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# Evidence for Negative Effects of Drought on *Baetis sp.* (Small Minnow Mayfly) Abundance in a Southern California Stream

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*Abstract.*—Benthic macroinvertebrate (BMI) sampling was conducted at two sites in Topanga Creek from 2003-2014. During this period, Southern California experienced extreme drought conditions (US Drought Monitor 2014). Examining trends in species composition over this period allows for a relatively long-term analysis of potential effects of drought on BMI communities. The Southern California Coastal Index of Biotic Integrity (SCC-IBI; Ode 2007) was applied to BMI samples from Topanga Creek to measure the effects of drought on quantitative biotic integrity. The following trends regarding the BMI community of Topanga Creek emerged during the course of this study: 1) Wet year rainfall in Topanga Creek Watershed positively correlated to relative and per sq. ft. springtime abundance of *Baetis sp.*, relative abundance of *Simulium sp.* up to 78.7 cm (31") rain, and negatively correlated to relative abundance of Chironomidae n. d., 2) percent algae cover in April and May positvely correlated to abundance per sq. ft. *Baetis sp.* and *Simulium sp.*, and 3) multiple regression analysis revealed a negative relationship between Chironomid n.d. and *Baetis sp.* abundance. BMI are an important food source for endangered steelhead trout and other native aquatic and terrestrial insectivorous species of special concern; significant changes to the BMI community could have trophic reprecussions for these and other wildlife. Long-term monitoring is important for tracking the influence of changes in climatic conditions on BMI community.

## Introduction

Benthic macroinvertebrate (BMI) communities, made up of snails, worms, insect larvae and nymphs, freshwater crustaceans, and other bottom-dwelling organisms of a freshwater stream, are a vital indicator of riparian ecosystem health (Ode et al. 2005). BMI sampling adds a biotic element to standard water quality testing procedures and is an invaluable tool for ecologists, resource management professionals, and anyone interested in investigating and maintaining healthy rivers (Fetscher et al. 2009). As primary consumers and decomposers of allochthonous and autochthonous detritus, diatoms, and macrophytes, benthic macroinvertebrates are the most basic link between aquatic and riparian vegetation and the rest of the stream community (Merritt et al. 2008, Covich et al. 1999). In Topanga Creek, BMI are an important food item for aquatic reptiles and amphibians, Arroyo chub, and federally endangered southern California steelhead trout. The adult imago of many aquatic insects are an important food source for birds, bats, and other terrestrial insectivores, especially within riparian zones.

Some BMI taxa, such as Ephemeroptera (mayflies), may appear and disappear from the benthos within a matter of weeks, while others, like some Odonata (dragon/damselflies),

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develop under water over the course of a year or more (Voshell 2002). Shifts in species composition may be the result of a current or past disturbance to stream integrity (Boulton et al. 1992). Habitat preferences, water quality thresholds, and additional life-history traits have been described for nearly 4,000 North American lotic macroinvertebrate species making it possible to key in on the nature of ecological disturbance such as sedimentation, pollution, or increasing temperatures (Vieira et al. 2006). Indices of Biotic Integrity (IBI) have been developed using this information to assign numeric and descriptive scores of ecological health to freshwater systems, such as the Southern California Coastal Index of Biotic Integrity (SCC-IBI) applied here (Fetscher et al. 2009, Ode 2007, Ode et al. 2005).

Drought can negatively affect stream function and aquatic biota by inducing low flows, pool isolation or drying, increased water temperature, sedimentation, and/or reduced dissolved oxygen (Lake 2011). Freshwater habitat and refuges suitable or preferred for particular BMI species can be severely reduced by prolonged drought (Lake 2003). Griswold et al. (2008) found that BMI community composition was altered by drought periods, favoring smaller-bodied species with shorter life cycles. Pool stagnation and fine sediment accumulation associated with drought have been shown to reduce *Baetis sp.* abundance (Iversen et al. 1978, Kaller and Hartman 2004). Less-tolerant or rheophilic families such as Baetidae and Simuliidae can face decline or expiration in prolonged drought conditions, while more tolerant species such as Chironomidae and Ceratopogonidae can become more abundant (Wright and Symes 1999).

