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Spatiotemporal trends analysis of benthic communities and physical habitat during non-severe drought and severe-drought years in a residential creek in California

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Both temporal and spatial trends analysis was conducted to determine if the condition of the benthic community of a residential California stream represented by metrics measuring richness, composition, tolerance/intolerance and trophic composition has changed from 2006 to 2015. A secondary objective was to determine if 10 habitat metrics and total habitat scores measured concurrently with the benthic assessments have also changed temporally or spatially over the same 10 year time period. The 2006 to 2015 time period for this study included both non- severe drought (2006-2008), and severe drought (2013-2015), years. The most significant results from this study were that the conditions of the benthic communities as well as the physical habitat conditions have declined in this water body from 2006 to 2015. Both non-chemical (habitat and water quality parameters) and potential chemical stressors (metals and pyrethroids) were evaluated to determine their possible role in the decline in benthic community conditions. The factors most likely contributing to the decline in benthic communities during the 10 year study period are declining physical habitat conditions measured by declining metrics such as velocity/depth/diversity, channel flow status and riparian areas and possibly low dissolved oxygen concentrations below effects thresholds. Both declining physical habitat and low dissolved oxygen concentrations are likely related to the severe drought conditions reported during 2013-2015.

Key words: residential stream, benthic communities, physical habitat, drought, metals, pyrethroids

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Environmental stressors that may impact aquatic biota in freshwater streams include but are not limited to floods, fires, droughts, hurricanes, volcanic activity, climate change, land use change, introduction of exotic species, physical change of attributes such as temperature, substrate, or hydrology, and chemical changes such as pollution or nutrient enrichment. In order to determine the possible impact of these various environmental stressors on resident aquatic life, biological endpoints are often used (Karr and Chu 1999). Of the various biological indicators, benthic macroinvertebrates are often used to monitor the effects of both chemical and non-chemical stressors in the aquatic environment (Cairns and Pratt 1993). Rosenberg and Resh (1993), have reported the following advantages for using benthic macroinvertebrates in biomonitoring: (1) they are ubiquitous and can be affected by environmental perturbations in many types of aquatic systems; (2) they encompass a large number of different species and therefore offer a spectrum of responses to environmental stressors; (3) their basic sedentary nature allows for effective spatial scale analysis of pollutant or disturbance effects; (4) they have long life cycles compared to other taxonomic groups which allow for elucidation of temporal changes caused by perturbations; and (5) they act as continuous monitors of the water they inhabit thus enabling long term analysis of both regular and intermittent discharges, variable concentrations of single and multiple pollutants, and even synergistic or antagonistic effects. Benthic macroinvertebrate sampling can also be conducted using simple inexpensive equipment and the taxonomy of many groups is well known with keys to identification available (Hellawell 1986). In addition, many methods of data analysis, including biotic diversity indices have been developed and are widely used for benthic macroinvertebrates (Ohio Environmental Protection Agency 2015).

Bioassessments, formally defined as a quantitative survey of physical habitat and biological communities (benthic macroinvertebrates) of a water body to determine ecological condition have been used in California's Central Valley for a number of years (Bacey 2005, Brown and May 2004, Hall et al. 2009, Hall et al. 2013). One stream in California where bioassessments with benthic macroinvertebrates have been conducted since 2006, is Pleasant Grove Creek (Hall et al. 2015). Pleasant Grove Creek is a typical residential stream in California's Central Valley located in Roseville, California. This stream is on the California 303d list (impaired water body) based on the presence of pyrethroids, low dissolved oxygen and sediment toxicity (California Water Boards, 2010).

Bioassessment multiple stressor studies have been conducted in Pleasant Grove Creek spanning 10 years since 2006, with an extensive spatial scale (21 sites) given the size of the stream (Hall et al. 2015). Therefore, this database provides a unique opportunity to conduct benthic community trends analysis for key benthic metrics from data sets where both sampling and benthic identifications have been consistent. There was also the opportunity with this data set, spanning from 2006 to 2015, to determine the possible influence of the severe drought conditions that occurred during 2013 to 2015, on benthic macroinvertebrate communities (Howitt et al. 2015). Various investigators have reported that drought conditions can have adverse effects on resident benthic communities (Beche et al. 2009, Lake 2003). However, consistent long term studies that assess the impact of drought conditions on benthic communities along with consistent measurements of habitat, water quality parameters and potential chemical stressors (for example, metals and pyrethroids) have not been conducted.

The primary objective of this study was to determine if nine benthic metrics representing measures of richness, composition, tolerance/intolerance and trophic composition have changed temporally or spatially (increased, remained stable or decreased) from 2006 to 2015 (excluding 2009-2012), in Pleasant Grove Creek. The following benthic metrics were used in this analysis: percent dominant taxa; percent tolerant taxa; Shannon diversity index; EPT (*Ephemeroptera*, *Plecoptera*, and *Tricoptera* Index) taxa; percent collector/gatherers; percent collector/filterer; percent intolerant taxa; taxa richness; and the number of *Hyalella* collected. A secondary objective was to determine if 10 habitat metrics and total habitat scores measured concurrently with the benthic sampling have changed temporally or spatially over the 2006 to 2015, time period in Pleasant Grove Creek.

