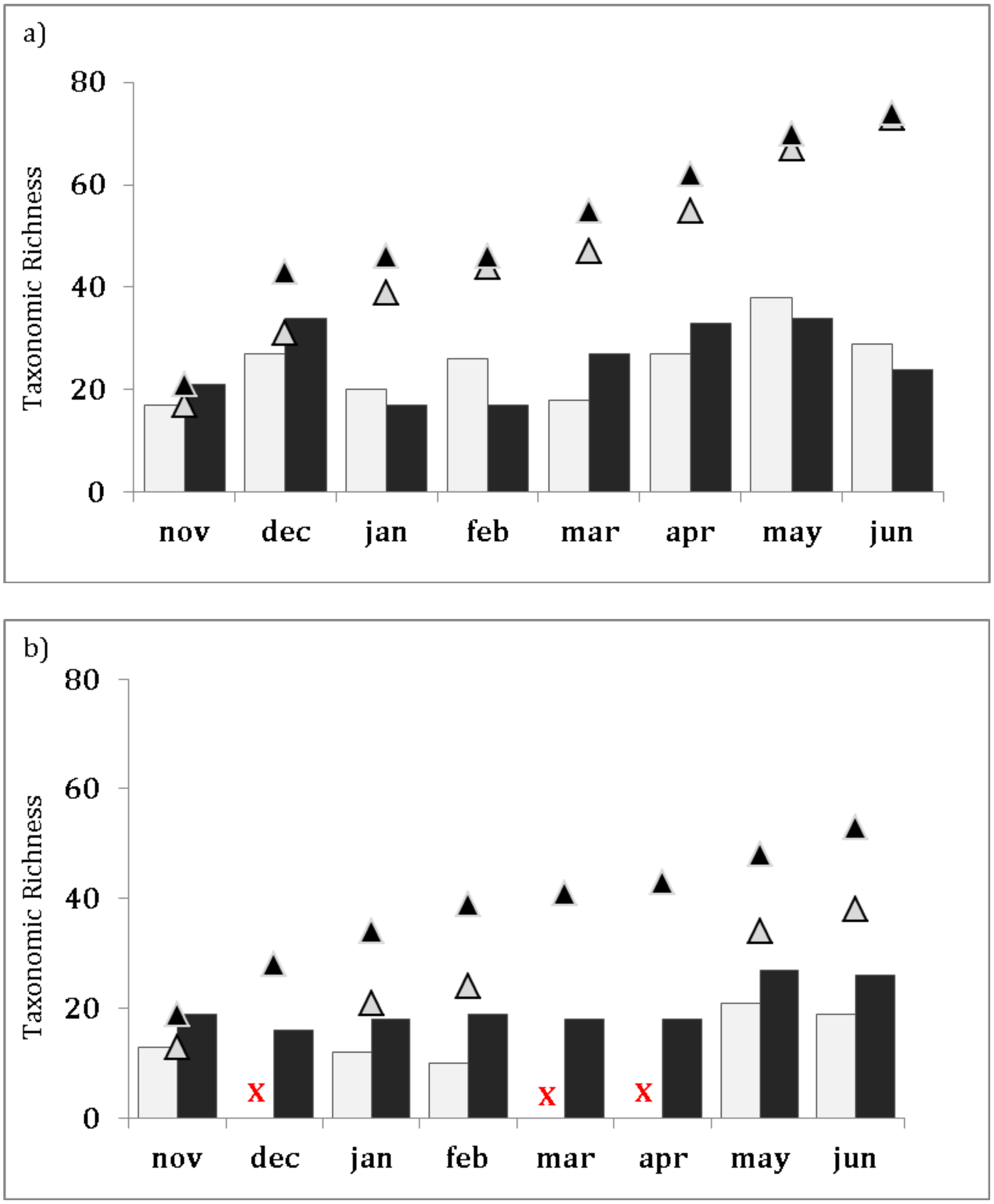

Fig. 2 Taxonomic richness for a) upstream and b) downstream samples. Bars represent taxonomic richness of samples collected in that month, and triangles represent cumulative taxonomic richness. Light bars represent perennial tributary samples and dark bars represent seasonal tributary samples. Red X's represent missing samples.

