Big Sur Fire Study
Winter 2008-2009

Final Report
January 19, 2010

Submitted by:

Bridget Hoover, Director
Lisa Emanuelson, Volunteer Monitoring Coordinator
Gary Conley, Water Quality Analyst

Water Quality Protection Program
Monterey Bay National Marine Sanctuary

Acknowledgements

Special thanks to the MBNMS SIMoN program for funding this study and to the volunteers who committed their time to sampling the rivers and creeks in Big Sur, CA.

Introduction

The Basin Complex forest fire was ignited in Big Sur, California by lightning strikes on June 21, 2008. The fire burned over 160,000 acres and was 100% contained on July 27, 2008. Over 460 miles of stream channel were within the burn zone[1]. The Chalk Fire began on September 27, 2008, was contained on October 30, 2008, and burned just over 16,270 acres. The watershed containing the Landels-Hill Big Creek Reserve (Control) is located between the two fires and was not burned (see Figure 1).

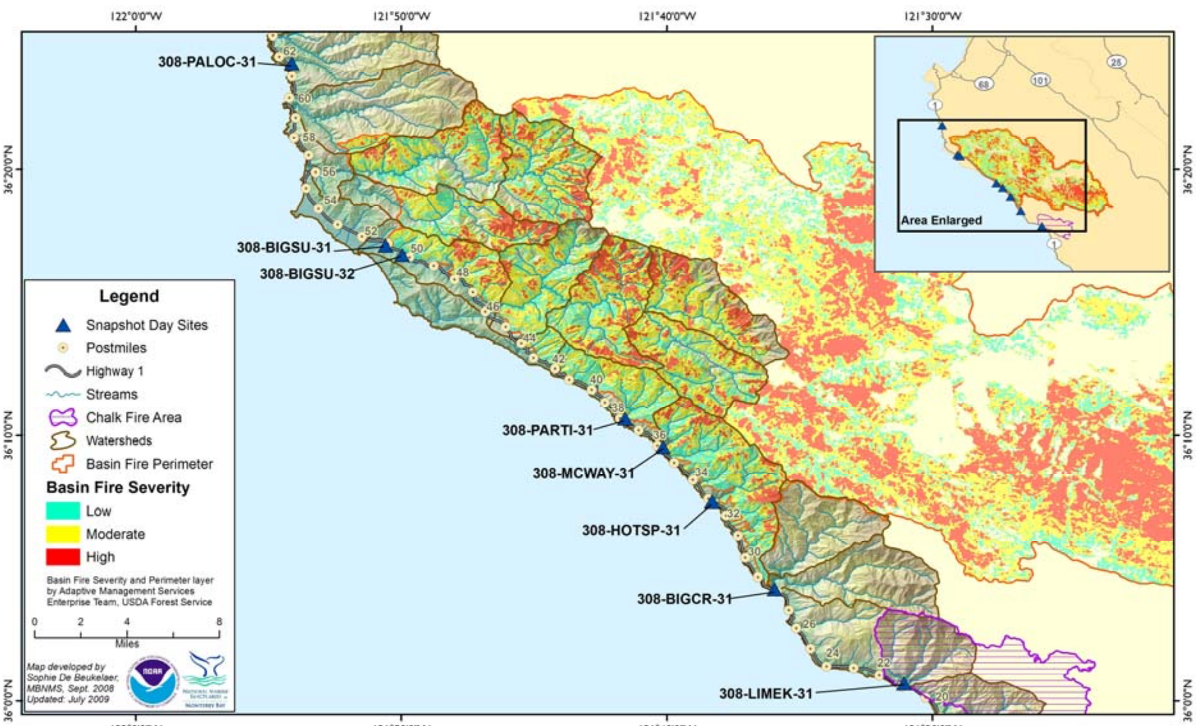


Figure 1. Burn severity map for the Basin Complex fire with monitoring sites. The Chalk fire is highlighted in pink.

Because of the severe terrain of the fire area, much of the fire suppression was conducted by air. Fire retardants were dropped from airplanes and helicopters to suppress the fire. The fire retardants used by the U.S. Forest Service contain about 85 percent water, 10 percent fertilizer, and 5 percent other ingredients: colorant (iron oxide - rust, or fugitive color that fades with exposure to sunlight), thickener (natural gum and clay), corrosion inhibitors, stabilizers, and bactericides[2]. Depending on the quantity dropped and the flow of the stream, the fertilizers may cause toxicity to aquatic organisms. Fertilizers are typically composed of specific combinations of ammonia, phosphate and nitrate.

---

[1] BAER Assessment (http://www.fs.fed.us/r5/lospadres/fire/baer/gallery/basin-indian-baer-initial.pdf)
[2] Wildland Fire Chemical products (http://www.fs.fed.us/rm/fire/wfcs/documents/envinfo.pdf)

The Monterey Bay National Marine Sanctuary's (MBNMS) Water Quality Protection Program (WQPP) has conducted water quality monitoring in the watersheds affected by the Basin Complex and Chalk Fires in Big Sur, CA for the last ten years during the annual Snapshot Day event. This study was developed to compare concentrations of nitrate-N, orthophosphate-P, total suspended solids and transparency following the wildfires with historical Snapshot Day measurements collected before the fires.

Since 2000, Snapshot Day (SSD) volunteers have convened the first Saturday of May each year to collect water quality data from over 100 water bodies entering the MBNMS (see Figure 2). This annual event has created partnerships, drawn over 1500 volunteers to date, and has helped foster an ethic of watershed stewardship in local citizens. Additionally, the ten years of data collected by volunteers has become an invaluable source of water quality data for the region. The water quality results are compared to water quality objectives for cold water fish in order to determine where beneficial uses are being attained and where effort is necessary to improve habitat and water quality conditions.

