# The Effects of Seasonal Drought on Fish Ecology in San Antonio Creek, CA

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## ABSTRACT

Aquatic systems in Mediterranean Climate regions commonly exhibit summer drought as a disturbance that can be important for natural selection and diversity of fish species. Drying pools have a number of abiotic factors that can be stressors such as increase in temperature and conductivity, and a decrease in Dissolved oxygen (DO and habitat loss. In this study, I determined which abiotic factors affect fish mortality using data collected of abiotic factors from five pools in San Antonio Creek, CA. To determine which physical habitat parameters may be correlated to fish losses, I calculated Spearman Rank (S.R.) correlations for pairs of physical habitat parameters and found the highest correlations to be between % algae and pool area (S.R.= -0.67, P= 0.0000). I observed that, as the summer progressed, riffles disappeared and all pools disconnected from the creek. There was a general increase in conductivity, algae, and shade, and a decrease in DO and pool depth in all or most sites. To study the effects of drought on fish mortality, I graphed the estimated number dead fish over time and compared the mortality to each physical habitat parameter over time. I found that there was an overall increase in fish mortality over time, and that fish mortality was highly correlated to dissolved oxygen and depth. Peaks and drops in temperatures were also followed by sudden mass fish mortality. Some species demonstrated extremely high tolerance to drought conditions that were not expected.

## KEYWORDS

Mediterranean climate, fish ecosystem, stream ecology, summer drought, drying streams

# INTRODUCTION

Although drought is a disturbance to aquatic systems, it can be a natural and predictable process that is important for natural selection and diversity of species. During drought disturbance as pools dry up, species seek refugia and may have physiological tolerance, such as high temperature and low dissolved oxygen (DO), or behavioral attributes such as a preference for shaded areas to survive harsh conditions (Magoulick, 2000; Magoulick & Kobza, 2003; Sheldon et al., 2010). These differences in behavioral strategies affect fish survival, their ability to reproduce, and thus species diversity. Those species subjected to recurring seasonal drought conditions are more likely to be resilient and tolerant to harsh conditions as opposed to those that reside in less stressful conditions (Cook et al., 2010; Dekar & Magoulick, 2007; Magoulick & Kobza, 2003). However, predicting responses to a disturbance such as drought is difficult because impacts from drought are variable and depend on natural features such as geography and anthropogenic impacts such as land management particular to each ecosystem (Crook et al., 2010; Magoulick, 2010).

Drying pools have a number of abiotic and biotic factors that can contribute to mortality of fish. Abiotic factors such as pool morphology, habitat structure, and water quality are known to be correlated with species assemblage or a taxonomic subset of a community (Arthington, Olden, Balcombe, & Thoms, 2010). Drought causes water levels to drop and riffles to dry up resulting in disconnected pools. Consequently, species become trapped. Other abiotic factors affected by drought that are important for a viable fish habitat are pool area, depth, and cover that are correlated with fish assemblage and diversity (Dekar & Magoulick, 2007; Magoulick, 2000). As water level drops, the fish are subjected to abiotic conditions such as low DO, increased temperatures and conductivity, and biotic factors such as increased predation and inter-species competition (Arthington, Olden, Balcombe, & Thoms, 2010; Crook et al., 2010; Matthews & Marsh-Matthews, 2003; Dekar & Magoulick, 2007; Sheldon et al., 2010). Predation increases during drought because reduced water levels and area restrict habitat where species can find shelter. However, the effects of seasonal summer drought on stream fish ecology and abiotic and biotic factors can be complex and are not well understood (Cook et al., 2010; Dekar & Magoulick, 2007).

San Antonio Creek (CA: Alameda Co.) is a Mediterranean climate type stream ecosystem that is characterized by seasonal predictable events which vary in intensity of flooding in late fall-winter and drying in late summer-early fall (e.g., Gasith and Resh, 1999). San Antonio Creek is located downstream of the San Antonio reservoir and has a history of predictable seasonal summer drying and the mass mortality of all fish as pools completely dry up (K. Yoshida, personal communication, August, 2010). However, knowledge about the role of drought on stream dynamics in San Antonio Creek and what factors affect species loss directly is limited (Crook et al., 2010; Dekar & Magoulick, 2007; Lake, 20003), and even less is known about California Mediterranean climate streams with predictable summer drying.

The objective of this study is to determine the effects of drought on fish mortality in San Antonio Creek. I ask specifically, what abiotic parameters affect freshwater fish mortality during a drought disturbance? I hypothesize that parameters such as size and characteristics of pools and vegetation cover will have an effect on fish mortality. I expect that temperature, DO, and water depth will be the most important abiotic factors contributing to fish losses. Because San Antonio Creek is relatively free of anthropogenic disturbances, it serves as a basis for understanding the role of natural disturbances on aquatic ecosystems.