Materials and Methods

Study area.—A total of 21 sites was sampled in Pleasant Grove Creek and its tributaries (South Branch and Kaseberg Creek) in the spring of 2006, 2007, 2008, 2013, 2014 and 2015 (Figure 1). Sites are referenced as PGC 1 through PGC 22 (no site PGC 13) throughout the text. Sites that are located near storm drains are highlighted in Figure 1. Pleasant Grove Creek, located in Roseville, California, USA, is characterized by numerous contiguous subdivisions of single family homes less than 10 years old. There is no industry in the area and also sparse commercial development and agriculture. The distance from the upstream to downstream site was approximately 19 km in the mainstem of Pleasant Grove Creek. The distance from the upstream to downstream site in South Branch was approximately 8 km while the distance from the upstream to downstream site in Kaseberg Creek was approximately 8 km.

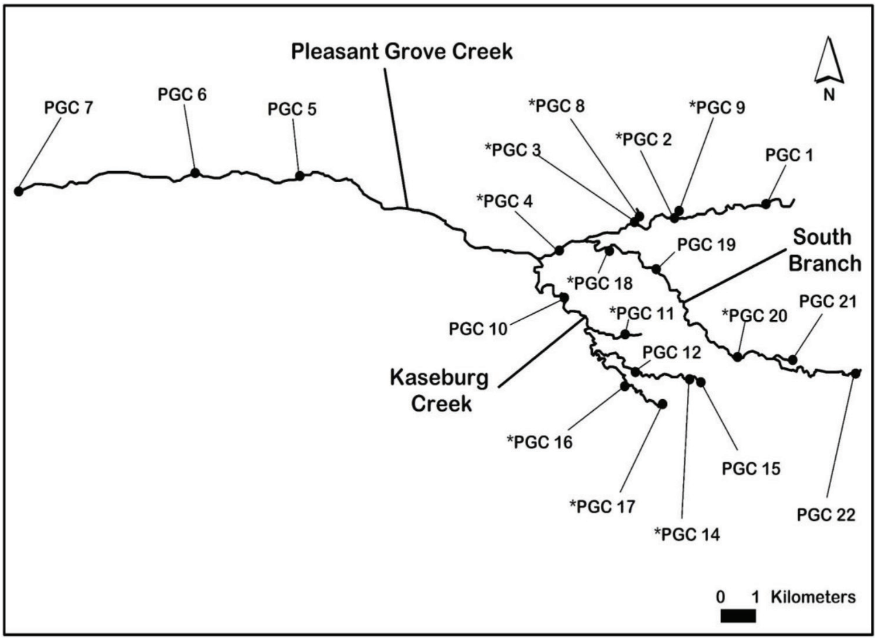

Figure 1.— Pleasant Grove Creek (PGC) core sites in California. Sites near storm drains are designated with an *.

Benthic macroinvertebrate sampling.—Benthic macroinvertebrates were collected in the spring of 2006, 2007, 2008, 2013, 2014 and 2015 from three replicate samples at all 21 sample sites. The sampling procedures were conducted in accordance with methods described in Harrington and Born (2000). Within each of these sample reaches, a riffle was located (if possible) for the collection of benthic macroinvertebrates. A tape measure was placed along the riffle and potential sampling transects were located at each meter interval of the tape. Using a random numbers table, three transects were randomly selected for sampling from among those available within the riffle. Benthic samples were taken using a standard D-net with 0.5 mm mesh starting with the most downstream portion of the riffle. A 30.5 x 61 cm section of the riffle immediately upstream of the net was disturbed to a depth of 10.2 to 15.2 cm to dislodge benthic macroinvertebrates for collection. Large rocks and woody debris were scrubbed and leaves were examined to dislodge organisms clinging to these substrates. Within each of the randomly chosen transects, three replicate samples were collected to reflect the structure and complexity of the habitat within the transect. If habitat complexity was lacking, samples were taken near the side margins and thalweg (deepest path) of the transect and the procedures described above were followed. All samples were preserved in 95% ethanol.

Due to the physical nature of this residential stream, it was often difficult to locate a substantial number of riffles to sample. Therefore, alternative sampling methods for non-riffle areas were used for all sites when needed as outlined in Harrington and Born (2000). This involved sampling the best available 30.5 x 61 cm sections of habitat throughout the reach using the same procedures described above. Nine 30.5 x 61 cm sections were randomly selected for sampling (i.e., stratified random sampling). Groups of three 30.5 x 61 cm sections were composited for each replicate for a total of three replicates per site.

