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Some observations of water quality in surface waters of the Moro Cojo Watershed, Monterey County, California

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Executive Summary

This study was conducted as part of a class project by students in the Advanced Watershed Science and Policy (ENVS660) course at California State University at Monterey Bay (CSUMB).

The Moro Cojo Slough has many water quality impairments. Tide gate failure at the downstream terminus of the slough has added the threat of increasing saltwater intrusion up the slough. We sought to monitor and determine the extent of such intrusion, as well as examine the variability of physical water quality and nutrient concentrations spatially in the slough and temporally over a 5-week period. We found that saline conditions exist in the majority of the slough. The furthest upstream grab sample site we monitored was at the Castroville Boulevard crossing near North Monterey High School, where hypersaline conditions exist. We found that nutrient concentrations are highly variable in the Moro Cojo Slough, both spatially and temporally. The Castroville Slough sampling site yielded the highest nutrient concentrations. Temperatures and dissolved oxygen values were consistent throughout the slough. Dissolved oxygen values tended to be hypoxic near the bottom of the channel, and super-saturated towards the top, which is common in this type of estuarine environment. Increased salinity could adversely affect California tiger salamander (*Ambystoma californiense*), Santa Cruz Long Toed Salamander (*Ambystoma Macrodactylum Croceum*), and *California* red-legged frog (*Rana draytonii*), and habitat, and needs to be addressed. Increased salinity can also impact farming operations in the area, which contribute substantially to the local economy.

Table of Contents

1 Introduction

1.1 Background

Wetlands provide many valuable ecosystem services including improvement of water quality, flood protection, carbon sequestration, erosion control, and important wildlife habitat (Wall 1998). Many wetlands in the United States have been lost to commercial or agricultural conversion. California has lost 91% of its original wetlands (USGS 2013). The loss of these important wetlands and their ecosystem functions has substantial consequences on the ecological health and stability of the landscape (Turner et al. 2000). Most loss of wetland habitat in California was the result of conversion to agriculture.

Monterey County's economy is largely dependent on agriculture. Nearly half of the counties jobs are related to farming or food manufacturing within the $4.4 billion agricultural sector (Monterey Farm Bureau 2015). Monterey County supplies a majority of the United States crops including strawberries, apples, broccoli, cauliflower and artichokes (City of Watsonville 2015). Given the area's agricultural importance, farmland is constantly expanding and has encroached upon the county's wetlands. Nearly 24% of the Elkhorn Watershed has become cultivated agriculture, with the most productive farms being located in the Springfield Terrace and Moro Cojo Sloughs (Elkhorn Slough Foundation 2015).

Wetlands in these regions such as Elkhorn and Moro Cojo Sloughs have served as a source of freshwater to these farms. Recent events including effects from drought conditions and the failure of the tide gates have lessened the freshwater available in the slough. The proximity of Moro Cojo to the coast and neighboring agricultural fields may result in water quality threats such as nutrient loading and seawater intrusion.

1.2 Salinity

Salinity is one of the leading factors limiting crop productivity across the United States, accounting for nearly $12 billion in costs annually (Pitman and Lauchli 2002). Increases in salinity can cause a variety of issues, with the major issue being crop yield reductions (Schwabe et al. 2006). Decline of crop yields can be extremely detrimental to Monterey County. Salinity fluctuations can be harmful to natural systems. Changes in salinity can result in shifts of plant communities and loss of biodiversity within wetlands (Neubauer 2013). An increase in saline water within Elkhorn and Moro Cojo Sloughs may have ramifications for plants and wildlife.

1.3 Nutrients

In addition to the detrimental effects of salinity, wetland health may also deteriorate due to high concentrations of nitrate, phosphate, ammonium, and silicate. The occurrence of increased nutrients often corresponds with the presence of nearby agriculture. Wetlands serve as an efficient way to mitigate excess nutrients in natural systems. However, the addition of nutrient loading from agriculture typically exceeds that ability (Mitsch and Gosselink 2000). Nitrate and phosphate components found in most fertilizers, enter wetlands through surface and subsurface runoff often resulting in eutrophication (Verhoeven et al. 2006). Ammonium is another common source of nitrogen used in fertilizers and exacerbates the rate of eutrophication in wetlands (Vymazal 2006). Additionally, silicate enters wetlands via terrestrial runoff causing an imbalance between silicate and nitrate concentrations. This imbalance can result in potential harmful algal blooms (Turner et al. 2003). The prominence of these nutrients in agriculture makes them potential threats to the Moro Cojo Slough.