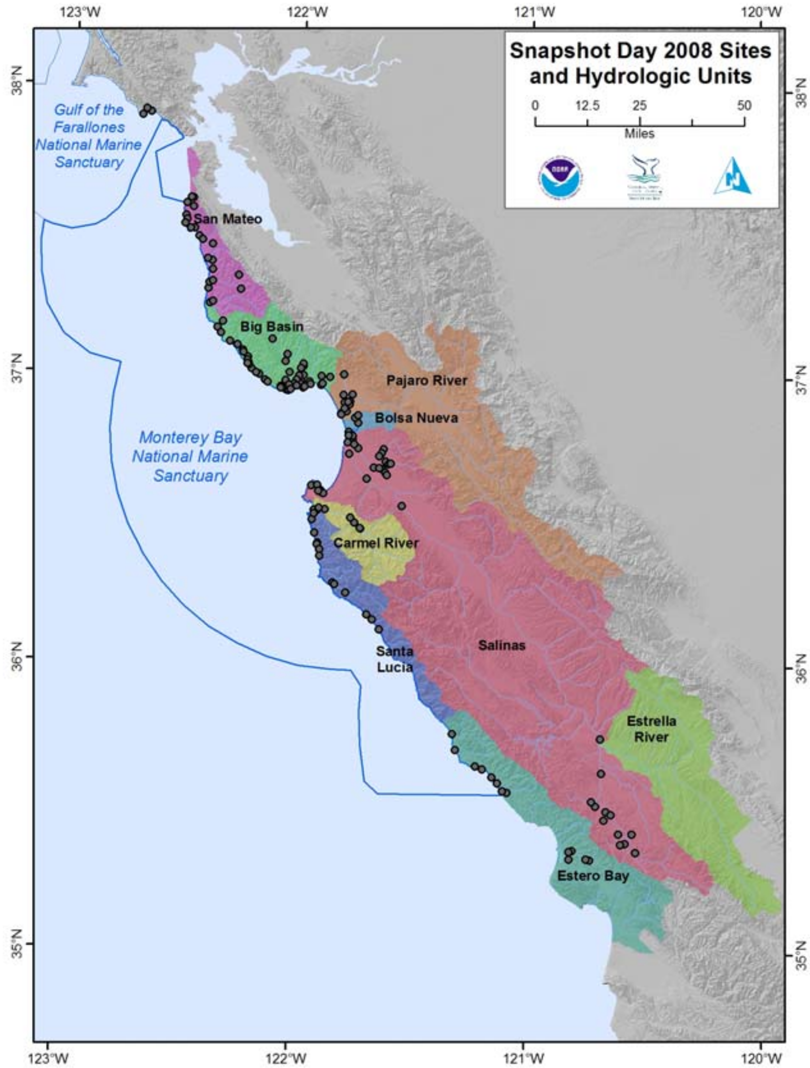


Figure 2. Map of Snapshot Day monitoring sites for 2008 event.

Water Quality Data

The 2008-2009 winter was somewhat dry for the Big Sur area. Just after the last large rain event on March 3, 2009, the Big Sur Ranger station had received a total of 29.98 inches of precipitation for the season. This was 0.24 inches less than the 2007-2008 winter and 9.0 inches less than the average annual rainfall for the area (Jeff Frey, personal communication, 3/3/09).

Monitoring was conducted seven times; three times during dry weather, and four times after rain events from September 11, 2008 to May 2, 2009. Eight stream sites were monitored during or immediately following each rainfall event. Six sites were located at the base of watersheds within the burn area and two sites were located in watersheds outside of the burn area (control watersheds); one to the north and one to the south (see Figure 1). At each location, field measurements were taken for dissolved oxygen, water temperature, conductivity, pH, and transparency. Samples were collected for analysis at a certified lab for nitrate, orthophosphate, and total suspended solids (TSS).

Figure 3. Barbara Woyt and Patty Brown monitoring at Andrew Molera State Park on the Big Sur River after first rains

For each watershed, there were 5-9 samples of each parameter collected before the fires (except for TSS which was not measured before the fires), and 4-7 samples collected after the fires. Water quality monitoring data were divided into three categories for comparison based on timing relative to the Big Sur fires and the meteorological conditions at the sampling time: pre-fire dry[3], post-fire dry[4], and post-fire wet[5]. Figures 5-8 show these data as box plots for each analyte measured in each watershed. The watersheds labeled ‘control’ are those in which fires did not occur, and data values of 0 for chemical analytes indicate that measurements were below the laboratory detection limit.

Figure 4. Looking downstream at Esalen (Hot Springs Cr) just after the first rain.

In most of the watersheds, including those not burned, the highest nitrate and the largest measurement ranges occurred during the dry post-fire period followed by the wet post-fire period. McWay canyon had the highest nitrate value of 0.70 mg/L. Nitrate concentrations were lowest and the data ranges were smallest during the dry pre-fire period for most watersheds. None of the nitrate measurements pre- or post-fire exceeded the Central Coast Ambient Monitoring Program (CCAMP) attention

---

[3] Pre-fire dry – Snapshot Day events April 22, 2000 to May 3, 2008

[4] Post-fire dry - monitored on September 11th, October 25th 2008, and May 2nd 2009

[5] Post-fire wet – monitored on November 2, 2008, February 7th, February 20th, and March 3rd, 2009

level of 2.25 mg-N/L (see Figure 5). Orthophosphate levels were highest with the greatest measurement ranges during the wet post-fire period for most watersheds. Orthophosphate measurements were usually below the detection limit during dry periods before and after the fires. Orthophosphate measurements exceeded the CCAMP attention level (0.12 mg- P/L) only once, during a rain event on March 3, 2009 at Andrew Molera State Park (see Figure 6). TSS concentrations were higher with larger ranges during wet conditions with a maximum TSS measurement of 3010 mg/L in the Andrew Molera State Park. TSS data were only available for wet and dry periods after the fires so no comparison to pre-fire data was possible (Figure 7). Transparency was lowest after the fires during wet conditions[6] (Figure 8).