NMDS ordinations for upstream sites are shown in Figure 5, and downstream sites are shown in Figure 6. Mud Creek and Big Chico Creek indicate distinct community

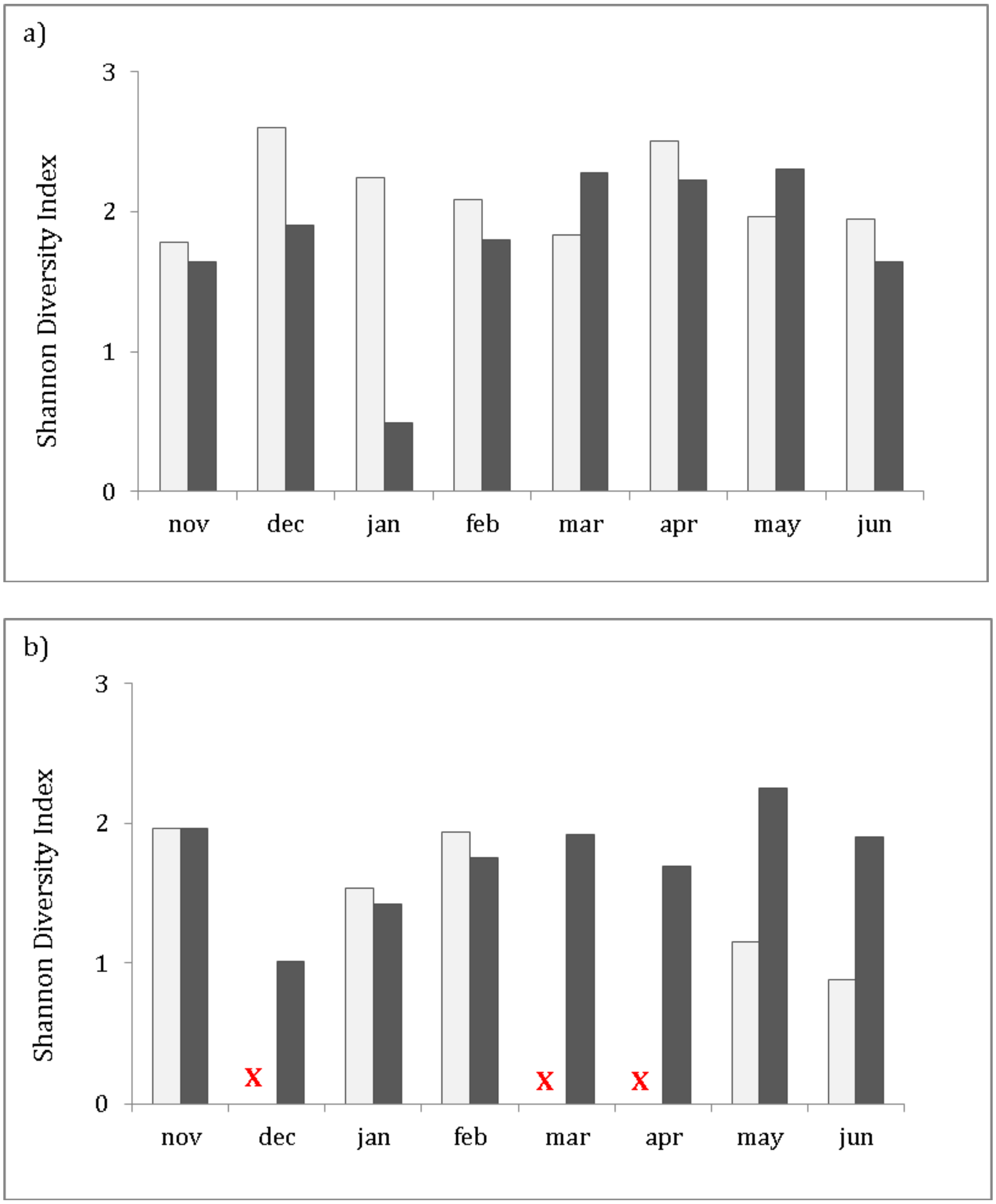

Fig. 3 Graphs showing Shannon Diversity indices (H'). Light bars represent perennial tributary samples and dark bars represent seasonal tributary samples; a = upstream sites and b = downstream sites. Red X's represent missing samples.