1.4 Regional water quality regulation

A number of waters in the Central Coast of California (CCC) are listed as impaired (SWRCB 2010). Management of these waters is done within the legislative framework of the Clean Water Act of 1972 (CWA). §303(d) of the CWA, the Total Maximum Daily Load (TMDL) program, asks States to define beneficial uses (BUs) for waters, determine pollutant loads necessary to protect them, and list those above the target load ('impaired waters') (Houck 2002). The Moro Cojo Slough has been identified as impaired.

The Moro Cojo Slough is a part of the Lower Salinas River and Reclamation Canal Basin watershed, where widespread and localized water quality impairments of BUs exist (CCRWQCB 2013). Widespread BU impairments in this region include municipal and domestic water supply, and aquatic habitat. Localized BU impairments include agricultural supply, ground water recharge, and water contact recreation. These impairments are due to exceedance of criteria for, or imbalances of, nitrate, total nitrogen, unionized ammonia, orthophosphate, dissolved oxygen, chlorophyll-a, microcystins, and algal biomass (SWRCB 2010).

Fertilizer application on irrigated farm land is cited as the major source of pollution and water quality stressor in this region (CCRWQCB 2013). TMDLs were implemented for nitrate, orthophosphate, and unionized ammonia. The allowable nitrate load has been set at 1.4 to 6.4 mg L^{-1} between May 1 and October 31, and 8 mg L^{-1} between November 1 and April 30. Additionally, the nitrate cannot exceed 10 mg L^{-1} in all receiving waters designated as impaired for drinking water supply. The allowable orthophosphate load has been set at 0.13 to 0.7 mg L^{-1} between May 1 and October 31, and 0.3 mg L^{-1} between November 1 and April 30. The allowable unionized ammonia load has been set to not exceed 0.025 mg L^{-1} in all receiving waters (CCRWQCB 2013).

1.5 Study area

The study area is located on the CCC, encompassing the Moro Cojo Slough watershed, which contains approximately 44 km^2 (Figure 1) (CCWG and CCR 2013). The Moro Cojo Slough drains into Moss Landing Harbor where the water can migrate into the Elkhorn Slough with the incoming tide (Dr. Fred Watson, CSU Monterey Bay, pers. comm. 3/13/2015). The Moro Cojo Slough is designated as a California State