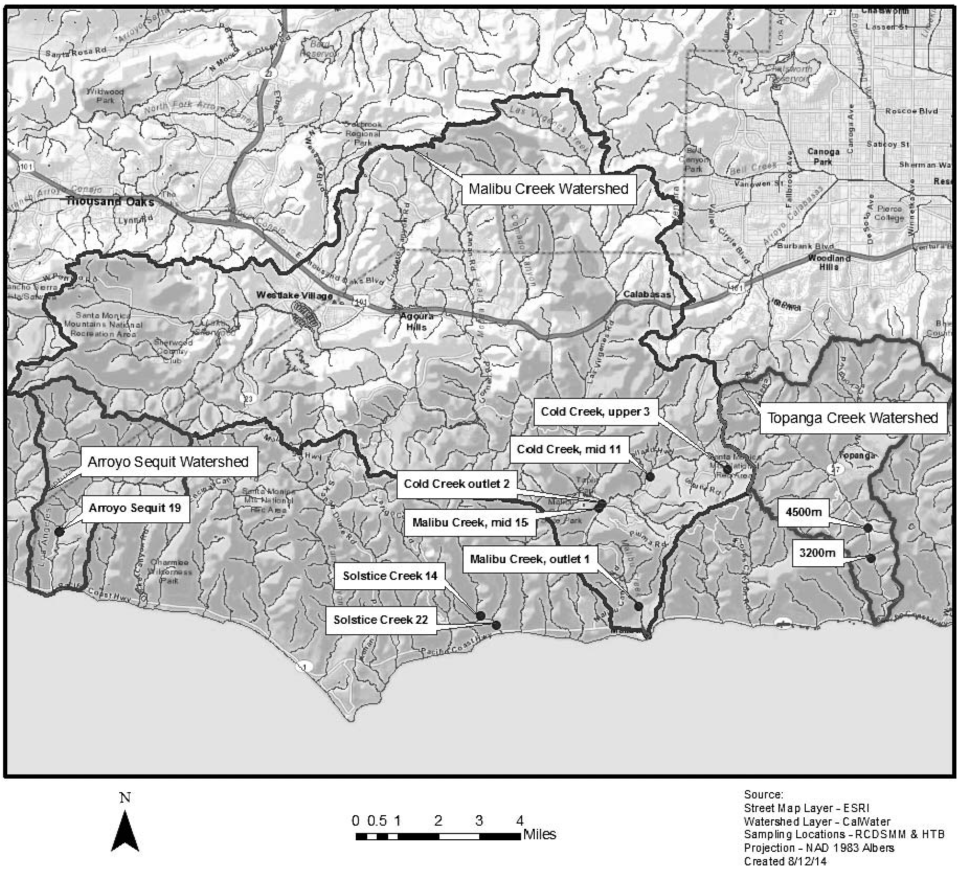
The goal of this study was to examine the response of benthic macroinvertebrates to drought in Topanga Creek from 2003 to 2014. Four additional creeks were included to see if any regional patterns emerged within the Santa Monica Mountains (Fig.1). Topanga Creek, Arroyo Sequit, Cold Creek, and Solstice Creek are considered regional reference streams, while a large dam and wastewater treatment plant impact Malibu Creek.

## Materials and Methods

### *Study Location*

Topanga Creek, a small perennial coastal mountain stream, drains a 47-km$^2$ watershed into the Santa Monica Bay, Los Angeles County. The watershed is part of the California Floristic Province biodiversity hotspot and provides vital habitat for federally endangered southern steelhead trout (*Oncorhynchus mykiss)*, 22 species of reptiles and amphibians, and numerous other plants and animals. Approximately 70% of the Topanga Creek watershed is protected parkland managed by California Department of Parks and Recreation. The remaining 30% is developed within the village of Topanga (pop. 8,289, US Census 2010). Both sampling sites are below the village of Topanga, and share a narrow canyon with a two-lane highway that runs alongside the creek in some areas.

Annual BMI sampling in Topanga Creek was carried out from 2003-2014. Drought intensity in this period varied by season and year throughout the decade between periods of normal winter rainfall and extreme drought conditions (US Drought Monitor 2014). The drought intensified as winter rains in 2012 and 2013 were insufficient to alleviate dry conditions, and by 2014 it was declared the worst drought on record since NOAA record-keeping began a century ago (NOAA 2014). Rain data for Topanga, Arroyo Sequit, Malibu, and Solstice watersheds were acquired from the Los Angeles County Department of Public Works. Algae percent cover was recorded during monthly foot surveys throughout the sample reaches 3200-3700m and 4000-4500m.