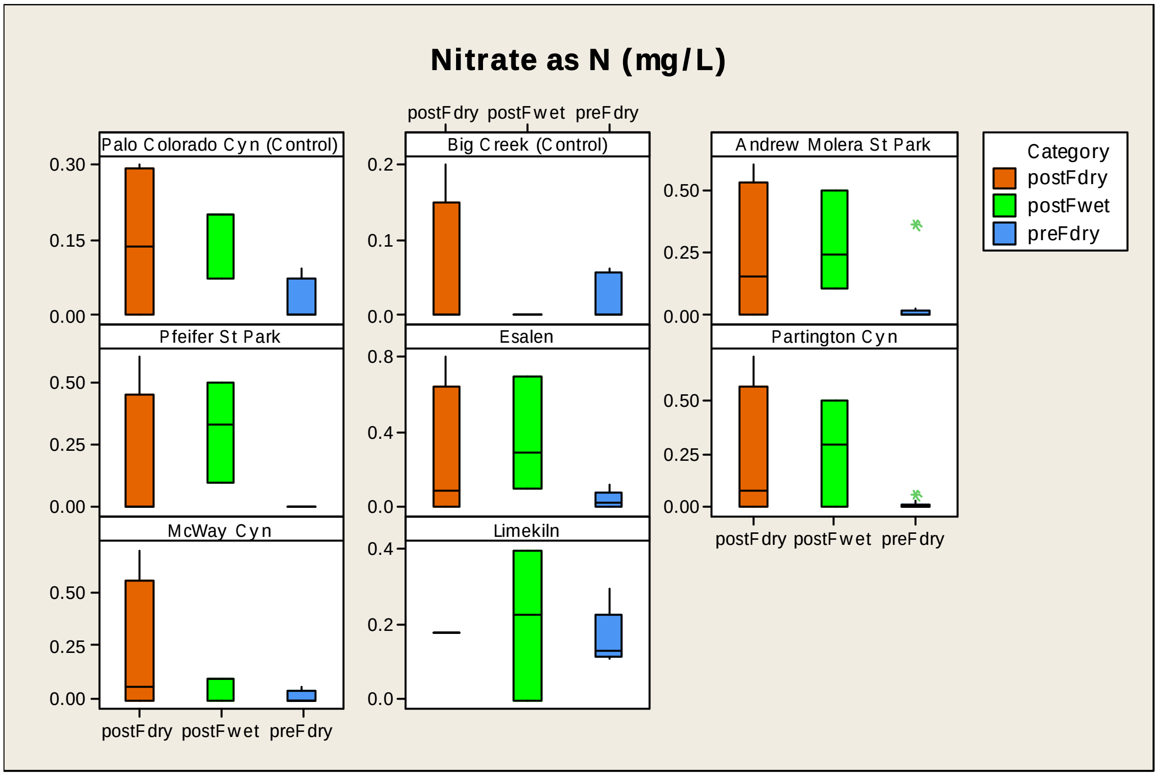


Figure 5. Nitrate concentrations in Big Sur creeks shown as box and whisker plots for each data category. None of the nitrate measurements exceeded the CCAMP attention level of 2.25 mg/L – N. The upper and lower bounds of the box denote the 25th and 75th percentiles, so that half of the concentration measurements fall within the box. The horizontal line within the box indicates the median value, the 'whiskers' (vertical lines) stretch to the 10th and 90th percentiles, and the stars are values outside of the 90th percentile value. Zero values indicate non-detects and absent data groups for certain analytes/watersheds indicate that no data were collected.

[6] Transparency is measured using a clear plastic tube, normally 120 cm long x 3.5cm wide. A stopper with a mini-Secchi disk image on its top is inserted into the tube bottom. The clearer the water, the higher the result measured in cm.

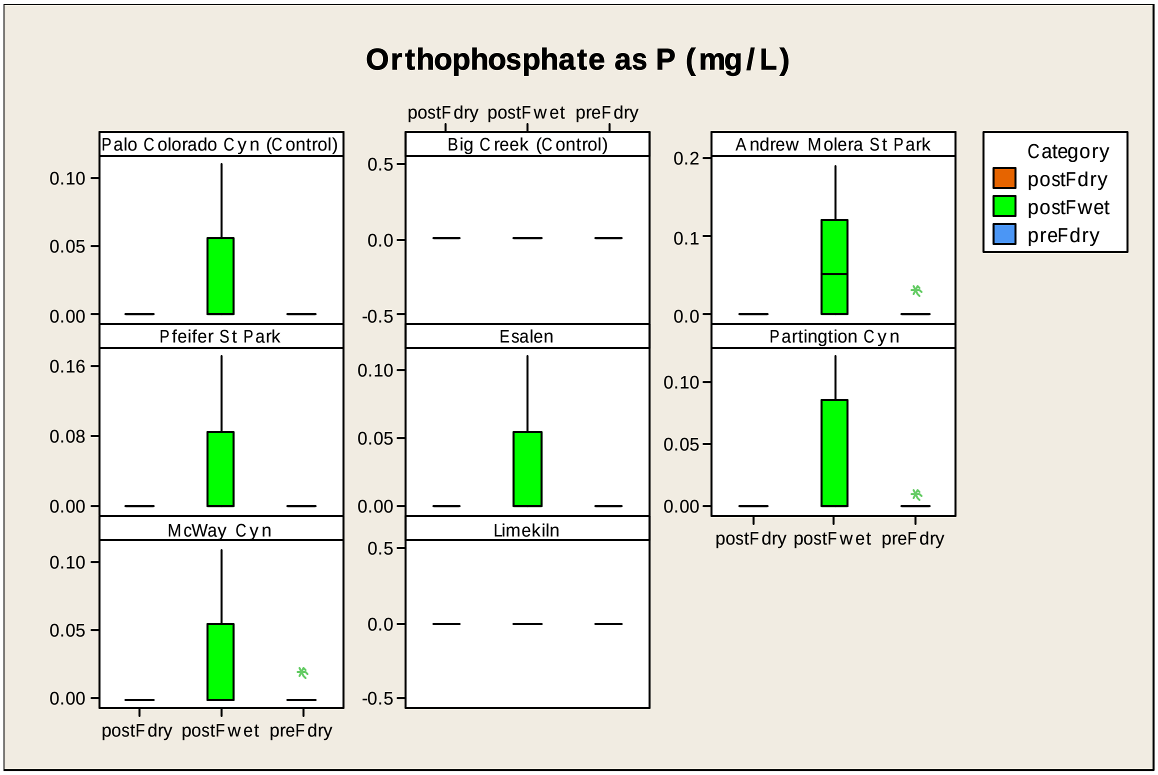


Figure 6. Orthophosphate concentrations in Big Sur creeks.