Taxonomy of benthic macroinvertebrates and metric development.—The goal of the current study was to identify all benthic samples to the species level if possible. For taxa such as oligochaetes and chironomids, family and genus level, respectively, were often the lowest level of identification possible. Benthic macroinvertebrate subsampling (resulting in a maximum of 300 individuals) and identifications were conducted by the California Department of Fish and Wildlife (CDFW) in Rancho Cordova, California, USA. The benthic macroinvertebrate samples were subsampled and sorted by personnel at the CDFW Laboratory located at Chico State University, Chico, California, USA. Level 3 identifications (species level identifications) followed protocols outlined in Harrington and Born (2000). Slide preparations and mounting for species such as midges and oligochaetes followed protocols from the United States Geological Survey National Quality Control Laboratory described in Moulton et al. (2000).

Taxonomic information was used to develop benthic metrics. Benthic metrics for wadeable streams in California were developed by California Department of Fish and Wildlife (Harrington and Born 2000). Metrics were selected to represent different categories of ecological information (i.e., richness, composition, tolerances and trophic measures). The various metrics were selected to maximize the effectiveness of detecting degradation in concert with communicating meaningful ecological information. The following benthic metrics (along with the expected response to impairment) were used in the analysis: percent dominant taxa (increase); percent tolerant taxa (increase); Shannon Diversity (decrease); EPT taxa (decrease); percent collectors/gatherers (increase); percent collectors/filterers (increase); percent intolerant taxa (decrease); taxa richness (decrease); and number of

Hyalella (increase). The *Hyalella* metric is not a typical metric used in this type of analysis but was used in this study because it is a commonly used toxicity test species in California. *Hyalella* are considered tolerant of general environmental stressors with a tolerance value of 8 on a scale of 0-10, with 10 as the most tolerant (U. S. Environmental Protection Agency 1999). However, *Hyalella* are very sensitive to pyrethroids (Giddings and Wirtz 2012).

Physical habitat assessments.—Physical habitat was evaluated at each site concurrently with benthic collections. The physical habitat evaluation methods followed protocols described in Harrington and Born (2000). The physical habitat metrics used for this study were based on nationally standardized protocols described in Barbour et al. (1999). The following 10 continuous metrics scored on a scale of 0-20 (0=very poor to 20=optimal) were evaluated: epifaunal substrate; embeddedness; velocity/depth/diversity; sediment deposition; channel flow status; channel alteration; frequency of bends/riffles; bank stability; vegetation protection; and riparian zone; and given a total score (maximum score=200).

Statistical analysis.—In advance of the statistical trends analysis, it was determined whether assumptions of normality and equal variance were met with the benthic and habitat data sets. If assumptions of normality and equal variance were met, as was the case for most of the data, regression analysis (a parametric test) was used to determine both temporal and spatial trends as recommended by other investigators (Hirsch et al. 1982). Trends were considered statistically significant if p values were less than 0.10 and r^2 values were greater than 0.25 (Hall and Anderson 2012). If assumptions of normality and equal variance were not met then a Spearman rank order correlation (a non-parametric test) was used to determine significant trends.

Results

Overview of the six year benthic community dataset.—The number of different benthic taxa collected by year in Pleasant Grove Creek were: 2006 (142); 2007 (145); 2008 (153); 2013 (153); 2014 (143) and 2015 (145). These results show that the range of number of different benthic taxa collected for six years of sampling (142 to 153) was similar. A total of 273 different benthic taxa were collected over the six year sampling period.

The number of individual benthic taxa collected by year were: 2006 (18,334); 2007 (17,994); 2008 (21,291); 2013 (15,993); 2014 (17,550) and 2015 (18,116). The number of individual benthic taxa collected by year ranged from 15,993 in 2013 during the severe drought period to 21,291 in 2008 during the non-severe drought period. In summary, a total of 109,278 individual benthic taxa were collected during the six years of sampling in Pleasant Grove Creek.

The five most dominant benthic taxa collected during six years of sampling in Pleasant Grove Creek and percent of the total samples were: immature tubificidae (oligochaetes)–9.3%; *Physa* (snails)–9.2%; *Hyalella* (amphipods)–7.2%; *Paratanytarsus* (chironomids)–6.5% and *Dugesia tigrina* (flatworms)–4.9%. All of these taxa are considered tolerant to moderately tolerant of environmental stressors (Harrington and Born 2000).

Temporal analysis of benthic metrics.—A temporal trends analysis of selected benthic metrics using standard linear regression showed a statistically significant increase in percent tolerant taxa from 2006 to 2015 (Table 1; Figure 2b). Since percent tolerant taxa increase in stressed environments, this significant increase in percent tolerant taxa suggests an increase in impairment in this stream over time. A statistically significant decline in EPT taxa–taxa that are sensitive to stress–was also observed in Table 1, and Figure 2d. This result would also suggest an increase in impairment. There were no statistically significant changes for the other seven benthic metrics presented in Table 1. However, increasing slopes for stress tolerant metrics such as percent dominant taxa and number of *Hyalella* and declining slopes for stress sensitive metrics such as Shannon Diversity Index and taxa richness would suggest a decline in benthic community condition.