Source:
Street Map Layer - ESRI
Watershed Layer - CalWater
Sampling Locations - RCDSMM & HTB
Projection - NAD 1983 Albers
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Fig. 1. Topanga Creek and Santa Monica Bay sampling sites 2000-2014. *Lower Topanga at 3200m, Upper Topanga at 4500m.

## *Sample Collection*

BMI samples were collected in spring (Apr 22-May 27) in 2003-2014 (except for 2008 and 2009) at two main stem locations: Upper Topanga (UT; 4500m) and Lower Topanga (LT; 3200m). LT is located within the low gradient (<3%) reach of the creek and UT is located above the Topanga Canyon Bridge (mile marker 2.02) in the higher gradient (3-6%) reach. Sampling protocol in years 2003-2012 followed the California Stream Bioassessment Protocol (CSBP; CDFG 2003). Standard 1-ft. wide D-shape kick nets were deployed left, center, and right of three consecutive riffle transects, for a composite sample of nine kicks. In 2013 and 2014, the SWAMP Bioassessment Procedure (Ode 2007) was employed. A 1-ft D-shape kick net was used to collect samples every 15m along a 150m transect, alternating along the way between 25%, 50% and 75% from right bank, for a composite sample of 11 kicks. Samples collected from UT in 2004 and 2007 were not viable for processing and were not included in the analysis. All Topanga Creek samples were preserved in ⩾90% ethanol or by freezing.

Additional samples were collected from Topanga Creek from five additional sites in May, July, September, November, and December of 2013, and February, April, and June of 2014 following California Stream Bioassessment Method (CDFG 2003) to compare results between sampling methods and examine phenology.

Regional stream survey samples were collected in June or July from 2003-2014 by Heal the Bay (Santa Monica, CA) at four additional upper Santa Monica Bay creeks: Arroyo Sequit (AS19), Cold Creek (CC2, CC3, CC11), Malibu Creek (MC1, MC15), and Solstice Creek (SC14). In 2003 BMI samples were collected using the California Stream Bioassessment Protocol (CDFG 2003); from 2005-2007, sampling was conducted using the US EPA targeted riffle composite (TRC) procedure (Peck et al. 2004; Ode 2007), and starting in 2008, sampling was conducted according to SWAMP Bioassessment Procedure (Ode 2007).

### *Sample Processing*

Using a dissecting microscope, organisms were picked from the sample and then sorted and identified according to standard taxonomic effort or to the lowest practical taxon based on specimen condition and size. Identifications and regional distribution were confirmed using the California DFW Aquatic Bioassessment Laboratory (ABL) Digital Reference Library (CDFW 2014) and Merritt et al. (2008). When identification was not possible, photographs were sent to the CDFW Aquatic Bioassessment Laboratory or identified to the lowest taxonomic level possible and recorded as non-distinct within that taxon. Heal the Bay regional comparison samples were processed by SLSII bioassessment lab.

### *BMI Analysis*

The relative abundance (%) and per sq. ft. abundance of each taxa present was calculated per sample. Processed samples were assessed according to SCC-IBI (Ode et al. 2005). For this index, seven metrics are used to assess ecosystem health: combined taxa richness of Ephemeroptera, Plecoptera, and Trichoptera taxa (EPT), Coleoptera taxa richness, predator taxa richness, % non-insect taxa, % tolerant taxa ($TV>7$), % intolerant individuals ($TV<3$), and % collector-gatherer + collector-filterer (CG+CF) individuals. Information regarding tolerance values and functional feeding groups was obtained on CAMLnet (Ode 2003). As SCC-IBI is designed for samples of 500 individuals, samples $>500$ were subsampled by randomizing sets, generating random numbers and selecting individuals 1-500.

Bray-Curtis Index of Dissimilarity was applied to whole samples, not sub-samples of 500, as it accounts for both sample size and shape (Bray and Curtis 1957).

$$B = \frac{\sum \left| X_{ij} - X_{ik} \right|}{\sum \left( X_{ij} - X_{ik} \right)}$$

Bray-Curtis calculations were based on the abundance per sq. ft. of eight taxa categories: *Baetis sp., Chironomidae n.d., Simulium sp., Ostracod, Elmidae, Acari, Planarian,* and *Hydropsychidae.*

Multiple regression analysis was performed applying a generalized linear model (Poisson regression) run in R software with *Baetis sp.* abundance per sq. ft. as the dependent variable and as a covariate. Other covariate factors input were wet year rainfall, percent algae cover, and Chironomidae n.d. abundance per sq. ft.. *Simulium sp.* was not included because *Simulium sp.* abundance and algae were highly correlated.