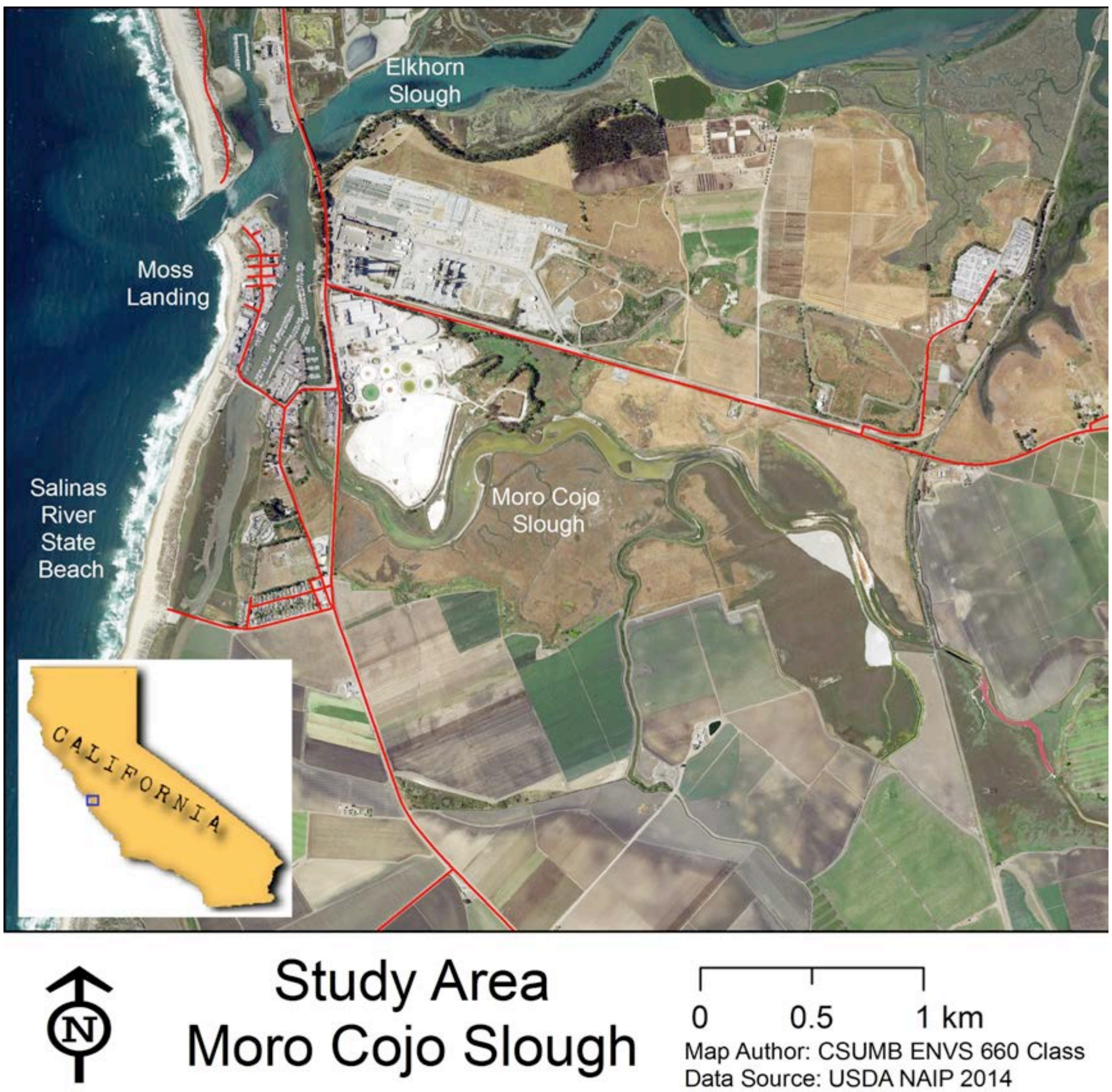

Figure 1. Moro Cojo Slough on the Central Coast of California, draining into the Elkhorn Slough and the Monterey Bay.

Marine Reserve (SMR), and the Elkhorn Slough has designated areas of State Marine Conservation Area (SMCA) and SMR (CDFW 2014). California SMRs and SMCAs are intended to conserve and protect marine habitat and marine life (CDFW 2014). The Moro Cojo Slough watershed is listed under §303(d) of the Clean Water Act (CWA) as impaired for select nutrients, pathogens, sediment, and pH (SWRCB 2010). These impairments predominantly stem from fertilizer application on irrigated crop land (CCRWQCB 2013).

1.6 Project goals

The project goals were to examine water quality in the Moro Cojo Slough focusing on nutrients and salinity, research existing historical data in the region, to inform future management steps. Our examination of the Slough might assist any mitigation efforts related to the tide gate failure and recent drought conditions.

2 Methods

2.1 Field sampling sites

We sampled from 18 sites in the Moro Cojo Slough for this study between November 1, 2015 and December 1, 2015 (Figure 2). Six of these sites were used for grab sampling, and 18 of these sites were used for salinity and grab sample transect monitoring. Data collected for this project will be used as part of Moss Landing Marine Labs long-term monitoring study.

2.2 Field sampling methods

Grab sample monitoring

We monitored MCS water quality at 6 sites G1 - G6 from November 5, 2015 to December 1, 2015 (Figure 2). We collected "grab samples" filtered through 0.2 μm filter and deposited in acid-washed nutrient bottles. Each sample was processed using a Lachat Flow Injection Analyzer. and analyzed for concentrations of PO4 (μg L^{-1}), N-NO2 (μg L^{-1}), N-NO3+NO2 (μg L^{-1}), NH4 (μg L^{-1}), and SiO2 (μg L^{-1}) (Wendt 2000). Time and temperature were also recorded at the time of sample collection.