## METHODS

### Study Area

We (Kristina Cervantes-Yoshida and I) selected five pools along the San Antonio Creek (37.58N; 38.58E) based on pool characteristics related to fish habitat preferences. The considerations we used for selecting the pools included tree cover/shade, pool depth, and the presence of connecting riffles. The pools we chose generally contained complete or nearly complete shading from tree cover, and the deepest available pools in the stream reach.

## Data Collection

To determine the effects of drought on fish mortality, we collected data on both abiotic factors within the pools between June and August 2010 until pools completely dried up or there were no more surviving fish. We collected data on the following parameters: dissolved oxygen (DO; ppm), temperature (°C), depth (m), wetted width of pool (m), length and perimeter of pool (m), conductivity (μS), vegetation/algae cover (%), and shade (%). We acquired measurements of DO with a handheld DO meter (YSI, Yellow Springs, OH) and conductivity with a conductivity meter (Hach C0150, Loveland, CO). We used rebar to set temperature loggers (HOBO, Bourne, MA) to record temperatures every 10 minutes throughout the summer. To achieve consistent length and width measurements, we set permanent markers with stakes. We measured the pool width by dividing the longest pool length into four positions (e.g. a 5 ft pool was measured every 1 ft) and measuring the width at each of these positions. We calculated average area of pools using the average pool length and width measurements. We estimated the percentage of vegetation/algae cover and shade by observation.

Once fish mortality began to occur and carcasses were visible in pools, we identified and documented the fish to species level, measured their fork length (cm), and counted the number of fish.

## Relationship between Measured Physical Habitat Parameters

I compared measured physical habitat parameters by calculating the correlation between pairs of variables. I tested the data for normality by using the Shapiro-Wilk test for normality. Because variables could not be transformed for normality, I calculated the Spearman Rank (S.R.) correlations and P-values for pairs of the physical habitat parameters. I considered S.R correlations $\geq 0.5$ to be strong and P-value $\leq 0.05$ to be significant. I made the assumption that each of the habitat parameters that I measured was potentially related to fish mortality.

### Effects of Drought on Habitat over Time

I studied the effects of drought by examining the habitat parameters over time. I plotted each of the parameters individually over time. I used graphs to represent the overall general trends of the effect of drought on the habitat parameters over time.

### Effects of Drought on Fish Mortality

To examine the effects of drought on fish mortality, I graphed the estimated number dead fish over time and compared it to each physical habitat parameter over time. I estimated the number of dead fish by adding the observed dead fish carcass count and missing dead fish count that was calculated. The missing dead fish count was calculated by subtracting the number of alive fish in the present week from the previous week's alive fish count. I plotted each species and determined the mean mortality date (date where half of the total deaths occur) per site. I determined the species resilience by quantifying its prevailing presence over time. I examined this graph to identify a fish mortality threshold, defined by a sudden increase or drop in the curve of the graph. I also calculated S.R correlations and P-value between estimated number of dead fish and each of the physical habitat parameters.

## RESULTS

### Study Site

All of the pools sites completely dried up over the course of the summer. I observed that riffles disappeared, all pools disconnected from the creek, and there was an overall decrease in pool depth. I also observed an increase in fish crowding in pools and an abundance of algae that decreased the water clarity in water. Pool sites demonstrated increased fish mortality and overall increased temperature.

## Relationship between Measured Physical Habitat Parameter

Physical habitat parameters showed a number of significant relationships. I found that there were two positive and two negative Spearman Rank (S.R.) significant correlations between parameters, but not relatively strong overall. For example, there was a positive correlation between algae and conductivity and a negative correlation between % algae and % area (Table 1).

**Table 1. Correlation Spearman Correlation values and p-values for measured physical habitat parameters.** Significant correlations are noted in bold.

| Parameters | Spearman Rank | P-value |
|---|---|---|
| DO-Pool Temp | 0.06 | 0.7514 |
| DO-% Shade | -0.13 | 0.0790 |
| DO-% algae | -0.37 | 0.0422 |
| DO-Pool Area | 0.36 | 0.0438 |
| DO-Conductivity | -0.38 | 0.0351 |
| **DO-Depth** | **0.5** | **0.0042** |
| % Shade-Conductivity | 0.20 | 0.2802 |
| **% Algae-Depth** | **-0.65** | **0.0000** |
| **% Algae-Area** | **-0.67** | **0.0000** |
| % Algae-Pool Temp | -0.34 | 0.0597 |
| **% Algae-Conductivity** | **0.54** | **0.0016** |

## Effects of Drought on Habitat over Time

The habitat parameters I examined were affected by drought over time. Overall, the sites showed a trend of increased conductivity (Fig. 1). There was an overall decrease in DO over time (Fig. 2) for pool sites 2, 3, and 5 but an increase in sites 1 and 4. Meanwhile % shade decreased overall in sites 1 and 4 but increased in sites 2, 3, and 5 (Fig. 3). % algae increased (Fig. 4) and pool depth (Fig. 5) decreased overall.