Table 1.—Linear regression of Pleasant Grove Creek benthic metrics trends for 2006, 2007, 2008, 2013, 2014 and 2015. Significant trends are in bold.

Benthic Metric	Linear Regression			Significant Trend Over Time?[a]
	r^2	P	Slope	
% Dominant Taxa	0.028	0.752	Increase	No
% Tolerant Taxa	**0.915**	**0.003**	**Increase**	**Yes**
Shannon Diversity Index	0.267	0.294	Decline	No
EPT Taxa	**0.615**	**0.065**	**Decline**	**Yes**
% Collector/Gatherers	0.177	0.406	Decline	No
% Collector/Filterers	<0.001	0.990	Decline	No
% Intolerant Taxa	0.157	0.437	Increase	No
Taxa Richness	0.412	0.169	Decline	No
# of Hyalella	0.156	0.439	Increase	No

[a] Statistically significant at $p < 0.10$.

Spatial analysis of benthic metrics.—Spatial analysis of benthic metrics generally confirmed the results from the temporal analysis presented above (Figure 3). For example, a greater number of sites were reported to have a significant increase in stress-tolerant metrics such as percent dominant taxa, percent tolerant taxa and percent collector-filterers. The exceptions were the stress tolerant metrics number of *Hyalella* and percent collectors-gatherers where a greater number of sites did not show increases for these metrics. In addition, stress sensitive metrics such as EPT taxa and taxa richness were also reported to significantly decrease at a higher number of sites as illustrated in Figure 3. The above results from spatial analysis suggest that benthic communities have declined in Pleasant Grove Creek during the 2006 to 2015 time period.

Temporal analysis of habitat metrics.—Temporal trends analysis of individual habitat metrics and total score in Table 2, and Figure 4, showed a significant decline from 2006 to 2015, for velocity depth diversity, channel flow status and riparian zone. A decline in these three metrics would demonstrate a decrease in habitat quality in Pleasant Grove Creek for the 10 year time span. It is also noteworthy that declining slopes (although not statistically significant) were also reported for epifaunal substrate, frequency of bends/riffles, bank stabilization, and total habitat scores. The declining slopes for these habitat

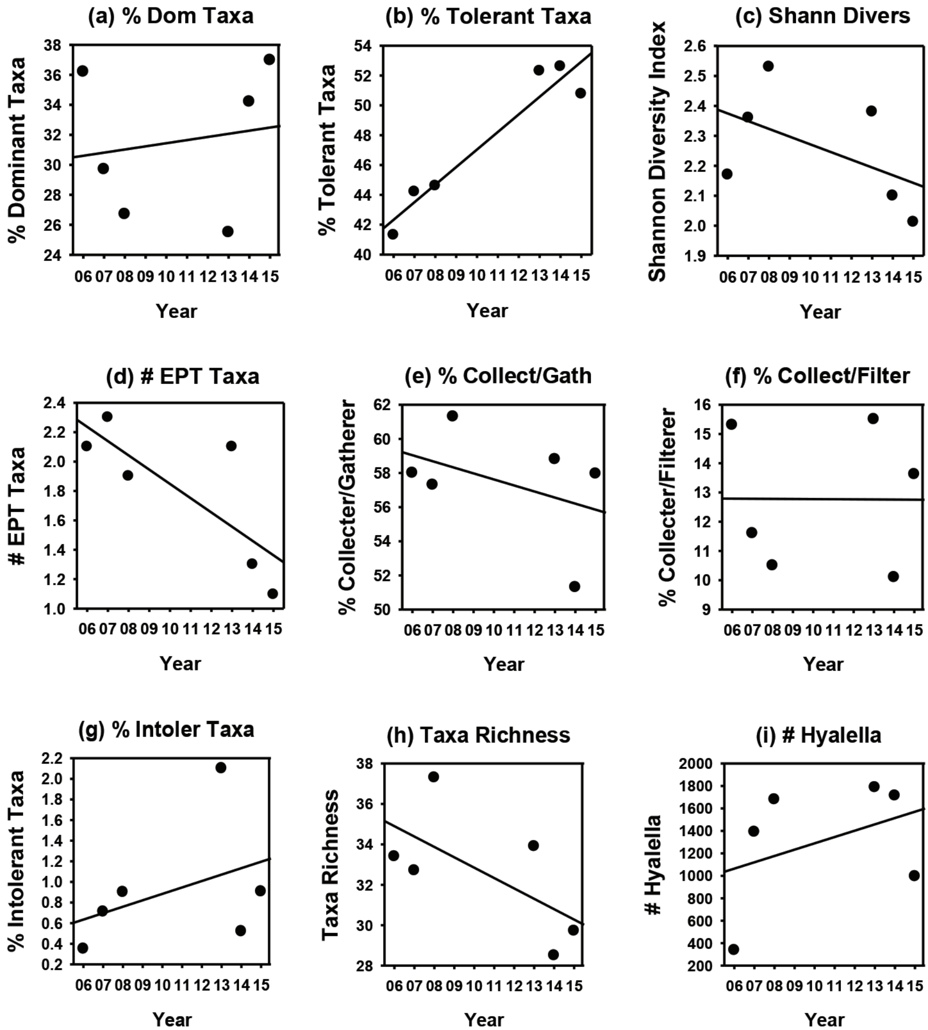

Figure 2.— Linear regression plots of nine Pleasant Grove Creek benthic metric trends for 2006, 2007, 2008, 2013, 2014 and 2015.

metrics and total score would also suggest a deterioration of physical habitat in this stream over time. Based on the above data, it appears that the overall habitat, that is consistently marginal based on annual sampling, has demonstrated a decline during the 2006 to 2015, time period in Pleasant Grove Creek.