Transect profile measurements

On November 19, 2015 we collected water quality samples above and below the halocline at the 12 locations (S1 - S12). For each location we collected grab samples filtered through 0.2 micron filters and deposited in acid-washed nutrient bottles. Each sample was processed using a Lachat Flow Injection Analyzer to determine nitrate concentration (Wendt 2000). Samples were analyzed for concentrations of phosphate (PO4 μg L^{-1}), nitrite (N-NO2 μg L^{-1}), total nitrate and nitrite (N-NO3+NO2 μg L^{-1}), ammonium (NH4 μg L^{-1}), and silicate (SiO2 μg L^{-1}).

Velocity and flow measurements

We recorded velocity measurements at sites G1 - G6 from November 5, 2015 to December 1, 2015. We collected velocity measurements at site 3 and site 6 on November 12, 2015 for computing flow measurements (Rantz 1982). At each location, we took velocity measurements with an OTT MF Pro flow meter at 60% depth of the slough channel.

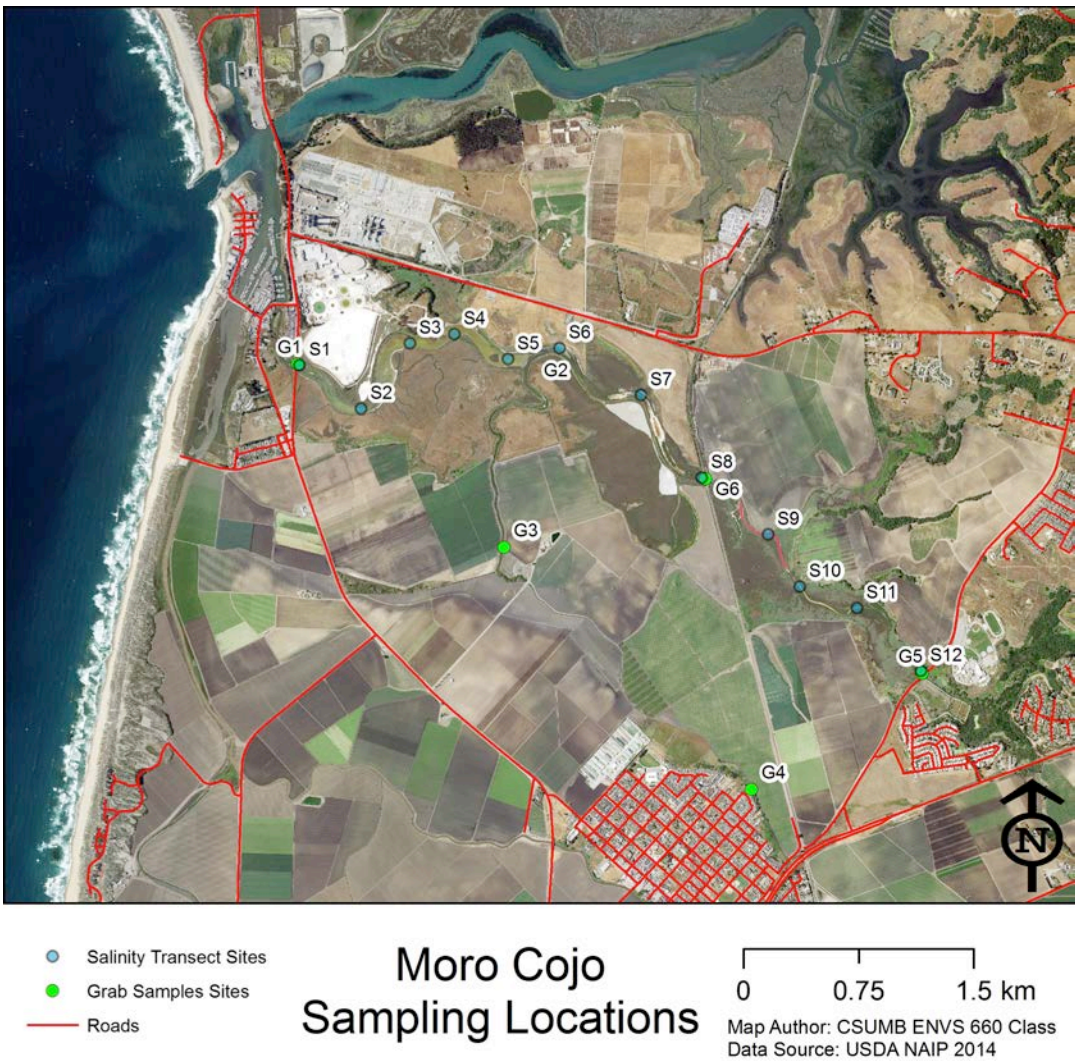

Figure 2. 18 sampling sites monitored during this study. 12 sites, S1 – S12, were used to monitor salinity and nutrients along a transect of the Moro Cojo Slough. 6 sites were used to take weekly grab samples for nutrients, and monitor flow.

3 Results

Salinity Transect

In situ measurements from the November 19, 2015 salinity transect yielded similar results throughout Moro Cojo Slough. Sites S1 through S12 have been affected by the tide gate failure, causing seawater to migrate through the entire slough (Figure 3). Each site had a shallow 0.02 m to 0.05 m layer of freshwater on top a much deeper, dense