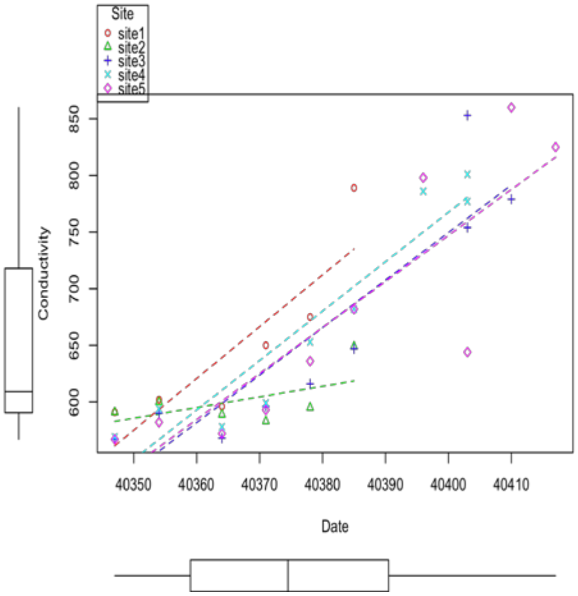

**Figure 1. Water conductivity over time for the 5 sites studied.**

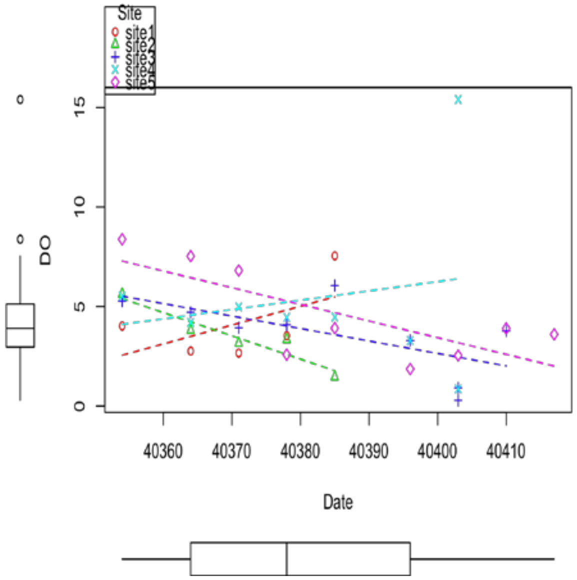

**Figure 2. Dissolved oxygen over time for the 5 sites studied.**

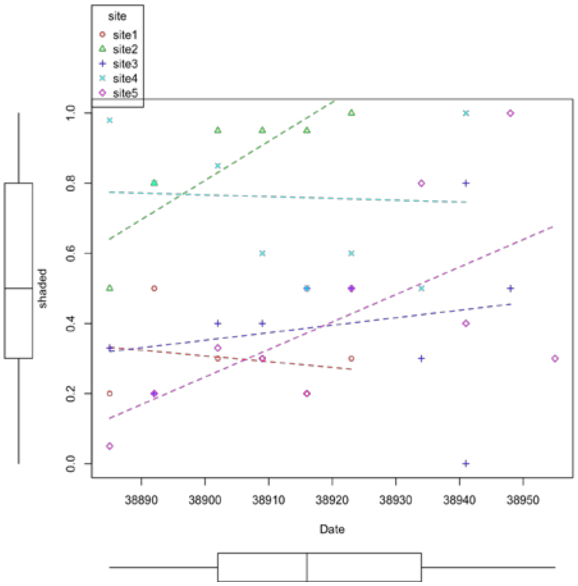

**Figure 3. % Shaded over time for the 5 sites studied.**

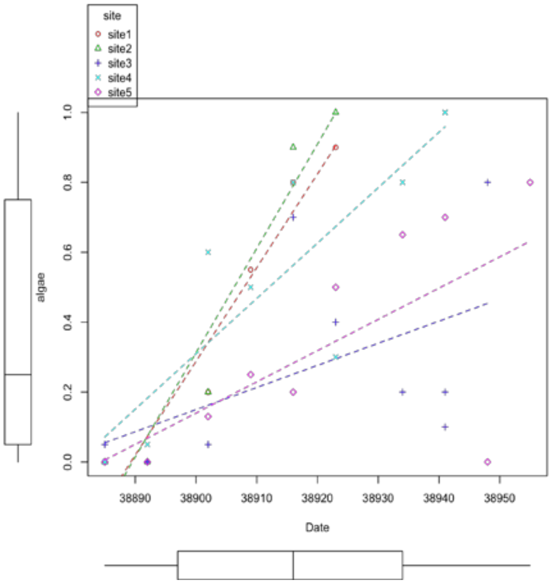

**Figure 4. % Algae over time for the 5 sites studied.**

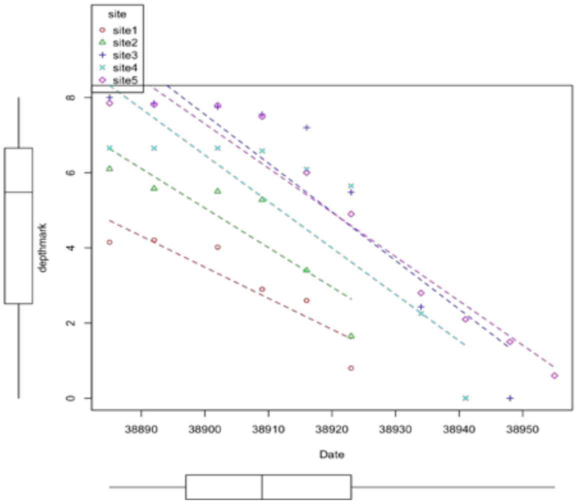

**Figure 5. Pool Depth over time for the 5 sites studied.**

## Effects of drought on fish mortality

I found that there was an overall increase in fish mortality over time, but I observed some discrepancies in the number of dead fish resulting from missing carcasses. Overall, the total count of number of dead fish added to alive fish was fewer than the total number of alive fish found in each of my sites in the previous weeks. *Cottus asper* (prickly sculpin) was the last to die in all the sites while *Oncorhynchus mykiss* (Rainbow trout) was the first to die in most of the sites (Fig. 6-10). The rate of drying tended to be slowest for deeper pools, which also had a larger number of fish overall. The median mortality date for all fish species was between 7/26/11-8/6/11 for site 1, 2, and 4, 8/6/11-8/13/11 for site 3, and 8/13/11-8/20/11 for site 5 (Table 2). The deeper pools tended to exhibit their highest mortality peak at later dates compared to the shallowest pools that had earlier drying dates.