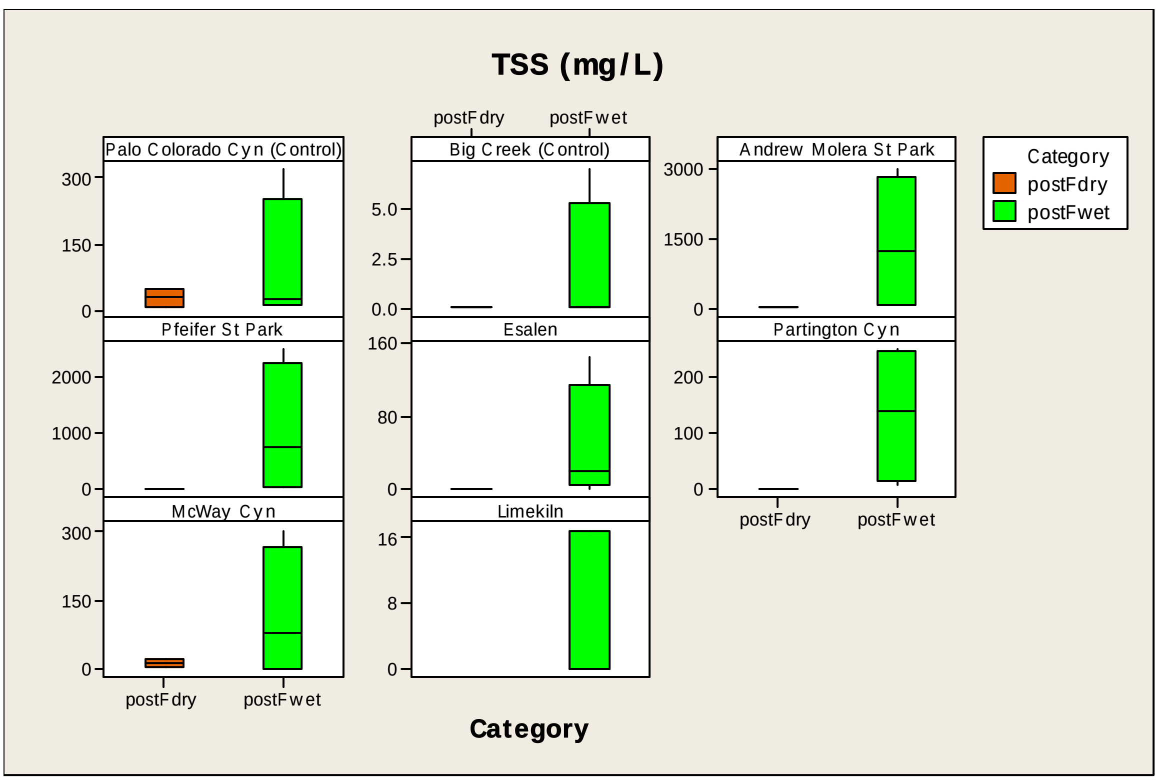


Figure 7. Total suspended solids in Big Sur creeks

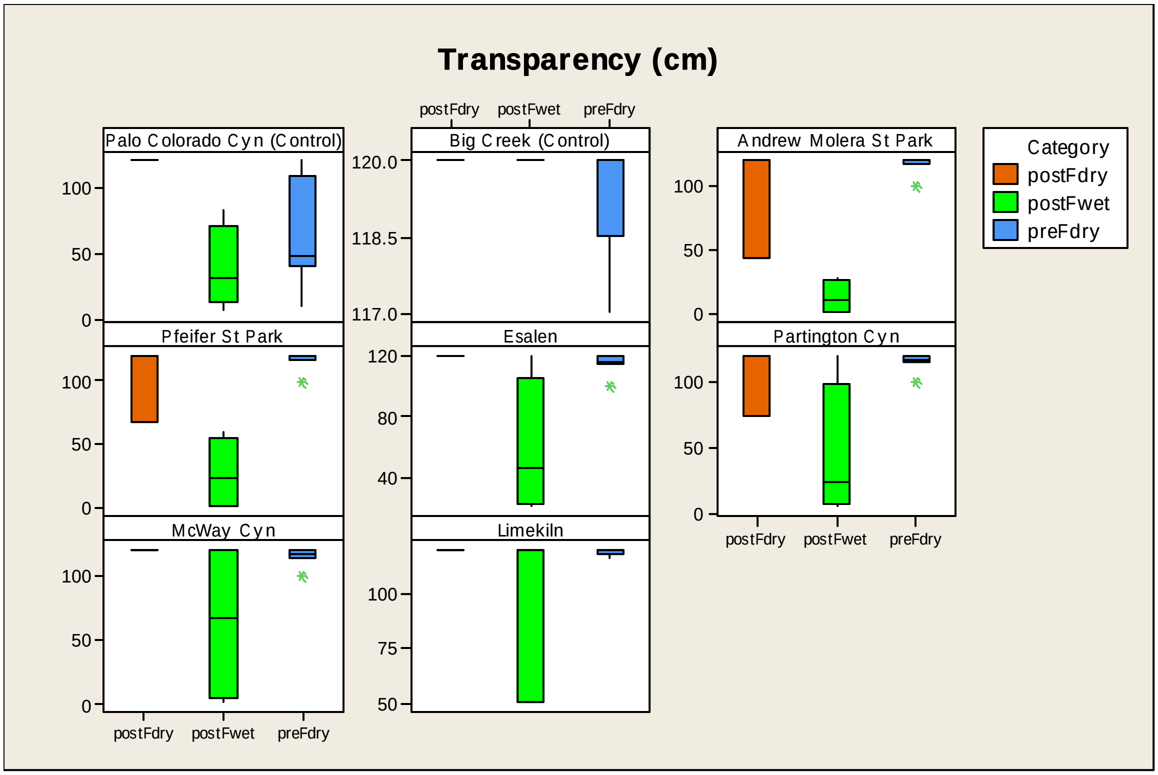


Figure 8. Transparency results in Big Sur creeks.