layer of saltwater (Table 1). Salinity of the saltwater layer ranged from 22.5 ppt to 37.1 ppt with the highest values being found at the upstream sampling locations. Temperature remained consistent at each site with the lowest recorded values being found on the bottom. Dissolved oxygen also followed a consistent trend throughout the slough. This trend featured lower values on the bottom with the topmost layer being supersaturated. Site 7 was an exception as the bottom produced values of 2.2 μg L^{-1} as opposed to 2.64 μg L^{-1} on the topmost layer. These low values were likely due to a pulse of suspended sediment observed at this location.

Values from nutrient samples varied between sites. Phosphate lowest value (209 μg L^{-1}) and highest value (518 μg L^{-1}) were found near each other at sites 1 and 2 respectively (Table 2). These values depicted extremes and the remaining sites typically had phosphate concentrations in the 300-400 μg L^{-1} range. Site 1 contained the highest nitrate levels at 419 μg L^{-1}. The next highest was found in the sediment pulse at site 7 (129 μg L^{-1}) and the remaining sites had relative low values ranging from 5-60 μg L^{-1}. Ammonium ranged from 15-1750 μg L^{-1} and we also measured high values from site 7. Concentrations of ammonium increased further upstream with the highest concentrations from bottom samples rather than surface samples. Silicate followed the same trend as ammonium, with concentrations increasing upstream and the surface samples yield smaller concentrations. Concentrations of silicate ranged from 1100 μg L^{-1} to 7280 μg L^{-1}.