## Results

### *BMI Community Composition*

A total of 15,303 macroinvertebrates were collected from UT and LT between 2003 and 2014. The number of individuals per sample ranged from 104 to 3,514. Six phyla, 21 orders, and a total of 76 taxa were represented. The majority of individuals (Relative Abundance 'RA' = 89%) fell within the class Insecta. Three genera and one family from class Insecta accounted

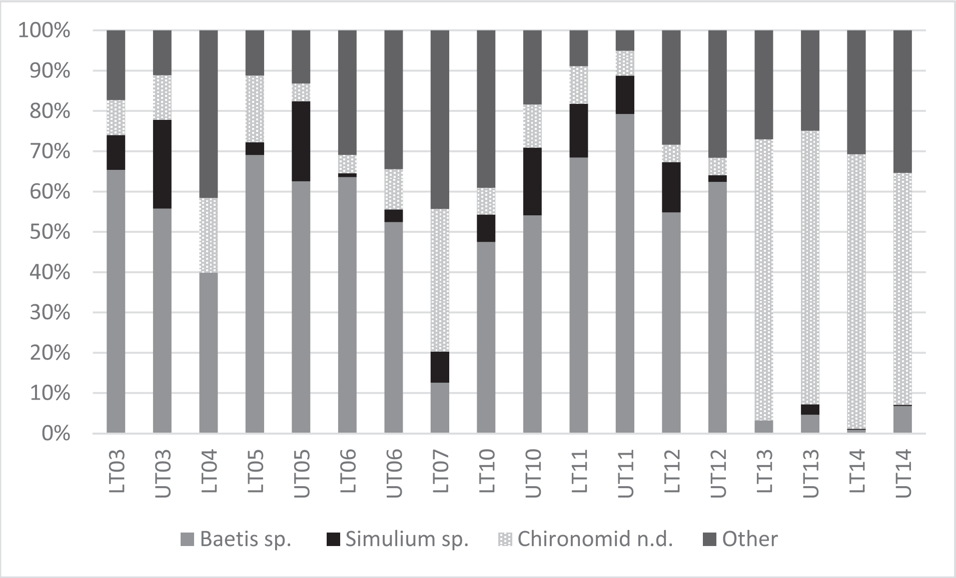

Fig. 2. Relative Abundance of 6 Major Taxon Categories: Upper and Lower Reaches Topanga Creek 2003-2014.

for 76% of total abundance; *Baetis sp.* (small minnow mayflies nymphs, 44% RA), Chironomidae n.d. (non-biting midge fly larva, 23% RA), and *Simulium sp.* (black fly larva, 9% RA; Fig. 2). Other families present throughout the sample period included: Planarian n.d. (flatworms, 3% RA), Elmidae n.d. (riffle beetle larva, 3% RA), Acari (water mites, 2% RA), Hydropsychidae n.d., (net spinning caddisfly larva, 2% RA) and Ostracoda n.d. (seed shrimp, 2% RA).

In samples from 2003-2012, *Baetis sp.* comprised 51% RA ($7.6 \leq n \leq 214.2$ per sq. ft.) and was the first or second most abundant taxa in all samples. In 2013 and 2014, *Baetis sp.* declined to 3% RA (abundance $0.8 \leq n \leq 1.3$ per sq. ft.) of all four samples. *Simulium sp.* abundance decreased from 11% RA 2003-2012, to less than 1% in 2013-2014. Between 2003-2012 and 2013-2014, Chironomidae RA increased from 15% to 66% RA. In samples collected on five occasions from five additional sites in Topanga Creek between May 2013 and June 2014, *Baetis sp.* and *Simulium sp.* each comprised less than 2% of all samples, and never more than 8% of any sample, confirming low abundance across sampling protocols.