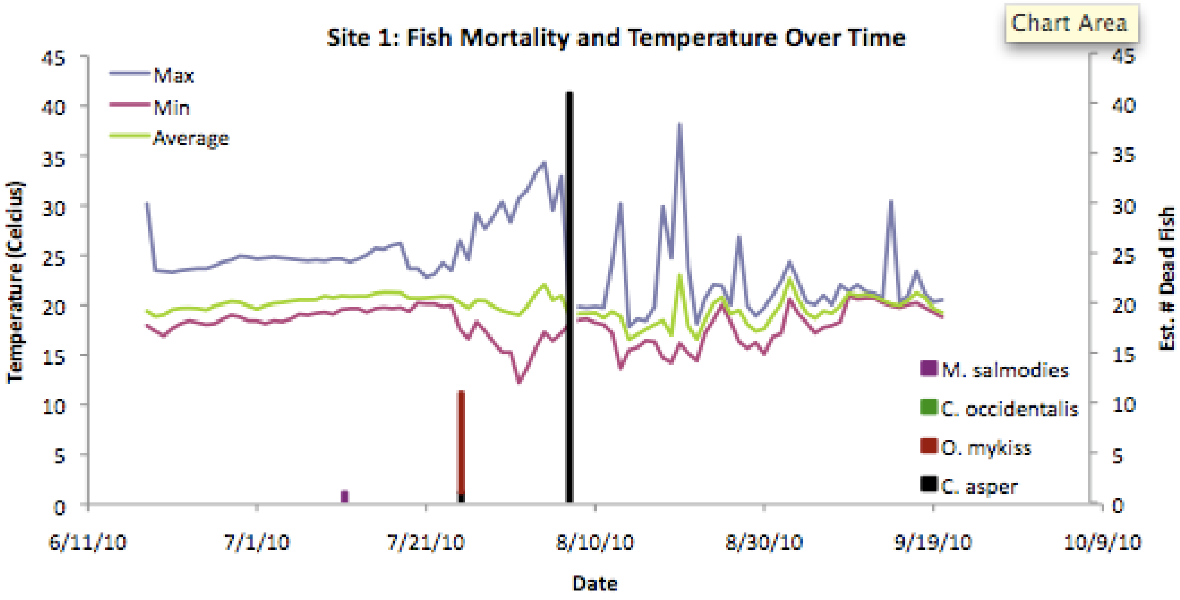

**Figure 6. Average, minimum, maximum temperature and Fish Mortality over time for Site 1.**

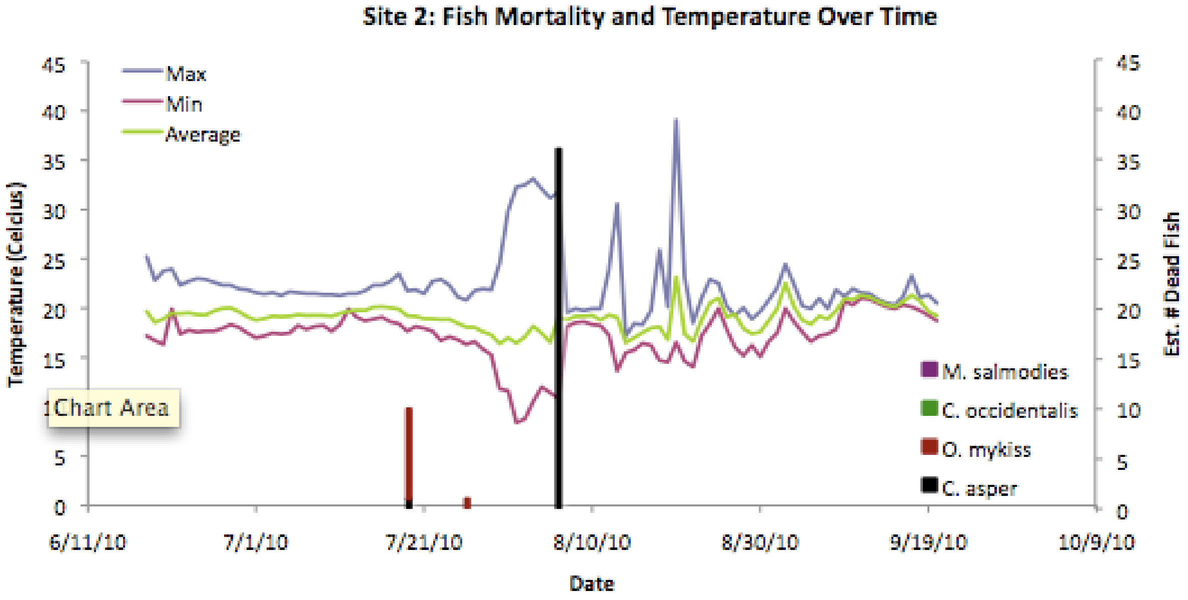

**Figure 7. Average, minimum, maximum temperature and Fish Mortality over time for Site 2.**

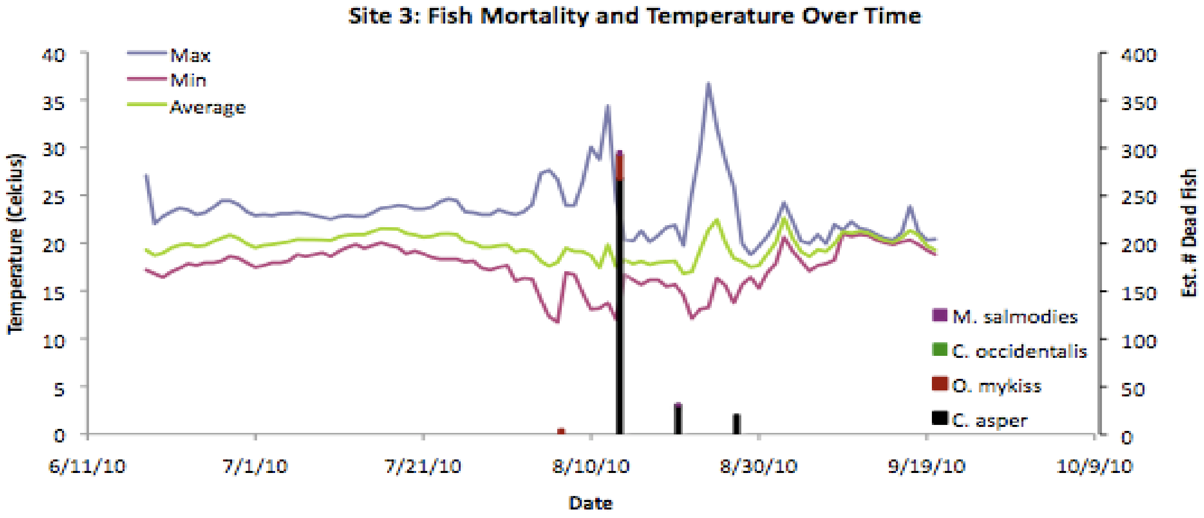