composition based on the separation of data points by site. ANOSIM results confirmed that there is a significant statistical difference in community composition between stream

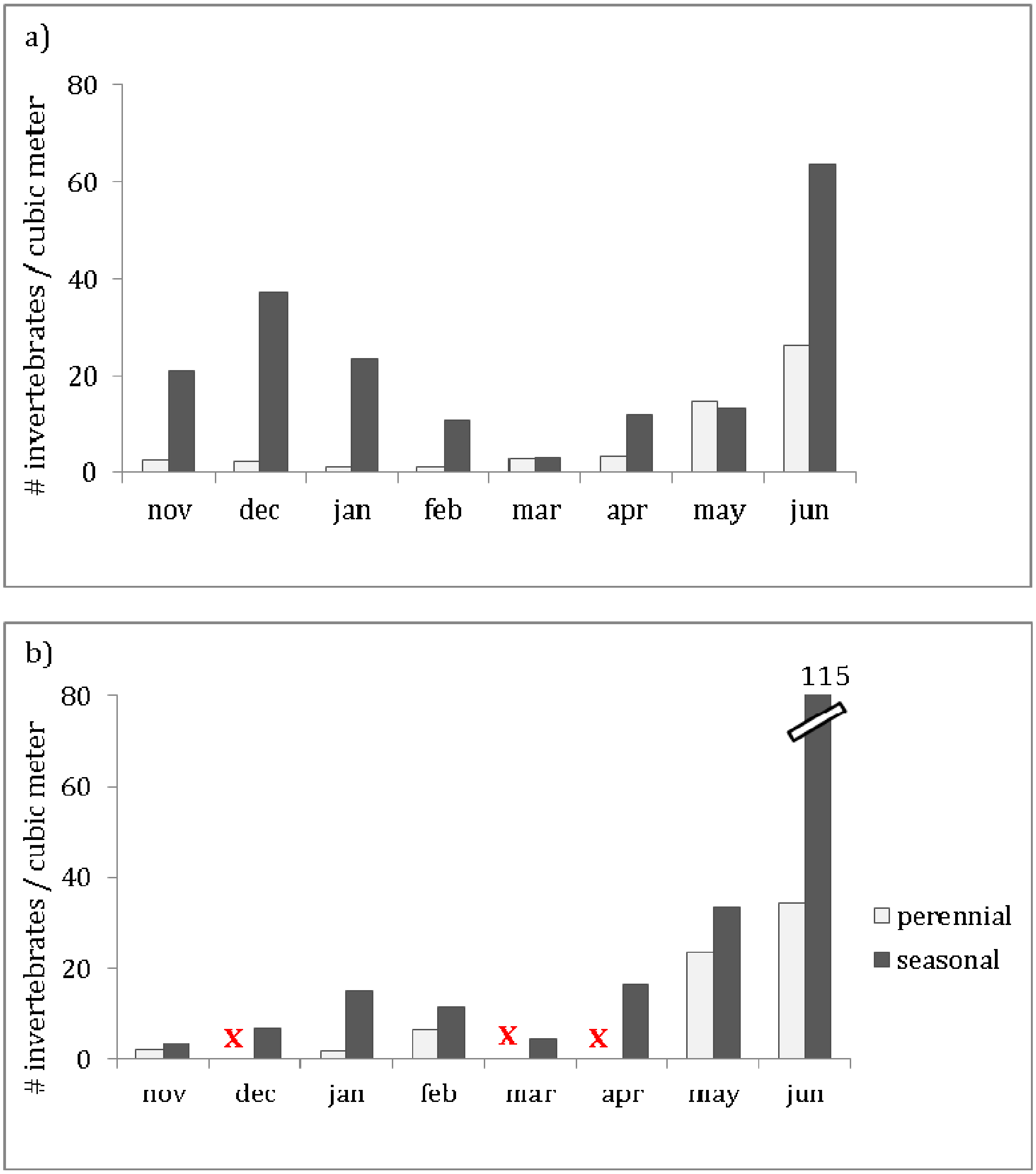

Fig. 4 Drift densities, in number of invertebrates per cubic meter of water sampled. Light bars represent perennial stream sites, and dark bars represent seasonal stream sites; a = upstream sites and b = downstream sites. Red X's represent missing samples.

types at both upstream (R = 0.309, p = 0.014) and downstream (R = 0.321, p = 0.023)locations. SIMPER results indicate that average community dissimilarity between

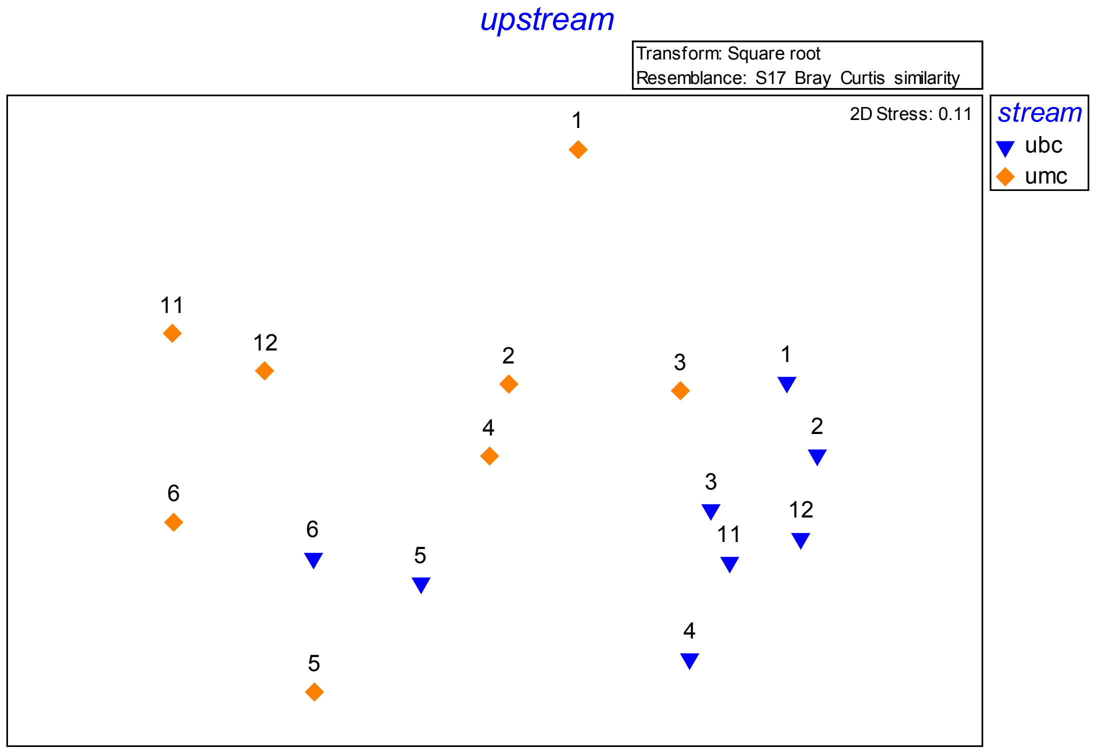

Fig. 5 NMDS ordination plot comparing community composition for upstream invertebrate drift composition. Numbers next to sample points refer to the month that sample was collected.

the creeks at the downstream sites is 66.59, and is driven primarily by small crustaceans (Copepods, cladocera, and ostracods) (24.14%), Chironomidae (11.11%), and terrestrial invertebrates (7.93%). Average community dissimilarity between the upstream sites is 65.62, and is driven by Chironomidae (10.81%), *Baetis* sp. (10.00%), and terrestrial invertebrates (6.48%). Figure 7 shows the abundances of taxa identified by SIMPER results to contribute to the differences between stream types.