Statistical Approach

Two hypotheses were tested to understand how the Big Sur fires may be related to the water quality parameters measured.

1) Burned watersheds had different ambient stream nutrient and transparency levels before and after the fires.

   H0: Pre- and post-fire groups of data have identical median values, versus
   H1: At least two groups before and after the fires differ in their median values (2-sided test).

2) Control watersheds had different ambient stream nutrient and transparency levels before and after the fires.

   H0: Pre and post-fire groups of data have identical median values, versus
   H1: At least two groups before and after the fires differ in their median values (2-sided test).

Data were plotted and tested for normality to help identify the most appropriate statistical method to formally test differences between the three data groups (pre-fire dry, post-fire dry, and post-fire wet). Correct interpretation of common statistical tests for differences between data groups (e.g. t-tests or ANOVA) is dependent on assumptions of an approximately normal data distribution. The example in Figure 9 shows results from the Anderson-Darling normality test, which indicated that many of the grouped data sets had highly skewed, non-normal distributions. This result indicates that to test the hypotheses, either an attempt should be made to transform the data to a normal distribution or use a non-parametric method that doesn't depend on assumptions of normality.

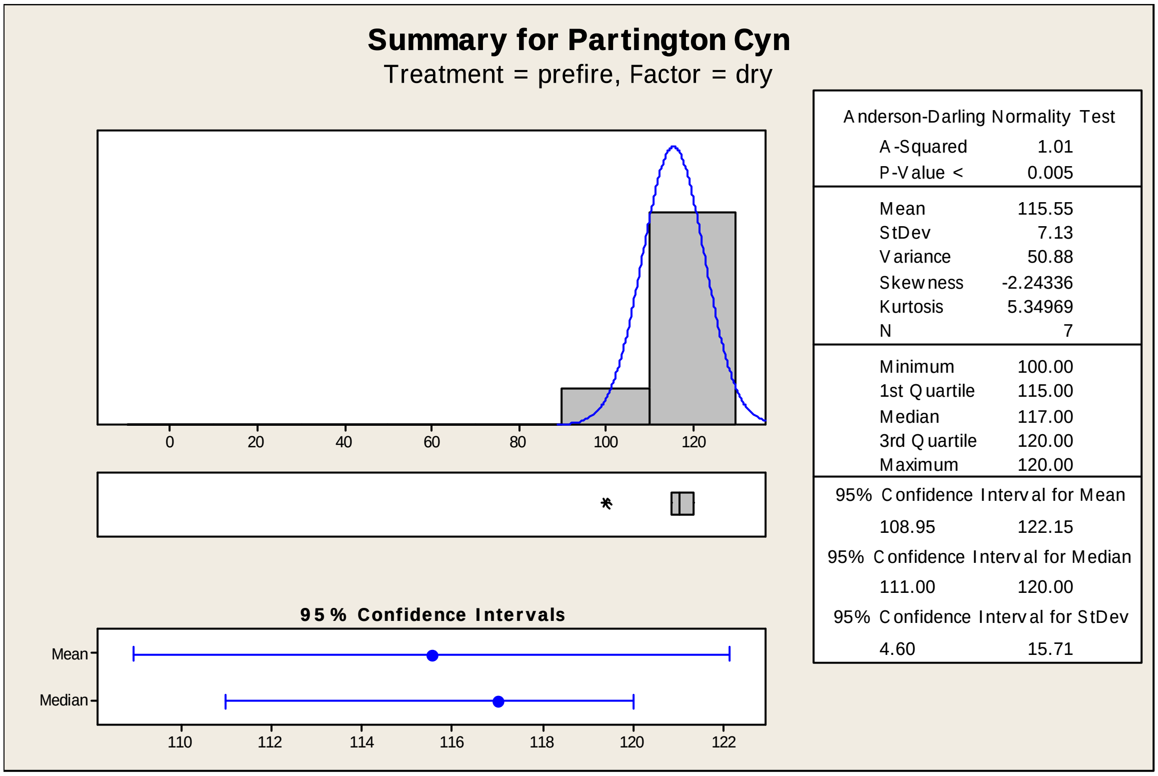


Figure 9. Anderson-Darling normality test.

Rather than attempt to transform the data, the non-parametric Kruskal-Wallis test (Helsel and Hirsch, 2002 p.159) was employed to test for differences between data groups. The Kruskal-Wallis test was implemented using a customized script written by Helsel (2008) for the MiniTab statistical package (http://www.minitab.com/en-US/default.aspx). Though the test requires no assumptions about the shape of the distributions being tested (e.g. normal, lognormal, binomial), the test does assume that data are from distributions of approximately the same shape. Using this test, if the alternate hypothesis (H1) is true, the data groups have different median ranks, indicating that the samples are likely to come from different data populations.

A family alpha level (all comparisons) of 0.05 was used in the Kruskal-Wallis test with a Bonferroni correction for multiple comparisons to yield an alpha level for each pair-wise comparison of 0.017 (98.3% confidence). The adjustment guarantees that pair-wise comparisons keep the actual probability family-wise type I errors (incorrect rejection of H0) not higher than the desired alpha level of 0.05.

Pre-Post Fire Comparison Results

Significant differences were found between data groups for nitrate and transparency before and after the fires. Nitrate and transparency showed differences between the dry pre-fire conditions and wet post-fire conditions in burned watersheds, but not between the dry pre-fire conditions and dry post-fire conditions (wet pre-fire data were unavailable). The control watersheds Palo Colorado Canyon and Big Creek, which did not burn showed no differences in nitrate, orthophosphate, or transparency before and after the fires.

In terms of the specific hypotheses that were tested:

1) Burned watersheds had different ambient stream nutrient and transparency levels before and after the fires

H0: Pre and post-fire groups of data have identical median values, versus
H1: At least two groups before and after the fires differ in their median values (2-sided test).

Reject H0 for nitrate levels in Pfeifer State Park watershed and for transparency levels in Pfeifer State Park and Andrew Molera State Park watersheds (see tables 1-3)

2) Control watersheds had different ambient stream nutrient and transparency levels before and after the fires

H0: Pre- and post-fire groups of data have identical median values, versus
H1: At least two groups before and after the fires differ in their median values (2-sided test).