Spatial analysis of habitat metrics.—Spatial analysis of habitat metrics and total score provided additional support for the declining habitat conditions in this stream as reported above based on temporal analysis (Figure 5). A greater number of sites showed a significant decrease for the following metrics: epifaunal substrate; velocity/depth/diversity; channel flow status; frequency bends/riffles; bank stability; and riparian zone. Spatial analysis of total habitat scores in Figure 5, also showed that five sites (PGC3, PGC9, PGC11, PGC14, and PGC21) had significant declining total habitat scores. In contrast, only one site (PGC10) had an increase in total habitat scores over the 2006 to 2015, time period.

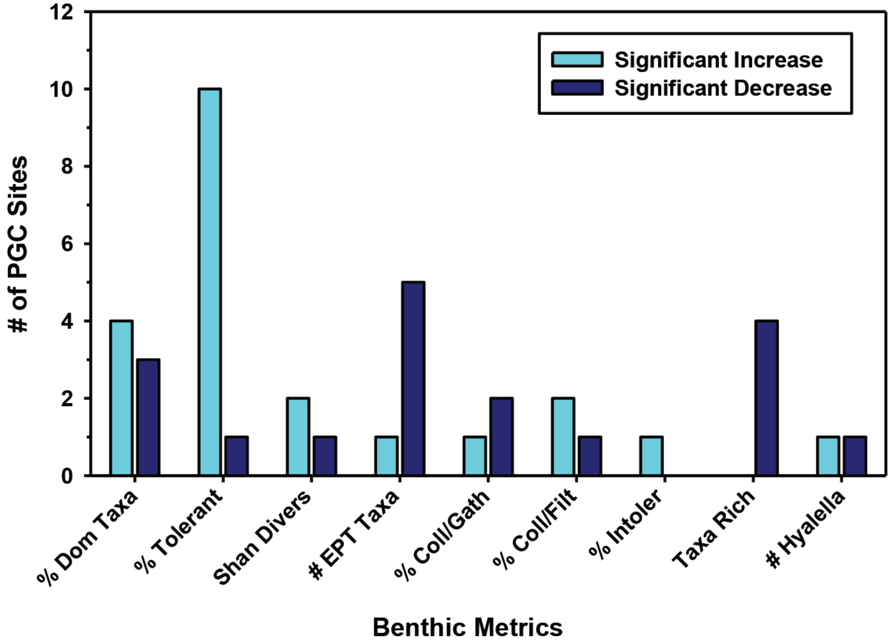

Figure 3.— Number of Pleasant Grove Creek sites with significant increasing or decreasing temporal trends for the various benthic metrics from 2006-2015.

Table 2.—Pleasant Grove Creek habitat metric trends data for 2006, 2007, 2008, 2013, 2014 and 2015. Significant trends are in bold. No data transformations were necessary to improve the overall fit of the data for statistical analyses.

Habitat Metric	Linear Regression		Slope	Significant Trend Over Time?[a]
	r^2	P		
Epifaunal Substrate	0.169	0.417	Decline	No
Embeddedness	0.016	0.808	Increase	No
Velocity Depth Diversity	**0.584**	**0.077**	**Decline**	**Yes**
Sediment Deposition	0.084	0.577	Increase	No
Channel Flow Status	**0.639**	**0.056**	**Decline**	**Yes**
Channel Alteration	0.066	0.622	Increase	No
Frequency of Bends/Riffles	0.503	0.115	Decline	No
Bank Stabilization	0.179	0.404	Decline	No
Vegetative Protection	0.187	0.391	Increase	No
Riparian Zone	**0.755**	**0.025**	**Decline**	**Yes**
Total Score	0.420	0.164	Decline	No

[a]Statistically significant at $p = 0.10$.