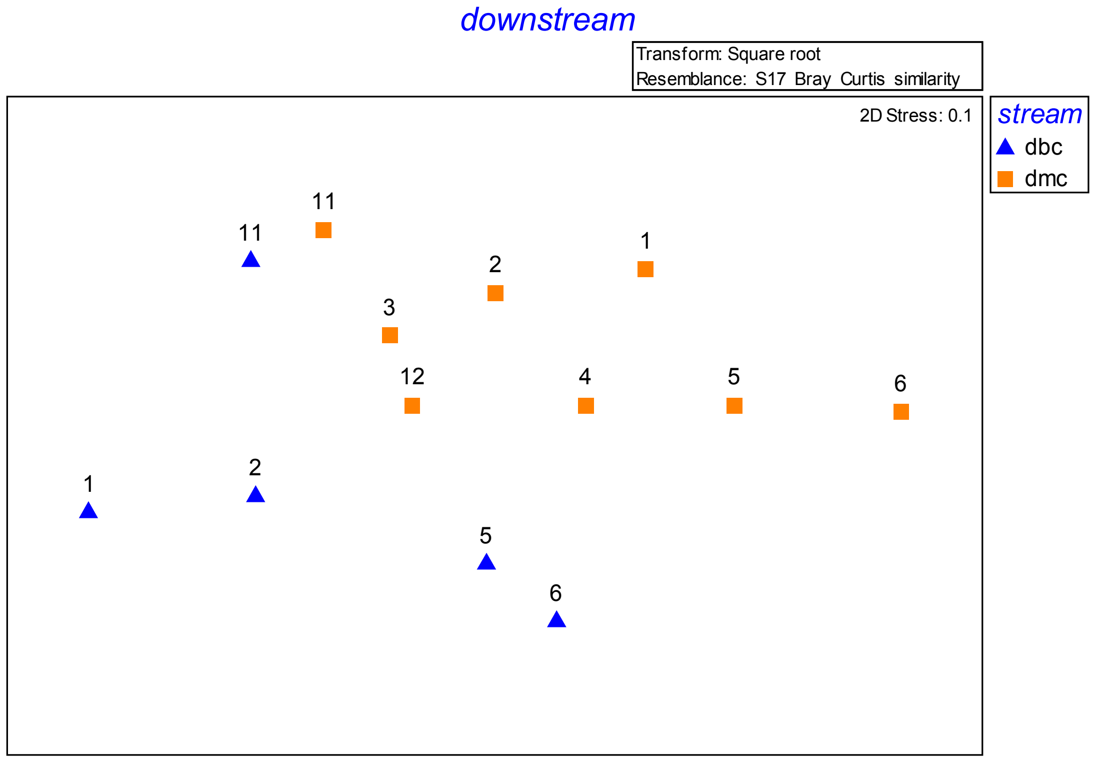

Fig. 6 NMDS ordination plot comparing invertebrate drift composition at downstream sites. Numbers next to sample points refer to the month that sample was collected.