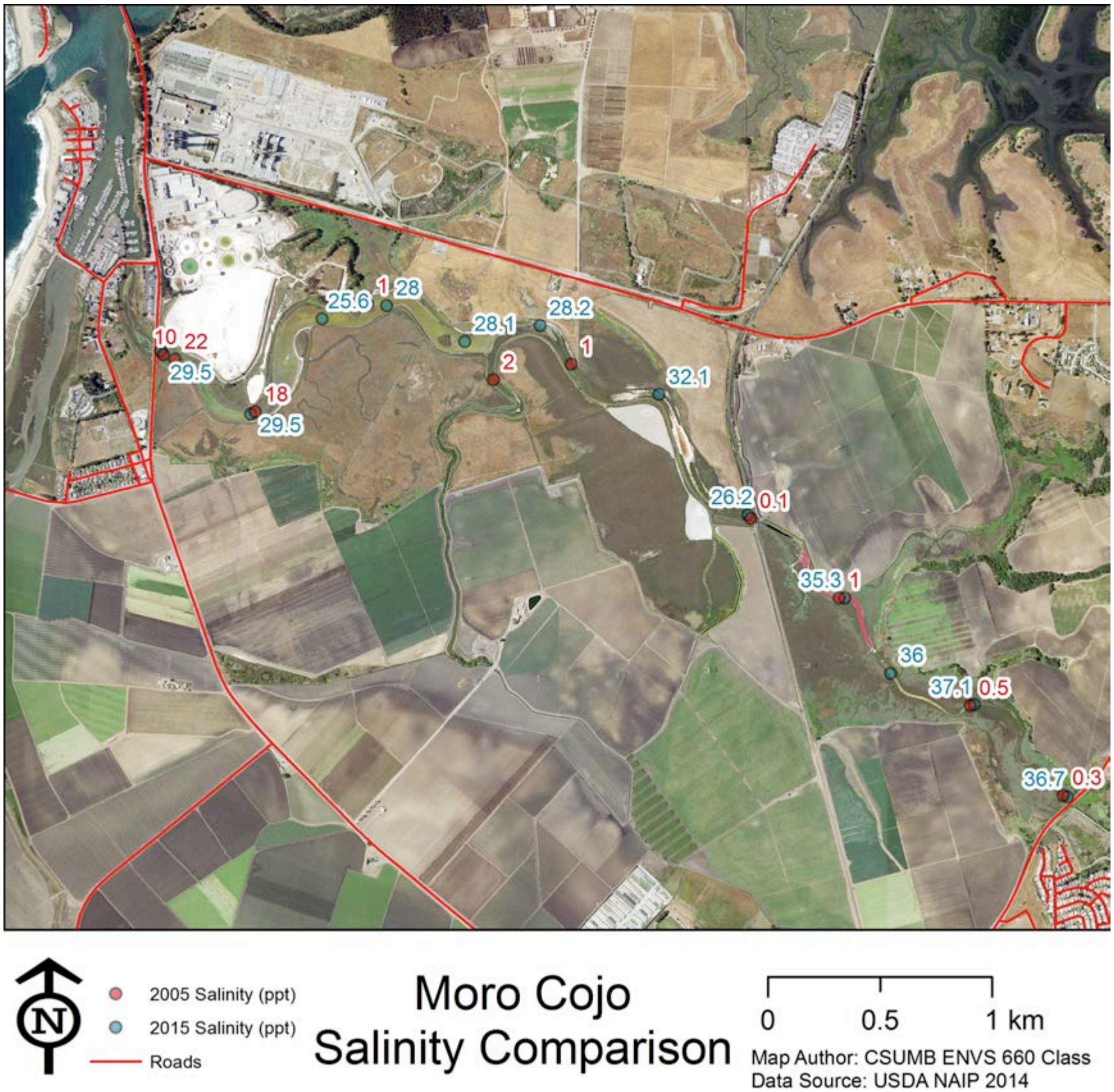

Figure 3. Salinity data taken November 19, 2015, after the tide gate failure, compared to samples taken in April 2005 (CCWG and CCR 2008).

Table 1. Depth, salinity, temperature, and dissolved oxygen values found at the surface, below the halocline, and at the bottom. In supersaturated conditions, dissolved oxygen readings were beyond the YSI reader's range. These conditions are depicted as "Over".

Site ID	Level	Depth (m)	Sal (ppt)	Temp (C)	DO (mg L^{-1})
	Surface	0.02	0.5	15.8	11.95
S1	Below HC	0.04	29.6	16	14.5
	Bottom	0.78	29.5	15.8	11.95
	Surface	0.02	0.3	17.3	Over
S2	Below HC	0.05	28.2	16.4	Over
	Bottom	0.84	29.5	16	6.51
	Surface	0.02	0.2	15.1	Over
S3	Below HC	0.05	22.5	16.3	Over
	Bottom	0.75	25.6	15.6	6.94
	Surface	0.02	0.3	15.4	Over
S4	Below HC	0.04	24.4	15.8	Over
	Bottom	0.66	28	14.7	2.97
	Surface	0.02	0.3	15.7	Over
S5	Below HC	0.04	24.1	15.6	Over
	Bottom	0.61	28.1	13.8	3.15
	Surface	0.02	0.3	14.9	Over
S6	Below HC	0.04	23.5	15.6	Over
	Bottom	0.51	28.2	13.4	3.45
	Surface	0.02	0.4	14.6	2.64
S7	Below HC	0.04	23.7	16.1	2.08
	Bottom	0.79	32.1	13.3	2.2
	Surface	0.02	0.4	14.5	11.05
S8	Below HC	0.04	25.8	14.4	8.6
	Bottom	0.6	26.2	13.4	5.02
	Surface	0.02	0.3	14.6	13.24
S9	Below HC	0.04	25.2	13.5	12.29
	Bottom	0.87	35.3	14.4	2.45
	Surface	0.02	0.3	15.3	11.61
S10	Below HC	0.04	24.3	15.1	9.65
	Bottom	0.8	36	14.9	2.86
	Surface	0.02	0.2	16	11.54
S11	Below HC	0.04	23.4	14.9	8.5
	Bottom	0.94	37.1	15.7	2.71
	Surface	0.05	0.2	15.5	10.2
S12	Below HC	0.1	20.7	13.9	8.11
	Bottom	0.8	36.7	16.5	2.04