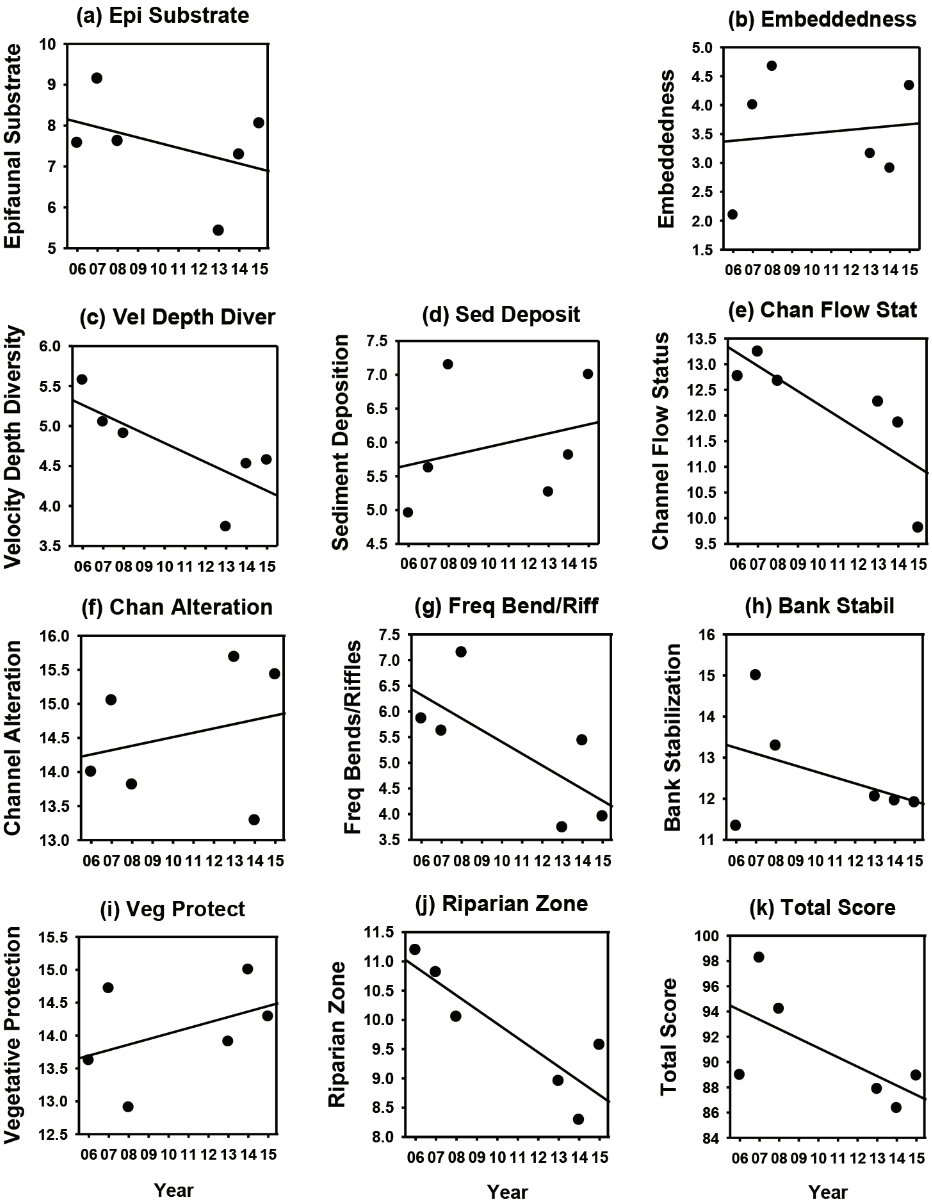

FIGURE 4.— Linear regression plots of 11 Pleasant Grove Creek habitat metrics trends for 2006, 2007, 2008, 2013, 2014 and 2015.

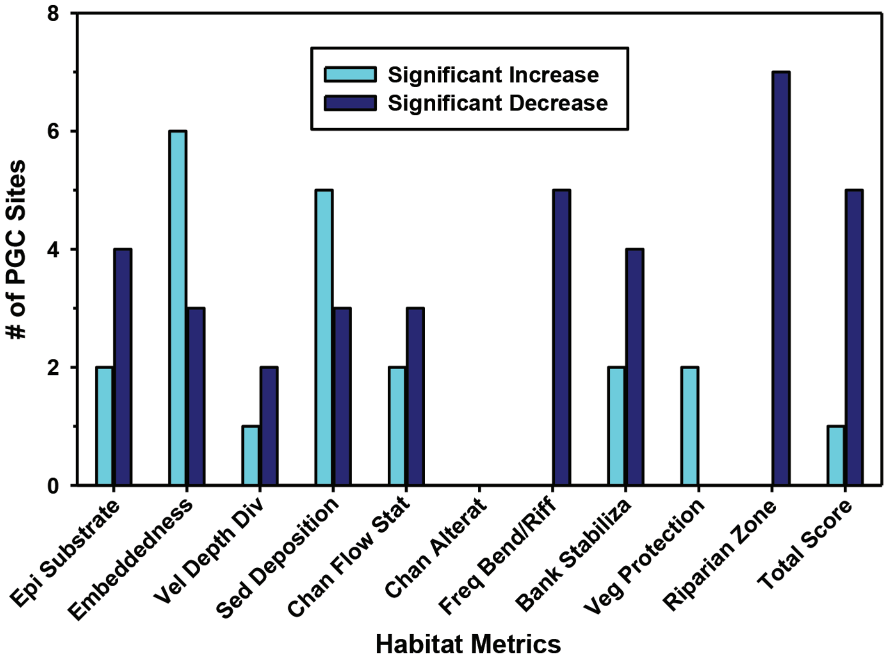

Figure 5.— Number of Pleasant Grove Creek sites with significant increasing or decreasing temporal trends for the various habitat metrics from 2006 -2015.