Fail to reject H0 for nitrate, orthophosphate, and transparency in all watersheds (see tables 1-3).

Results are shown for comparisons of pre- and post-fire measurements in tables 1, 2, and 3 for nitrate, orthophosphate, and transparency, respectively and charts of the significant results are shown in Appendix A.

Table 1. Nitrate data group comparison results are given as p-values for the data group pairs in each watershed. P-values indicate the probability of being in error when failing to reject the null hypothesis of no difference between data groups; so that a p-value below 0.01 means that we can be more than 99% confident that median values of data groups are different from one another. A Bonferroni adjustment for multiple comparisons yields a required p-value of 0.017 for significant results in pair-wise comparisons to maintain the desired family alpha level of 0.05. Significant results are indicated by stars.

	Pre-Fire Dry vs. Post-Fire Dry	**Pre-Fire Dry vs. Post-Fire Wet**	**Post-Fire Wet vs. Post-Fire Dry**
Palo Colorado Cyn (Control)	0.260	0.062	0.458
Big Creek (Control)	0.807	0.272	0.404
Andrew Molera St Park	0.218	0.034	0.376
Pfeifer St Park	0.310	0.005*	0.086
Esalen	0.402	0.031	0.086
Partington Cyn	0.203	0.091	0.635
McWay Cyn	0.210	0.202	0.899
Limekiln	-	-	-

*** $p \leq 0.017$**

Table 2. Orthophosphate data group comparison results given as p-values. Dashes indicate insufficient data to perform the test.

	Pre-Fire Dry vs. Post-Fire Dry	**Pre-Fire Dry vs. Post-Fire Wet**	**Post-Fire Wet vs. Post-Fire Dry**
Palo Colorado Cyn (Control)	1.00	0.174	0.354
Big Creek (Control)	-	-	-
Andrew Molera St Park	0.799	0.030	0.092
Pfeifer St Park	1.00	0.174	0.355
Esalen	1.00	0.174	0.355
Partington Cyn	0.742	0.181	0.221
McWay Cyn	0.675	0.631	0.469
Limekiln	-	-	-

Table 3. Transparency data group comparison results given as p-values. Dashes indicate insufficient data to perform the test. Significant results are indicated by stars.

	Pre-Fire Dry vs. Post-Fire Dry	Pre-Fire Dry vs. Post-Fire Wet	Post-Fire Wet vs. Post-Fire Dry
Palo Colorado Cyn (Control)	0.084	0.209	0.011*
Big Creek (Control)	0.342	0.301	1.00
Andrew Molera St Park	0.931	0.005*	0.026
Pfeifer St Park	0.931	0.005*	0.026
Esalen	0.244	0.142	0.024
Partington Cyn	0.089	0.090	0.132
McWay Cyn	0.188	0.650	0.119
Limekiln	-	-	-

*** $p \leq 0.017$**

Nitrate levels differed for pre-fire and post-fire conditions in only one of the burned watersheds. The significant difference detected was between the pre-fire dry and the post-fire wet data groups in Pfeifer St. Park watershed (table 1). Nitrate levels did not change for the pre-fire dry vs. post-fire wet conditions for the unburned Palo Colorado Cyn. and Big Creek watersheds (table 1). There were no nitrate differences between data groups that were both measured after the fires in wet and dry conditions (table 1, column 3). Orthophosphate showed no significant differences between any of the data groups, although the pre-fire dry and the post-fire wet data sets in the Andrew Molera St. Park watershed had the lowest p-value (0.03) of all the comparisons (table 2). Transparency levels differed for the pre-fire dry and the post-fire wet data sets for the burned watersheds Andrew Molera St. Park and Pfeifer St. Park (table 3). One of the unburned watersheds (Palo Colorado Cyn.) showed differences between post-fire data groups (wet and dry conditions) for transparency.

Discussion of Limitations

The amount of rainfall during and preceding sampling may have been an important factor for nutrient and transparency levels in the coastal streams, since it changed the timing and volume of runoff exiting the watersheds. Association between fires and increases in storm runoff, sediment, and nutrient loading are well documented (e.g. Gameno-Garcia and Rubio, 2000).Water quality constituents may have a direct or inverse relationship with stream flow discharge, or the relationship can be more complex and depend on antecedent hydrologic conditions, land use dependent activities, and watershed characteristics (USGS, 2000). The

Figure 10. Major debris flow which occurred on November 1st at McWay Creek (looking downstream).

fact that water quality differences before and after the fires were not detected during dry conditions highlights the importance of hydrologic variability in these watersheds for understanding post-fire sediment and nutrient transport. The dry condition measurements were in the spring before the fires and in the fall after the fires. Changes in the hydrologic state of the watersheds due to different antecedent rainfall conditions during spring and fall may have obscured a water quality response in the burned watersheds.

The relatively little rainfall that occurred during the 2008-2009 winter was probably not sufficient to mobilize enough material in many of the Big Sur watersheds to create a strong water quality signal relative to background sources of variability, while others experienced dramatic sediment movement events (see figure 10). Also, the timing of sampling may have simply missed events that moved large amounts of material through the watershed, so that water quality effects were not captured in the sampling. Accounting for variability due to meteorological changes by flow adjustment of measurements or using flow as an explanatory variable in statistical tests may improve our statistical power for understanding of water quality changes in these watersheds.

A number of important landscape spatial factors were not considered explicitly in this analysis. Differences between watersheds including area, land cover, slope, aspect, drainage density, rainfall patterns, burn severity, and burn extent likely influenced the post-fire hydrologic characteristics. Big Creek may have been the more appropriate control watershed since the topography and land use more closely matched that of the burned watersheds. Palo Colorado watershed includes a substantial amount of developed landscape, while the burned watersheds and the Big Creek control watershed consist of nearly all steeply sloping shrublands. The proportion of burned area within watersheds relative to the total watershed area was another important difference from one watershed to another. We would expect to find the signal of water quality changes due to fires easier to detect in those watersheds in which a larger proportion of the area was burned. Future work should include a detailed spatial analysis of land use and watershed characteristics, along with an assessment of the proportion of burned area in each of the watershed.