Table 2. Results from transect grab sampling. "A" samples were taken above the halocline, while "B" samples were taken below the halocline.

Site #	Date	PO4 (μg L^{-1})	N-NO2 (μg L^{-1})	N-NO3+NO2 (μg L^{-1})	NH4 (μg L^{-1})	SiO2 (μg L^{-1})
S1, A	11/19/15	216.00	17.00	379.00	27.80	1300.00
S1, B	11/19/15	209.00	18.00	412.00	31.20	1100.00
S2, A	11/19/15	518.00	46.20	13.10	48.00	2440.00
S2, B	11/19/15	503.00	14.50	11.00	15.30	2360.00
S3, A	11/19/15	418.00	30.00	8.28	41.10	2690.00
S3, B	11/19/15	401.00	57.20	10.80	75.20	2630.00
S4, A	11/19/15	422.00	69.20	20.80	54.70	2950.00
S4, B	11/19/15	425.00	43.40	10.70	41.60	2640.00
S5, A	11/19/15	373.00	87.00	28.00	81.90	2890.00
S5, B	11/19/15	406.00	71.50	22.40	56.40	3140.00
S6, A	11/19/15	401.00	15.10	5.00	33.60	2630.00
S6, B	11/19/15	402.00	11.90	5.51	33.90	2580.00
S7, A	11/19/15	377.00	75.60	32.70	352.00	2990.00
S7, B	11/19/15	387.00	262.00	129.00	956.00	3650.00
S8, A	11/19/15	372.00	92.00	47.00	134.00	1740.00
S8, B	11/19/15	354.00	45.20	18.80	324.00	2020.00
S9, A	11/19/15	310.00	74.80	26.00	1400.00	3880.00
S9, B	11/19/15	366.00	89.40	47.80	58.30	1210.00
S10, A	11/19/15	380.00	81.70	42.30	50.30	1170.00
S10, B	11/19/15	328.00	82.40	35.20	1410.00	3570.00
S11, A	11/19/15	420.00	51.40	18.60	42.00	1170.00
S11, B	11/19/15	351.00	150.00	56.40	1400.00	4130.00
S12, A	11/19/15	368.00	117.00	52.20	147.00	1940.00
S12, B	11/19/15	442.00	359.00	56.50	1750.00	7280.00

Nutrient Sites

Grab samples collected at sites G1 through G6 typically show higher concentrations of phosphate, nitrate, ammonium, and silicate earlier in November (Table 3; Figures 4 – 6). Following a series of rain events, concentrations of these nutrients diminished. Nutrient concentrations varied between sites. Site G3 was located at the Castroville Slough, and contains freshwater due to it being unaffected by the tide gate failure. G3 consistently yielded higher nutrient concentrations. The highest nitrate value (15140 μg L^{-1}) was found at this site and vastly exceeded the highest value from a site within Moro Cojo Slough (G4; 1452 μg L^{-1}). The greatest concentration of phosphate was found upstream near a tile drain by the train tracks (G6) while the lowest concentration was found near the tide gate by Highway 1 (G1). Ammonium concentrations increased moving up the slough and ranged from 51 μg L^{-1} to 7020 μg L^{-1}. The highest ammonium concentration was found at site G6 and was more than double the second highest value. Silicate concentrations remained high in the middle of the slough, though the greatest overall value was recorded upstream at site G6 (10140 μg L^{-1}) and the lowest overall value was recorded downstream at site G1 (707 μg L^{-1}).