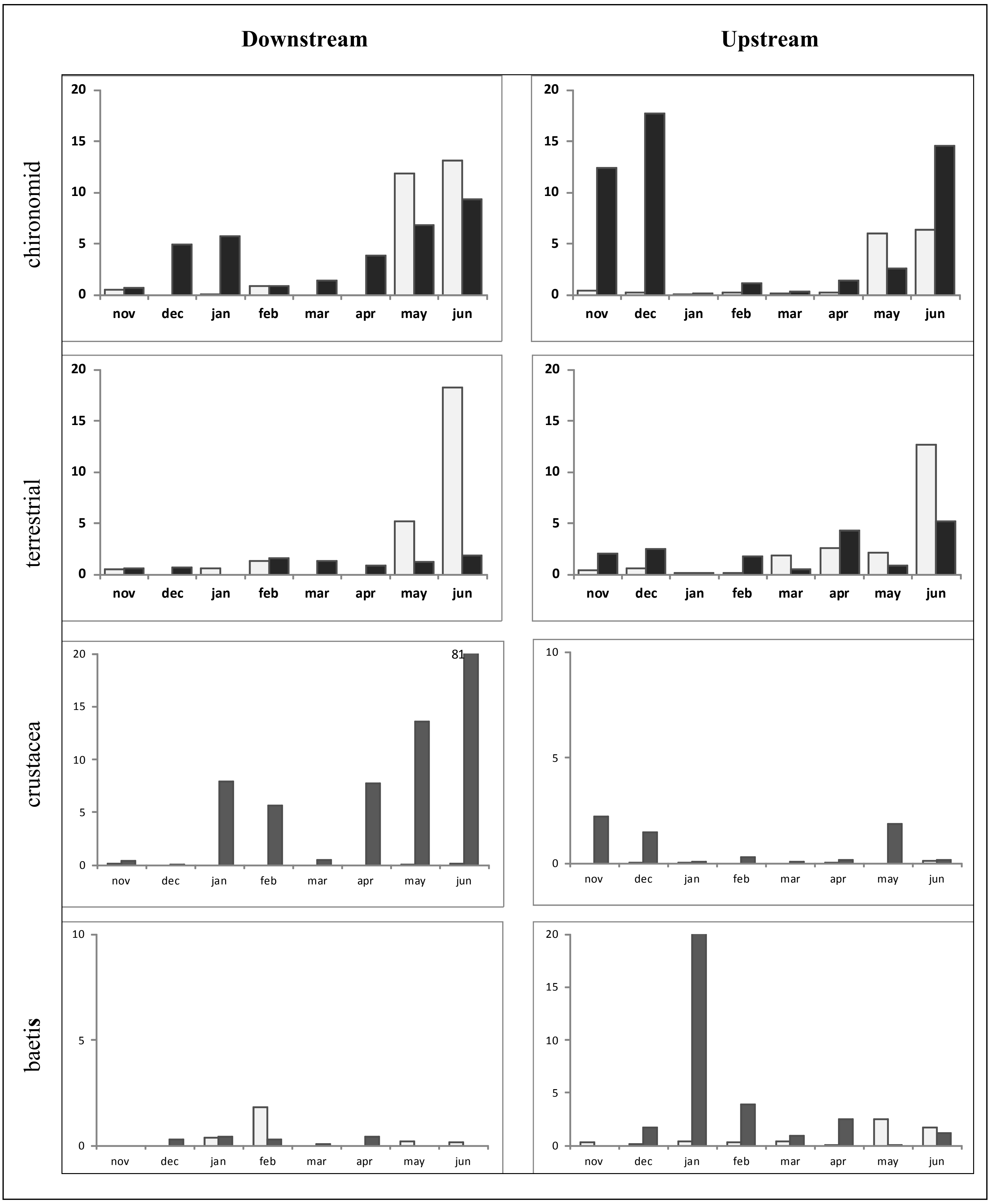

Fig. 7 Drift densities (# per cubic meter) of taxonomic groups identified by Simper analysis to contribute to differences between stream types. Light bars represent perennial tributary samples and dark bars represent seasonal tributary samples