Conclusions

The results presented here show changes in nitrate and transparency levels in two of the burned watersheds and no changes for unburned watersheds from before to after the fires. Since all of the significant differences before and after the fires occurred within data groups that also had different meteorological conditions (wet vs. dry), it is difficult to draw specific conclusions about relationships between the fires and water quality changes. This complication is illustrated by the significant change in transparency levels detected between post-fire wet and dry conditions measured in the unburned Palo Colorado Cyn. watershed ($p = 0.011$). However, the fact that none of the unburned watersheds showed significant differences in nutrient or transparency levels before and after the fires and two of the burned watersheds did, provides tentative evidence for the influence of fires on water quality conditions in some of the Big Sur watersheds.

The water quality measurements collected as part of this study can improve our understating of post-fire dynamics of sediment and nutrient transport out of the Big Sur coastal watersheds and into the nearshore marine environment. The measurements do not indicate nutrients or sediments are a pollution problem in these watersheds either before or after the fires when compared to the Central Coast Ambient Monitoring Program (CCAMP) attention levels. While this preliminary analysis shows water quality changes in some of the Big Sur watersheds after the 2008 fires, more meaningful conclusions will require incorporation of other pre-fire data water quality data sets and continued monitoring during the 2009-2010 winter.

References

Gimeno-Garcia, E., Andreu, V., Rubio, J.L. 2000. Change in Organic Matter, Nitrogen, Phosphorus, and Cations in Soil as a Result of Fire and Water Erosion in a Mediterranean Landscape. European Journal of Soil Science, 51:201-210.

Helsel, D.R. 2008. Applied Environmental Statistics. Course handbook. 260 pp.

Helsel, D.R., Hirsch, R.M. 2002. Statistical Methods in Water Resources. In Techniques of Water-Resources Investigations of the United States Geological Survey, Hydrologic Analysis and Interpretation. U.S. Geological Survey. 515 pp. http://water.usgs.gov/pubs/twri/twri4a3/

United States Geological Survey, 2000. Trends in Surface-Water Quality During Implementation of Best Management Practices in Mill Creek and Muddy Run Basins, Lancaster County, Pennsylvania. USGS Fact Sheet 168-99 http://pa.water.usgs.gov/reports/fs168-99.pdf

APPENDIX A. Kruskal Wallis Multiple Comparisons Charts

Charts are shown for watersheds that had significant differences between data groups (family alpha = 0.05)

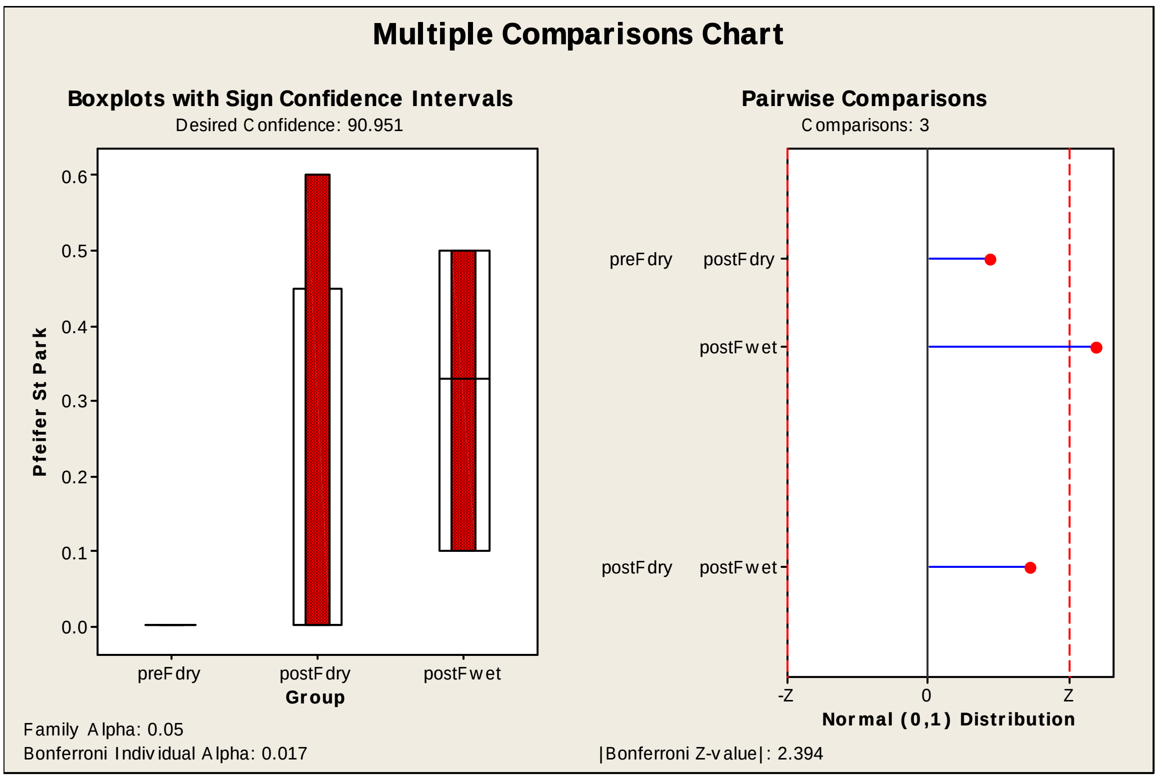
Nitrate

Pfeifer St Park

```
The following groups showed significant differences (adjusted for ties):

       Groups                  Z-value vs. Critical value   P-value

     preFdry vs. postFwet          2.82040 >= 2.394          0.0048
```



Orthophosphate

```
There were no significant group differences (adjusted for ties).
```