Bray-Curtis dissimilarity coefficients for abundance per sq. ft. of eight dominant taxa calculated between all years ranged from 0.06 (LT 2010 to 2011, highly similar) to 0.95 (three pairs, highly dissimilar). Dissimilarity coefficients for 2013 and 2014 were each significantly higher than 2004, 2006, 2007, 2010, 2011, and 2012, $t(14,26) = 2.6 \leq 4.3$, $p < .05$ (two-tailed), upper and lower scores combined. The year 2005 had above average rainfall (61.2 inches) and also a high species composition dissimilarity coefficient. Wet year rainfall explained variation in Bray-Curtis dissimilarity coefficients, which were significantly higher in years with lower rainfall where above average rainfall years 2005 and 2011 were excluded ($R^2 = 0.85$, $F_{1,13} = 30.5$, $p < 0.01$).

Functional feeding group composition differed less than taxa composition, and was dominated by collector-gatherers in all years 2003-2014 (range: 63% to 95% RA; Fig. 3). Collector-filterers were the second most abundant feeding group overall, and they declined significantly from 2003-2012 to 2013-2014, $t(16)=2.9$, $p>.05$ (two-tailed).

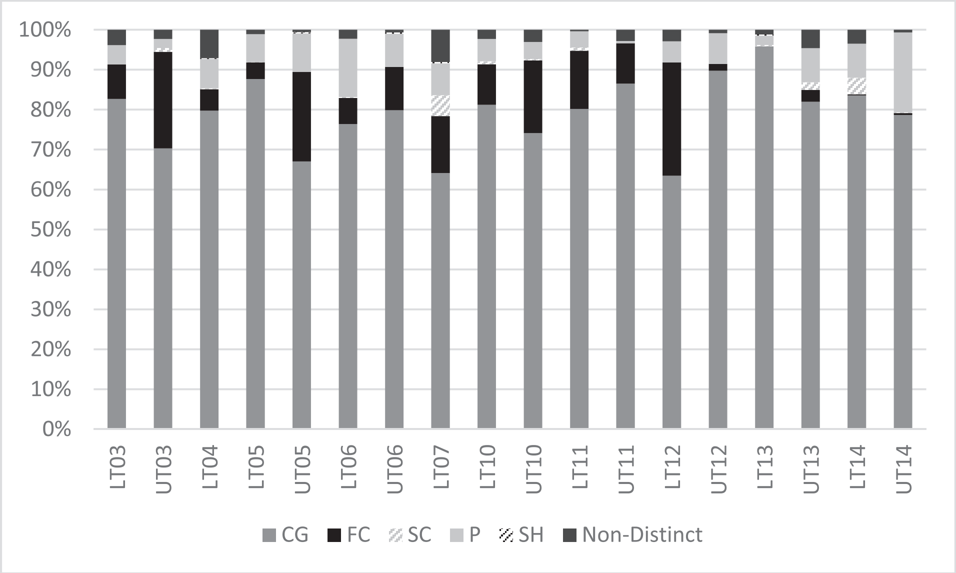

Fig. 3. Relative Abundance of 6 Major Feeding Group Categories: Upper and Lower Reaches Topanga Creek 2003-2014.

### *Rainfall Correlations*

*Baetis sp.* relative abundance and abundance per sq. ft. significantly and positively correlated to wet year rainfall (WYR; $R^2=0.41$, $F_{1,16}=11.36$, $p<0.01$, $R^2=0.80$, $F_{1,16}=11.36$, $p<0.000001$; Fig. 4a.). Correlation to relative abundance was stronger when above average rainfall in 2005 (61.22”) was removed; however *Baetis sp.* abundance measured per sq. ft. was highest this year. *Simulium sp.* RA also positively correlated to wet year rainfall (WYR), only with 2005 data removed ($R^2=0.25$, $F_{1,14}=4.79$, $p<0.05$. Chironomidae n.d. RA negatively correlated to WYR with no upper limit to rainfall ($R^2=0.26$, $F_{1,16}=5.49$, $p<0.05$; Fig. 5). Neither Chironomidae n.d. nor *Simulium sp.* abundance per sq. ft. correlated to WYR, nor did