CHAPTER IV

DISCUSSION

The primary finding of this study is that invertebrate drift densities were greater in a seasonal stream compared with a neighboring perennial stream. Specifically, I found higher abundances of aquatic invertebrates in seasonal stream drift, while terrestrial invertebrates were more abundant in perennial stream drift. These study results are consistent with others that have found seasonally aquatic habitat to have greater invertebrate drift densities than invertebrate drift in perennial habitat (Dance & Hynes, 1979; Sommer *et al*., 2001; Benigno & Sommer, 2008). However, this study is unique in that I compare invertebrate drift to between two neighboring tributaries of a large perennial river. Similar research comparing temporary and perennial streams has typically focused on benthic macroinvertebrates in low-order mid-elevation intermittent streams in California's Mediterranean climate region (Abell, 1984; Bottorff & Knight, 1988; Bêche & Resh, 2007), and other Mediterranean climate regions (Dance & Hynes, 1979; Bonada, Rieradevall & Prat, 2007; Álvares & Pardo, 2009). By focusing on invertebrate drift in tributaries near the confluence with a large perennial river, these findings provide insight into the resources available to fish that enter these habitats from the main river channel (Limm & Marchetti, 2009).

While diversity metrics were similar between tributary types on a month to month basis, cumulative taxonomic richness over the study period was greater in the seasonal tributary. Seasonally flowing streams that do not retain surface water throughout the dry period, like Mud Creek, have been reported to have lower diversity than perennial and intermittent reaches (Abell 1984; Anna *et al.*, 2009). However, the results from this study are more consistent with results from intermittent tributaries, which cease to flow but maintain standing surface water during the dry season. Compared with perennial waters, intermittent tributaries generally have similar diversity but different faunal compositions (Bonada *et al*., 2008). Community structure in seasonal waterways generally changes dramatically as flow ceases and pools dry (Stanley, Fisher & Grimm, 1997). Greater cumulative taxonomic richness over the study period reflects a shift in taxa corresponding to changing habitat characteristics in the seasonal tributary, while the community composition is less variable over the study period in the more stable perennial tributary (Gasith & Resh, 1999).

Differences in community composition between seasonal and perennial tributaries were driven primarily by three taxonomic groups: (1) terrestrial invertebrates, which were a major component of drift in the perennial tributary; (2) small crustaceans (cladocerans, copepods, and ostracods), which were most abundant in seasonal tributary samples; and (3) chironomidae, which were present in both tributary types, but showed different seasonal patterns in abundance in the different tributary types. The high abundance of terrestrial invertebrates in the perennial tributary may be explained by the presence of a well-developed riparian overhead canopy that provides a high degree of allochthonous input to the stream. Terrestrial inputs are much less in the seasonal tributary, as riparian vegetation in the valley reach of Mud Creek is routinely cleared of vegetation to maintain floodwater conveyance. Cladocerans, copepods, ostracods and chironomidae all have life histories that can include drought resistant life stages, and are commonly found in high abundances soon after rewetting of seasonally aquatic habitat (Williams, 2006). Chironomid lavae are often the most abundant taxa in aquatic habitats (Merrit & Cummins 1996), and we found them to dominate abundances at all sample sites. However, the seasonal timing of high chironomid abundances differed between stream types. In this study, chironomnid larvae re highly abundant in the seasonal tributary after winter flows resume, but present only in very low numbers in the perennial tributary during the same winter period.

Rivers that dry are often not recognized as valuable habitat (Erman & Hawthorne, 1976; Schwartz & Jenkins, 2000), but they may play a critical role in supporting native biodiversity (Baltz & Moyle; 1993, Maasri *et al*, 2008). The results from this study combined with previous research documenting spawning and rearing in temporary tributaries of the Sacramento River (Limm & Marchetti, 2009; Walther, 2009) suggest that temporary or seasonally inundated tributaries may be a valuable resource for native fish in the region. More work is needed to better understand the ecological significance that seasonally flowing tributaries play in terms of the greater landscape level context within large river systems. Mud Creek may be unusual among similar tributaries in the northern Sacramento Valley as it is used extensively by juvenile salmon (P. Maslin, unpubl. data), and greater abundances of larval fish were found in Mud Creek compared with other seasonally flowing tributaries in the region (Walther, 2009). A more complete accounting of the variability among flow regimes in seasonal tributaries of the region, combined with more information on how food web resources vary among these streams, may help us understand the role these neglected aquatic habitats play for native aquatic organisms.

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