**Figure 8. Average, minimum, maximum temperature and Fish Mortality over time for Site 3.**

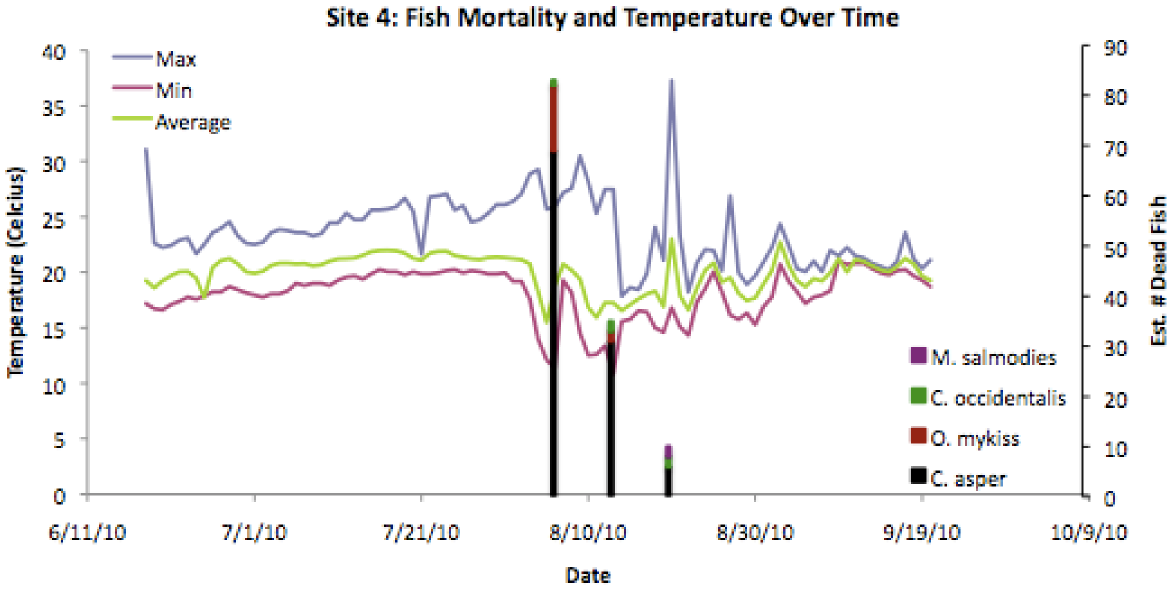

**Figure 9. Average, minimum, maximum temperature and Fish Mortality over time for Site 4.**

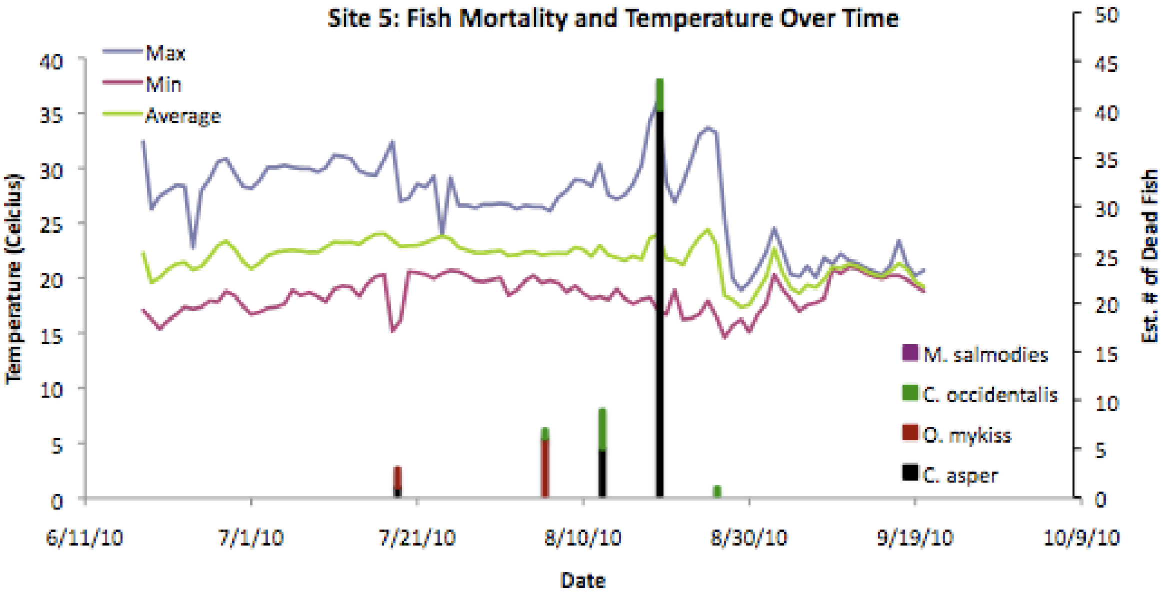

**Figure 10. Average, minimum, maximum temperature and Fish Mortality over time for Site 5.**

**Table 2. Max Depth, Pool Isolation Date, Drying Date, and Mean Mortality Date**. Pool Isolation Date is the date when pools became isolated and disconnected from the rest of the stream and pools. Drying Date is the date when the pools completely dried up.