Discussion

A significant finding from this study is that benthic community conditions have declined in Pleasant Grove Creek from 2006 to 2015. Lotic aquatic systems, such as Pleasant Grove Creek, are very complex and are subject to multiple stressors, so it is often difficult to determine factors responsible for the decline in the condition of benthic communities. Various possible factors that may be responsible for the decline in benthic community condition in Pleasant Grove Creek are physical habitat decline, severe drought (also correlated with habitat decline), water quality stressors (e.g., reduced dissolved oxygen), and chemical contaminants (metals and pyrethroids). The possible role of each factor as a contributor to benthic community decline in Pleasant Grove Creek is discussed below.

Impaired physical habitat (including sediment loading) has been identified as a major stressor to aquatic life in California streams (Anderson et al. 2003; Hall et al. 2007). Altered physical habitat structure is also considered one of the major stressors of aquatic systems throughout the United States resulting in extinctions, local expirations and population reductions of aquatic fauna (Karr et al. 1986, Rankin 1995). Identifying degraded physical habitat in streams is particularly critical for biological monitoring as failure to do so can sometimes hinder investigations on the effects of toxic chemicals or other water quality related stressors. Rankin (1995) has reported that there is a small but still significant risk of reporting a water quality related impact when one does not exist (i.e., a false positive) when habitat assessments are insufficient or absent. Physical habitat evaluations are not intended to replace biological assessments but rather to add an additional line of evidence about the status of lotic systems when conducted in concert with biological assessments.

The physical habitat metric temporal trends reported in the current study shows that habitat has declined in Pleasant Grove Creek from 2006 to 2015, based on a significant decline in key metrics such as velocity/depth/diversity, channel flow status, and riparian zone. The decline in physical habitat occurs concurrently with the decline in benthic community condition during this 10 year time period. Previous bioassessment multiple stressor studies in Pleasant Grove Creek spanning 2006 to 2015, have shown that physical habitat, and not chemical stressors such as metals or pyrethroids, have a stronger correlation with benthic community metrics (Hall et al. 2015). Therefore, the results from historical data analysis of the bioassessment multiple stressor studies and the declining habitat trends data in the current study would support the decline in habitat conditions as a likely reason for the decline in benthic community condition in Pleasant Grove Creek from 2006 to 2015.

Severe drought conditions during 2013 to 2015, as reported by Howitt et al. 2015, is suspected in reducing stormwater runoff, overall stream flow and wetted stream bed area as habitat for benthic communities in Pleasant Grove Creek when compared with the earlier years of sampling during non-severe drought years in 2006-2008. The best evidence to support this severe drought period (2013-2015) vs the non-severe drought period (2006-2008) would be direct documentation of continuous flow from gauging stations in Pleasant Grove Creek during these two three year windows of time. Unfortunately, continuous flow data were not available for Pleasant Grove Creek for all years of sampling to demonstrate the extremely dry conditions during 2013- 2015. However, flow data were available for another waterbody in the general area (Arcade Creek) that can serve as a suitable surrogate (U.S. Geological Survey 2016). A t-test comparison of Arcade Creek mean flow data for 2006-2008, with 2013-2015, showed significantly higher flow five days prior to Pleasant Grove Creek sampling in 2006-2008 (mean discharge of approximately 2.8 ft^3 /sec) when compared with 2013-2015 (mean discharge of approximately 0.2 ft^3/sec). Therefore, the available data would support lower flow and reduced wetted stream area in Pleasant Grove Creek in 2013-2015, when compared with 2006-2008.

There are a number of studies that have been designed to determine the influence of drought conditions on benthic macroinvertebrates (Suren and Jowett 2006, Miller and Golladay 1996, Rose et al., 2008, Boulton 2003, Acuna et al. 2005, Chessman 2015, Love et al. 2008, Beche et al. 2009, Lake 2003, Bogan and Lytle 2011, Sponseller et al. 2010, Stanley et al. 1994, Wood and Petts 1999, McElravy et al. 1989, Resh 1992, and Beche and Resh 2007, among others.) For example, Rose et al. (2008) reported that stream assessments during drought only give an indication of river health at sites where water still persists, which may only be a small proportion of the remaining stream network. Stanley et al. 1994 have reported that the greatest changes in macroinvertebrate composition occur during drought when sites become isolated from upstream reaches. Beche et al. (2009), have reported that droughts have equivocal effects on the abundance and richness of invertebrate communities in two California streams as drought may reduce habitat suitability, particularly in already water stressed temporary habitats. Other investigators have also reported that severe drought periods greater than one year are more likely to result in persistent habitat changes, reduce the sources of nearby benthic colonists characteristic of higher flows, and to cause some local benthic populations to disappear due to lack of suitable habitat (Lake 2003).