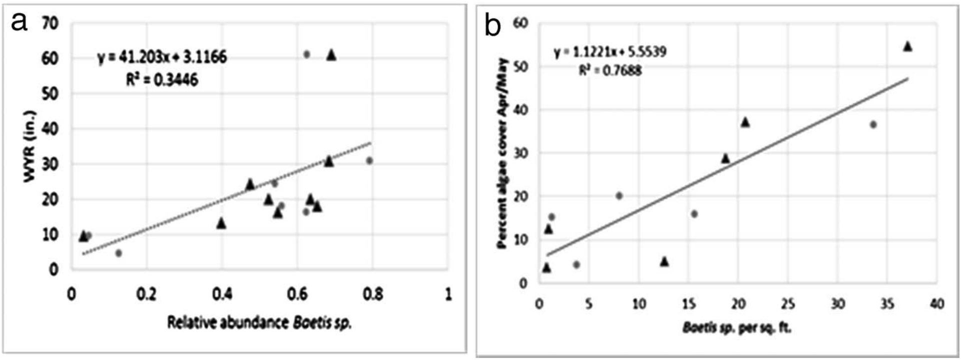

Fig. 4. (a) Relative abundance of *Baetis sp.* and wet year rainfall in Topanga Creek (b) Abundance per sq ft. of *Baetis sp.* and observed algae in Topanga Creek. Black triangles depict Lower Topanga samples and gray circles depict Upper Topanga

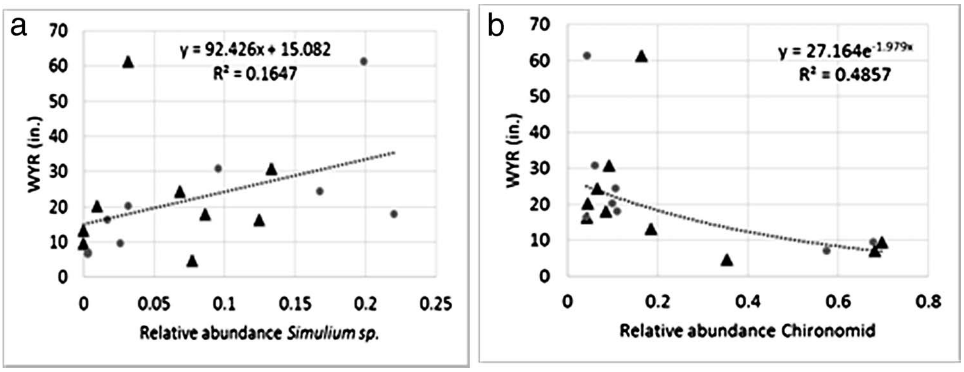

Fig. 5. (a) Relative abundance of *Simulium sp.* and wet year rainfall in Topanga Creek (b) Relative abundance of Chironomidae n.d. and wet year rainfall in Topanga Creek. Black triangles depict Lower Topanga samples and gray circles depict Upper Topanga.

any FFG group. In regional samples, only Solstice Creek also showed a significant and positive correlation between *Baetis sp.* RA and WYR ($R^2$=0.60, $F_{1,5}$=7.38, $p<0.05$; Fig. 6).

Abundance per sq. ft. for eight dominant taxa was compared to observed algae cover in both reaches from 2007-2014. *Baetis sp.* and *Simulium sp.* were found to positively and significantly correlated to percent algae cover ($R^2$=0.77, $F_{1,9}$=29.9, $p<0.0005$, $R^2$=0.69, $F_{1,9}$=19.6, $p<0.005$; Fig. 4b.). Multiple regression analysis was run to examine the relationship between *Baetis sp.* abundance per sq. ft. and WYR, algae, and Chironomidae n.d.. Rainfall and algae remained significant predictors of *Baetis sp.* ($p<.0005$, $p<.05$). When controlling for rain and algae, Chironomid n.d. abundance per sq. ft. was also a significant predictor of *Baetis sp.* abundance ($p<.0005$).

### *SCC-IBI Analysis*

The Southern California Coastal Index of Biotic Integrity (SCC-IBI; Ode et al. 2005) was applied to determine if the marked change in taxonomic composition resulted in decreased scores of biotic integrity in 2013-2014. Three out of ten samples from Lower Topanga and five out of eight samples from Upper Topanga had >500 individuals and were sub-sampled to 500 individuals appropriate for SCC-IBI scoring. LT04 (n=464) was also included in SCC-IBI analysis. Overall, there was no significant correlation between total SCC-IBI scores and wet year rainfall or other creek conditions (Table 1). SCC-IBI scores ranged from 22-57, categorized as ‘poor’ to ‘fair.’ The lowest metric score across all samples was % intolerant individuals, which never surpassed a score of 1. Conversely, the highest metric on average was % tolerant taxa (average score of 6).