| Site | Max Depth | Pool Isolation Date | Drying Date | Mean Mortality Date |
|---|---|---|---|---|
| 1 | 4.15 | 7/19/10 | 8/6/10 | 7/26/10-8/6/10 |
| 2 | 6.1 | 7/12/10 | 8/13/10 | 7/26/10-8/6/10 |
| 3 | 8 | 7/19/10 | 8/27/10 | 8/6/10-8/13/10 |
| 4 | 6.6 | 7/26/10 | 8/20/10 | 7/26/10-8/6/10 |
| 5 | 7.85 | 7/19/10 | after 8/27/10 | 8/13/10-8/20/10 |

Some physical habitat parameters were found to be significantly correlated to Fish Mortality. I found that fish mortality was significantly correlated particularly to pool depth (and area, and DO (Table 3).

**Table 3 Correlation Spearman Correlation values and p-values for measured physical habitat parameters and number of dead fish count.** Significant correlations noted in bold.

| Parameters | Spearman Rank | p-value |
|---|---|---|
| Number of dead fish-Pool temp | -0.16 | 0.4016 |
| Number of dead fish- %Shade | 0.2 | 0.2808 |
| Number of dead fish-% algae | 0.45 | 0.0107 |
| **Number of dead fish- Pool Depth** | **-0.61** | **0.0002** |
| **Number of dead fish-Pool Area** | **-0.61** | **0.0002** |
| **DO-Number of dead fish** | **-0.65** | **0.0000** |
| **Number of dead fish-Conductivity** | **0.51** | **0.0037** |

## DISCUSSION

I discovered that there was an overall increase in fish mortality over time, and that fish mortality was significantly correlated to DO and decreases in pool depth resulting from loss of habitat. Peaks and drops in temperatures were followed by sudden mass fish mortality, indicating that fish species are highly sensitive to extreme temperature changes.

### Effects of Drought on Habitat

As drought impacted the sites there was an overall increase in conductivity, algae, and shade, and a decrease in DO and pool depth in all or most sites as expected for Mediterranean-climate streams (Gasith & Resh, 1999). The increase in algae probably depleted oxygen and DO levels through respiration (Lake, 2000). Algae blooms were expected because of increased temperature, which also reduces the clarity of the water (Lake, 2000). Sites 1 and 4 were in contrast to the other sites with an overall increase in DO and a decrease in % shade.

## Effects of Drought on Fish Mortality

Fish mortality increased over time as expected as the pools dried and habitats became smaller; some species demonstrated an unexpected extremely high tolerance to drought conditions. However, all fish species were sensitive to extreme changes in habitat parameters. For example, high temperature peaks were often followed by the mass mortality of fishes (Figure 6-10). *Oncorhynchus mykiss* (Rainbow trout) demonstrated the lowest tolerance to temperature with a threshold between 26-34 ºC and often died earlier in the summer compared to other four species found in all sites. *Cottus asper* (prickly sculpin) demonstrated the highest temperature tolerance adaptation with a threshold between 30-36 ºC and often died last in the summer in all sites.

Fish tolerances tended to be highest in smaller, lower-level predators such as *C. asper* (32-89 mm) as opposed to *O. mykiss* that was larger in size (45-140 mm), which consumes *C. asper*. The low tolerance to drought-induced conditions may be a result of the high nutritional requirements of larger predators that are diminished with decreased habitat (Sheldon et al., 2010). The range in mass mortality and fish abundance tended to increase with lower drying rates and deeper pools. For instance, site 3 (Figure 8), which was the deepest pool, demonstrated the highest fish mortality compared to the shallowest site 1. The high fish mortality can be attributed to higher initial fish quantities in deeper pools (site 3 and 5) compared to the shallower sites 1 and 2. The mean mortality date (Table 2) is also later in the summer for deeper pools (site 3 and 5), which demonstrates that higher pool area and depth may delay fish mortality substantially.