The severe drought conditions experienced from 2013 to 2015, in the current study is likely related to the significant decline in the velocity/depth/diversity metric and channel flow status metric as previously discussed. Both of these metrics are important for benthic communities and are dependent on flow conditions. Although continuous flow data were not available for Pleasant Grove Creek for all years of sampling as previously discussed, individual flow measurements conducted at each of the 21 sites during the six year period showed that flow could only be measured at less than half the sites during 2013-2015 (presence of pools or dry stream bed), in contrast to 2006-2008, where flow was measured at more than half the sites. Velocity/depth/diversity is a measure of various velocity depth regimes present (slow/deep; slow/ shallow; fast/deep; and fast/shallow) so lower flow conditions experienced during a severe drought period could cause a reduction in this metric. The channel flow status metric is a measure of the percent of the channel that is filled by water so this metric is also highly dependent on the flow and the amount of water in the stream. Since the drought conditions are likely responsible for the decline in these two habitat metrics and these metrics are important for the condition of benthic communities, it is logical to assume that the severe drought conditions contributed to the decline in resident benthic community condition.

Standard water quality measurements of temperature, dissolved oxygen, pH, conductivity, salinity and turbidity were conducted at each sample site during each year of the six year sampling effort. The one water quality parameter that does appear to decline to stressful conditions during the six year study is dissolved oxygen. Oxygen availability in aquatic environments is widely recognized as a factor influencing the composition of freshwater benthic communities because it critically affects the distribution of many aquatic species (Hynes 1960). Lee and Lee (2002), have reported a toxic threshold of 5.0 mg/L for dissolved oxygen for aquatic species. In the current study, annual mean dissolved oxygen concentrations were greater than 6 mg/L for all years except 2015. For 2015, the annual mean dissolved oxygen concentration was 4.2 mg/L and dissolved oxygen values less than 5.0 mg/L were reported at 12 of 21 sites, thus suggesting stressful low dissolved oxygen conditions for benthic communities. Rose et al. 2008 have reported that reduced dissolved oxygen concentrations are a consistent response to drought conditions in water bodies. Therefore, the low and potentially stressful dissolved oxygen concentrations reported during one of the three severe drought years (2015) may have adversely impacted resident benthic communities.

In addition to the non-chemical stressors discussed above, both metals and pyrethroids are also potential chemical stressors to resident benthic communities that have been consistently measured in sediment at all sample sites during the six years of bioassessment sampling in Pleasant Grove Creek (Hall et al. 2014, Hall et al. 2015). Temporal trends analysis of the Pleasant Grove Creek metals data (arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc) from 2006 to 2015, showed no statistically significant change in concentrations for the eight metals and total metals (Hall et al. 2015). Therefore, the metals trends data demonstrating no significant temporal change over the 10 year time span do not suggest a relationship with metals and declining benthic community condition.

The following pyrethroids have also been measured concurrently in sediment with benthic communities in this waterbody: bifenthrin, cypermethrin, cyfluthrin, deltamethrin, esfenvalerate, fenpropathrin, lambda-cyhalothrin, and permethrin (Hall et al. 2014, Hall et al. 2015). Temporal trends analysis of these eight pyrethroids in sediment showed a significant decline in concentrations for six of the eight pyrethroids measured from 2006 to 2015 (Hall et al. 2016). The pyrethroids trends data, showing a decline over time, would suggest that there is no correlation with benthic community decline because if pyrethroids were a key stressor one would expect an increase in benthic community condition with a decline in pyrethroids. However, this was not the case. A summary of six years of bioassessment multiple stressor data in Pleasant Grove Creek also indicated that pyrethroids were not a significant stressor to benthic community metrics when evaluated using multivariate analysis that included both habitat metrics and metals (Hall et al. 2015). Therefore, the available data demonstrate that there is no relationship between pyrethroid concentrations in Pleasant Grove Creek and the decline in benthic community condition.

In summary, the likely factors contributing to the decline in benthic community conditions in Pleasant Grove Creek from 2006 to 2015, are declining physical habitat conditions and low dissolved oxygen concentrations. Both of these factors are likely associated with the severe drought conditions present during 2013 to 2015. This result is not surprising as numerous studies addressing the impact of drought on benthic communities in freshwater lotic systems previously discussed above provide support for this finding. Continued benthic sampling in Pleasant Grove Creek in 2016, with the predicted El Nino (Northern California Water Association Newsletter 2015) and associated predicted intense rainfall could provide insight on the possible impact of drought conditions on benthic communities. If increased rainfall resulted in increased stream flow and wetted stream area, then continued benthic sampling would provide useful information to determine if benthic communities can recover to pre-drought conditions in Pleasant Grove Creek. However, it may take more than one year of non-drought conditions for benthic communities to recover in this water body.

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