## Discussion

Drought is a defining feature of many ecosystems including those within Mediterranean climates, and it is predicted that droughts will become more frequent and intense over the next few decades (Houghten et al. 1995). Severe drought is known to affect BMI assemblages and result in alterations to community composition (Resh et al. 2012). The current drought in Southern California is the most severe on record (NOAA 2014). While these conditions cause concern for the integrity of freshwater ecosystems, they also provide an opportunity to study potential implications of climatic patterns on freshwater benthic macroinvertebrate communities. In

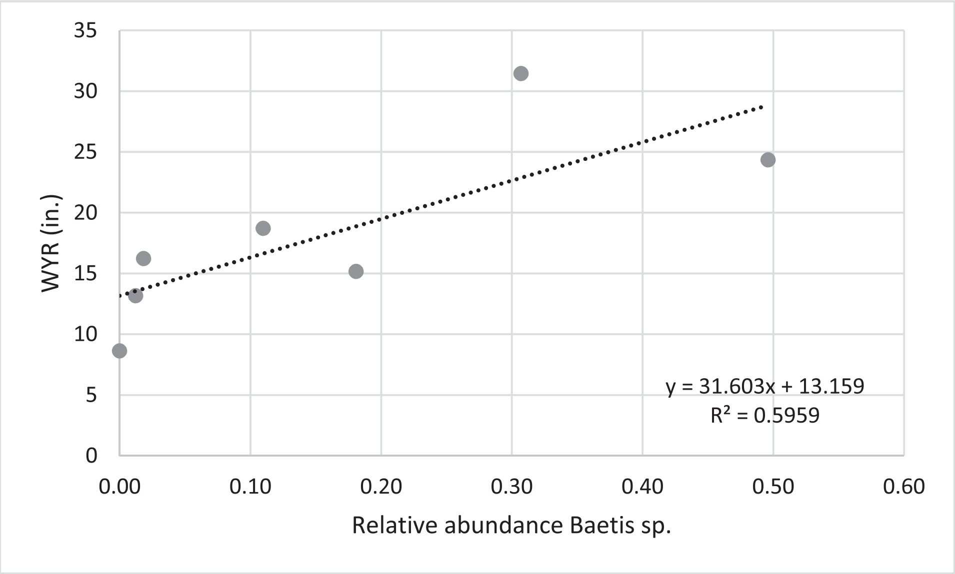

Fig. 6. Relative abundance of *Baetis sp.* compared to wet year rainfall in Solstice Creek.

2013, the Topanga Creek BMI community experienced a sharp decline in *Baetis sp.* and *Simulium sp.* abundance, and increase in Chironomidae n.d.. Each of these taxa abundance correlated to WYR, suggesting a strong relationship between annual precipitation and BMI community composition in Topanga Creek. This correlation also held true for another Santa Monica Mountains stream, Solstice Creek.

For *Simulium sp.* in Topanga Creek, the correlation to rainfall did not hold up in the case of above average rainfall (155.5 cm), and in fact all taxa appeared to diverge from the linear trend under these high rainfall conditions. This might be due to discharge rates high enough to displace certain BMI taxa. Both *Baetis sp.* and *Simulium sp.* also positively correlated to algae cover in April and May. When available, algae can be a preferred food source for Ephemeroptera, resulting in more robust growth and gill size (Mayer and Likens 1987, Gupta et al. 1994).

Chironomidae n.d. relative abundance was favored in low rainfall conditions. Multiple regression analysis showed that *Baetis sp.* and Chironomidae n.d. abundance per sq. ft. was significantly related when rainfall and algae were held constant, however this was not evident in a direct comparison. This indicates that there is a distinct relationship between *Baetis sp.* and Chironomidae n.d. that is mediated by abiotic and biotic factors such as precipitation and algal productivity. This relationship might hinge on competition for food or habitat, or sedimentation dynamics. Angradi et al. (1999) found that Ephemeroptera taxa richness is reduced when fine sediments accumulate, while some genus of Chironomidae, particularly burrowers or sediment case-makers, increase. Frost et al. (1995) affirms that changes in the abundance of one species can lead to disproportionate response from other species. Krug et al. (2012) found that both Diptera and Ephemeroptera larva are important food sources for endangered southern steelhead trout (*Oncorhynchus mykiss*), occurring in 69% and 92% of 13 stomach samples collected in Topanga Creek in March 2011. Continued monitoring is recommended to measure the resiliency of *Baetis sp.* and *Simulium sp.* under future rain conditions.