A top predator such as *Micropterus salmoides* (Largemouth bass) is rarely found in such a harsh environment. However, in site 4 a *M. salmoides* individual demonstrated great resilience in spite of poor habitat conditions with extremely low pool depth of and low DO. The effects of drought on macroinvertebrate fauna may reduce both optimal and overall prey availability causing shifts in fish diets towards less nutritious prey (Lawrence et al., 2010). Therefore, *M. salmoides* may have adapted to the shift in diet during drought events that made it possible for it to survive in a decreased habitat area with limited nourishment. The presence of such a top predator exemplifies how species diversity is dependent on interaction between pool inhabitants and resource availability (Lake, 2000).

Extreme changes in DO, conductivity, and depth levels were also attributed to fish mortality as reflected by high spearman correlations (Table 3). Decreases in DO, depth, and habitat area, and increases in temperature and conductivity are known to increase fish mortality (Arthington, Olden, Balcombe, & Thoms, 2010; Crook et al., 2010; Dekar & Magoulick, 2007). Algae blooms can cause hypoxia and reduce DO to very low levels that can cause fish mortality (Glasgow& Burkholder, 2000). However, the algae-fish mortality S.R. correlation was not significant, but could be due to the fact that data was collected during daytime. DO levels are typically lowest during night time because of biota respiration (Glasgow& Burkholder, 2000). Fish mortality was highly correlated particularly to habitat parameters related to loss of habitat such as area and depth, suggesting that fish mortality could be attributed to predations and inter-species and intra-species competition as there was limited space to seek harbor from predation and also because of crowding and competition among fish (Dekar & Magoulick, 2007; Magoulick, 2000). Evidence of predation can be attributed to the discrepancy in the count of dead fish resulting from missing carcasses.

Although significant correlations between fish mortality and habitat parameters related to loss of habitat and space were expected, low correlations between other physical habitat parameters and fish mortality were unexpected. For example, although I observed a graphical relationship between fish mortality and temperature peaks and drops (Figs. 6-10), Spearman correlation between the two parameters were not significant (Table 3). The correlation results may not be an accurate representation of the system, because fish mortality was compared to the average of temperatures from loggers during the actual fish count day every two weeks. However, Fig. 6-10 more accurately represents the averages of the temperature logger data for the whole summer, including the temperature before and after the mortality fish date counts, that are not reflected in the temperature data used for S.R. correlations. Figures 6-10 demonstrates that there were several days with increases in temperature before the mortality of fish, which suggest that perhaps there was also a cumulative increase in temperature effect that may have also contributed to fish mortality.

## Limitations

The limitations of this study are primarily related to study design. For example, the timeline of data collection is limiting because it is a representation of summer and fall conditions for only one year. A more extensive and longer study might increase my ability to draw stronger conclusions about fish mortality, especially as it relates to the more sensitive and resilient species. Drought effects are difficult to study in terrestrial and aquatic ecosystems because of its unpredictability in time and because droughts develop slowly. In addition, we did not include a control site that did not dry up to compare in the study, and the number of sites was relatively low (only 5). A minimum of 20 sites and some control sites would provide better representations of the ecosystem.

In addition, predation by terrestrial animals contributed to the removal of fish carcasses that resulted in missing fish mortality data. I attempted to minimize error in death count to account for the discrepancies in the dead fish count by comparing it to previously known alive fish. Also, some error in the alive fish count was incurred as a result of low visibility of fish and inaccuracy in count. Nevertheless, the alive fish data was used to estimate the missing fish from dead count.

## Future Directions

Future research should include a larger study design using multiple streams. San Antonio Creek is relatively devoid of anthropogenic disturbances and, therefore, the results are likely optimally the consequence of summer drought, rather than other disturbances because of its Mediterranean climate. A more intensive approach with a larger scale study of multiple years, multiple streams, and also a larger dataset would be beneficial. Further studies could attempt to better explain the role that fish carcasses play in energy transfer in the aquatic-terrestrial food web.

## Broader Implications

Understanding the impacts of drought on fish ecology is a necessary goal when considering impending global warming. The occurrence and intensity of drought will increase in Mediterranean climate regions, which already experience harsh intervals of seasonal drought and flooding (Lake, 2000; Gasith & Resh, 1999). Global warming will contribute to higher fish mortality because of an increased drought disturbance and will ultimately affect fish diversity related to differences in fish tolerance to abiotic factors, especially if fish do not adapt to sudden and extreme habitat conditions (Crook et al., 2010; Dekar & Magoulick, 2007).

Other studies that examine both anthropogenic and seasonal drought may need a management approach that is specific to the local ecology of the area. Local assessments can better provide a management protocol that is sensitive to the uniqueness of the area that may not be expressed in a more generalized concept or set of expected processes.

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