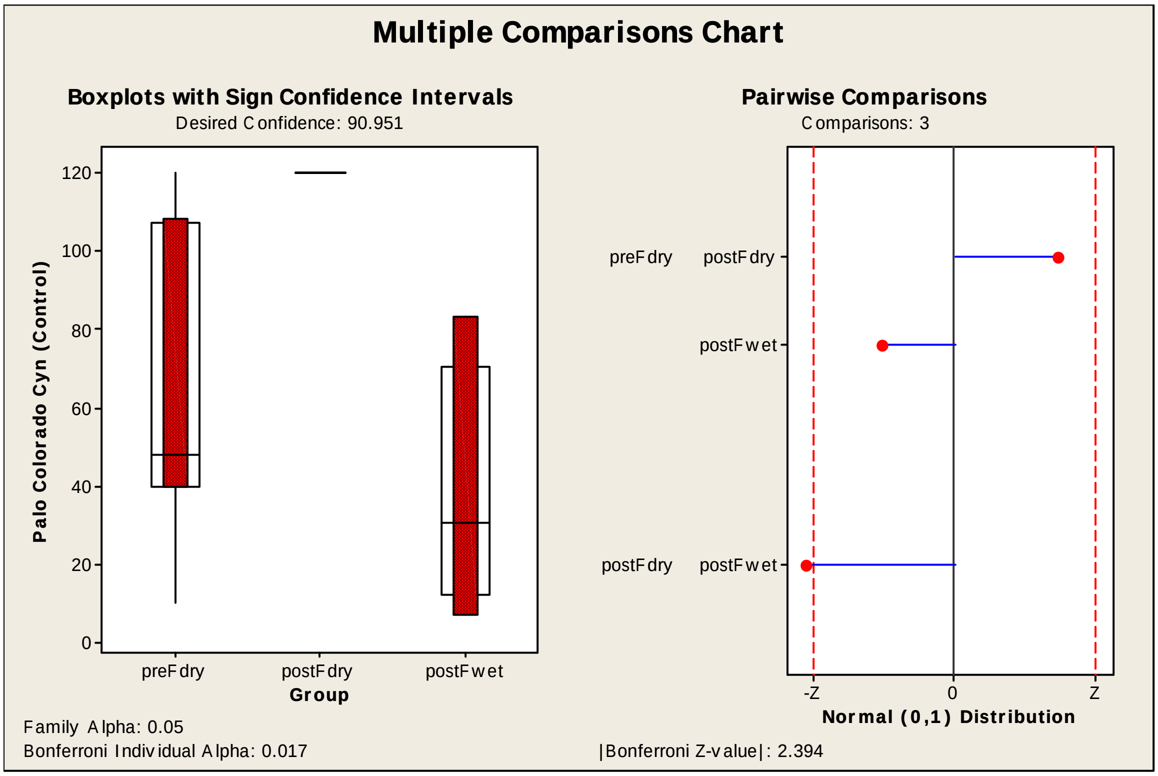
Transparency

Palo Colorado Cyn (Control)

```
The following groups showed significant differences (adjusted for ties):

        Groups                  Z-value vs. Critical value   P-value

     postFdry vs. postFwet         2.53656 >= 2.394          0.0112
```

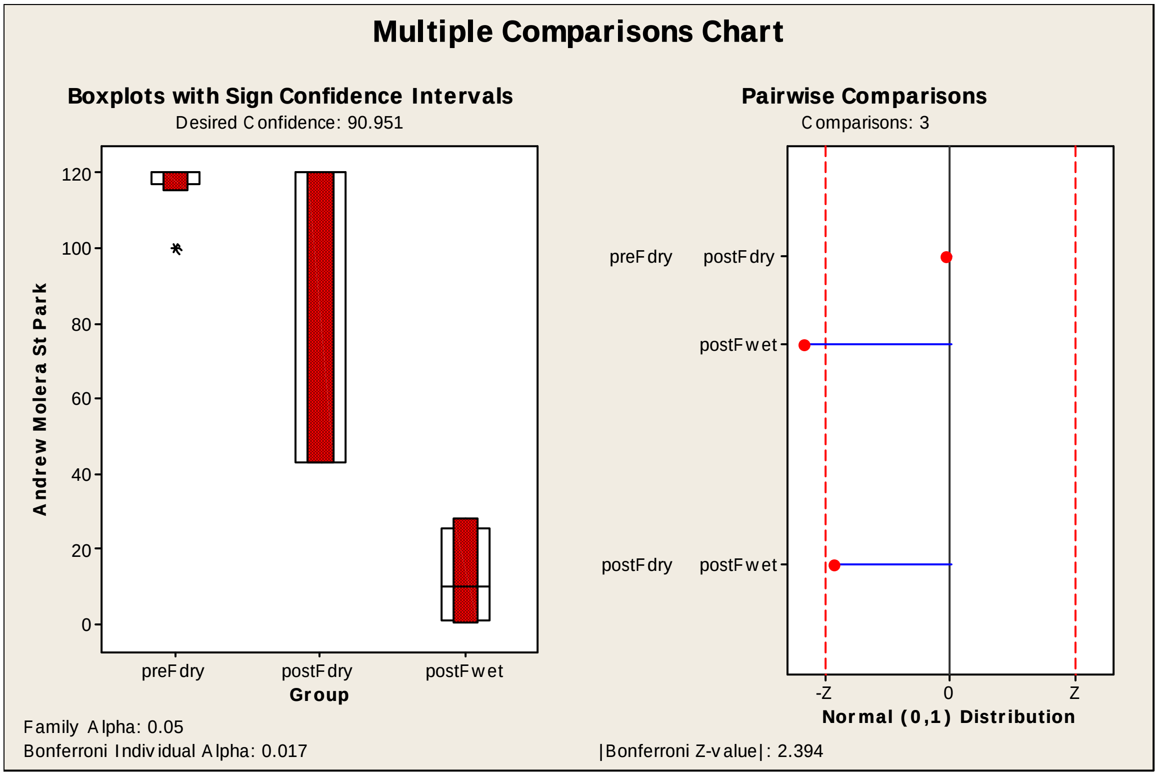


Andrew Molera St Park

```
The following groups showed significant differences (adjusted for ties):

   Groups                   Z-value vs. Critical value   P-value

  preFdry vs. postFwet          2.80706 >= 2.394          0.005
```



Pfeifer St Park

```
The following groups showed significant differences (adjusted for ties):

         Groups                    Z-value vs. Critical value    P-value

     preFdry vs. postFwet           2.82040 >= 2.394           0.0048
```