Both *Baetis sp.* and Chironomidae n.d. are classified as collector-gatherers with a tolerance value of 6 (Ode 2003). Despite changes in community demographics, trophic structure can

Table 1. Topanga Creek SCC-IBI metrics and creek conditions 2003-2014.

| Sample ID | (n) | %CF+CG | % Non-Insect taxa | % Tolerant taxa | Coleoptera taxa | Predator taxa | % Intolerant | EPT taxa | SUM (0-70) | SUM (0-100) | Flow (cfs) | Mean depth (in) | Water temp (°C) | DO % | WY Rainfall (in.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UT03 | 500 | 1 | 8 | 10 | 4 | 1 | 0 | 2 | 26 | 37 | 0.43 | 3.9 | 14.7 | 90 | 17.92 |
| LT04 | 464 | 5 | 8 | 4 | 4 | 8 | 1 | 1 | 31 | 44 | ND | ND | ND | ND | 13.16 |
| LT05 | 500 | 3 | 3 | 8 | 0 | 1 | 0 | 1 | 16 | 23 | 0.16 | 9.8 | 17 | 65 | 61.22 |
| UT05 | 500 | 0 | 5 | 8 | 4 | 0 | 1 | 5 | 23 | 33 | 0.34 | ND | 15.1 | 69 | 61.22 |
| UT06 | 500 | 1 | 5 | 5 | 4 | 2 | 0 | 8 | 25 | 36 | 0.15 | 11.3 | 15.6 | 100 | 20.04 |
| LT07 | 500 | 5 | 7 | 7 | 7 | 4 | 0 | 10 | 40 | 57 | 0.05 | 8.7 | ND | ND | 4.61 |
| UT10 | 500 | 2 | 8 | 6 | 2 | 5 | 1 | 5 | 29 | 41 | 1.13 | 9.3 | 10 | ND | 24.32 |
| LT14 | 500 | 4 | 2 | 2 | 2 | 6 | 1 | 2 | 19 | 27 | 0.06 | 2.2 | 14.9 | 76 | 6.85 |
| UT14 | 500 | 1 | 4 | 3 | 5 | 0 | 0 | 2 | 15 | 21 | ND | 9.6 | 6.85 | 72 | 6.85 |

remain stable (Beche et al. 2009; Vannuchi et al. 2013). This occurred to some extent in Topanga Creek, as functional feeding group distribution was less variable than species composition over time. Collector-gatherers made up the far majority, which is typical in riparian lower reaches (Hawkins et al 1981). The shift in community was accompanied by a simplification of FFG array. The decline of collector-filterer abundance correlated to *Simulium sp.* declines, indicating *Simulium sp.* was a significant collector-filterer in both the Upper and Lower Reach of Topanga Creek.

Although Topanga Creek is facing impacts of drought, it remains an important reference stream and continues to provide crucial habitat to wildlife. Catastrophic shifts in BMI community compositions have been observed to occur from stable to alternate states, sometimes irreversibly (Scheffer et al. 2001; Beche et al. 2009). In other cases, communities have rebounded within 1-3 years post-drought (Boulton 2003). How the aquatic and riparian zone insectivorous wildlife of Topanga Creek respond to the replacement of *Baetis sp.* with Chironomid n.d. and other changes among the BMI community are currently unreported. Continued long-term monitoring of BMI will support regional advances in understanding species composition trends and how they are influenced by climatic disturbances such as drought.

## Conclusions

Long-term BMI monitoring is important in Topanga Creek, and other drought-affected freshwater ecosystems, to determine the influence of climatic events on taxonomic composition. In this study, drought intensification aligned with declines in *Baetis sp.* and *Simulium sp.* relative abundance. Algae presence also influenced the abundance of these two taxa, although there was no notable trend between rainfall and algae found in this study. Long-term data sets will enable scientists to track what components of BMI composition are constantly in flux, responding to biotic and abiotic processes and events, and which are perennially resilient up to the point at which catastrophic events may induce long-term disturbance within the established community. Future work in this watershed should focus on the potential recovery response of *Baetis sp.* post-drought.

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