T-tests

Student's t-tests were run to determine presence of statistically different values in nitrate concentrations between the upstream MCS sites and the downstream MCS sites, as well as between the freshwater and the saline water in the MCS. We believed that assessing up and downstream concentrations of nitrate might asses the ability of restored wetlands in the watershed at reducing nitrate. However, we found no statistical evidence that there were nitrate differences between the up and downstream sites within the MCS (Student's t-test, n=7, p=0.22, α=0.05; Appendix). Additionally, we found no statistical evidence that there were nitrate differences between the freshwater layer and the saline layer in the MCS (Student's t-test, n=24, p=0.79, α=0.05; Appendix).

Table 3. Results from nutrient grab samples, sites G1 – G6.

Site #	Date	PO4 (μg L^{-1})	NO2 (μg L^{-1})	NO3+NO2 (μg L^{-1})	NH4 (μg L^{-1})	SiO2 (μg L^{-1})
G1	11/10/15	324	31.7	957	79.4	2750
G1	11/17/15	431	27.6	1.00E+03	132	2050
G1	12/1/15	95.1	6.67	100	111	707
G2	11/5/15	438	22.9	20.6	177	4210
G2	11/10/15	1980	52.4	77.9	69.2	6700
G2	11/17/15	511	87.8	264	56.8	2650
G2	12/1/15	479	49.3	13.9	51.2	3130
G3	11/5/15	982	668	8560	2820	5120
G3	11/12/15	1094	482	15140	1020	9140
G3	12/1/15	1536	185.6	1452	2240	7780
G4	11/10/15	134	81.9	1040	485	14190
G4	11/17/15	224	79.2	810	435	7420
G4	12/1/15	543	28.4	18.1	3040	6210
G5	11/5/15	126	18.9	13.8	631	4860
G5	11/10/15	156	47.9	315	593	3850
G5	11/17/15	150	30	40.7	774	3310
G5	12/1/15	239	173	209	1080	3830
G6	11/5/15	2300	270	990	7020	10140
G6	11/12/15	431	35.1	252	75.1	4760
G6	12/1/15	465	128	85.9	773	3830

Velocity and flow

Velocity measurements taken at sites G1 through G6 during the study period ranged from −0.067 m s^{-1} to 0.040 m s^{-1}, where positive values represent downstream river flow, and negative represent upstream river flow. Negative values could be a result of eddying, or from tidal influence. Computed river flow at site 3 on November 12, 2015 was −0.042 m^3 s^{-1}. Computed river flow at site 6 on November 12, 2015 was 0.032 m^3 s^{-1}.

Table 4. Temperature, velocity, and salinity data collected with the grab samples at sites G1 – G6.

Site #	Date	Temperature (C)	Velocity (m s^{-1})	Salinity (ppt)
G1	11/10/15	15.1	−0.065	25.9
G1	11/17/15	13.3	−0.050	22.4
G1	12/1/15	13.0	−0.067	26.0
G2	11/5/15	21.1	−0.003	23.9
G2	11/10/15	16.8	−0.015	22.1
G2	11/17/15	11.9	−0.003	22.4
G2	12/1/15	9.20	−0.024	19.9
G3	11/5/15	17.7	0.005	2.00
G3	11/12/15	12.8	See Q calc	1.60
G3	12/1/15	13.8	0.040	1.10
G4	11/10/15	16.3	0.013	0.30
G4	11/17/15	12.7	−0.009	0.30
G4	12/1/15	---	NA	---
G5	11/5/15	20.9	−0.005	32.3
G5	11/10/15	18.1	−0.007	35.2
G5	11/17/15	11.5	−0.004	22.0
G5	12/1/15	---	−0.004	---
G6	11/5/15	18.0	−0.008	28.2
G6	11/12/15	15.9	See Q calc	26.4
G6	12/1/15	10.4	−0.007	22.4

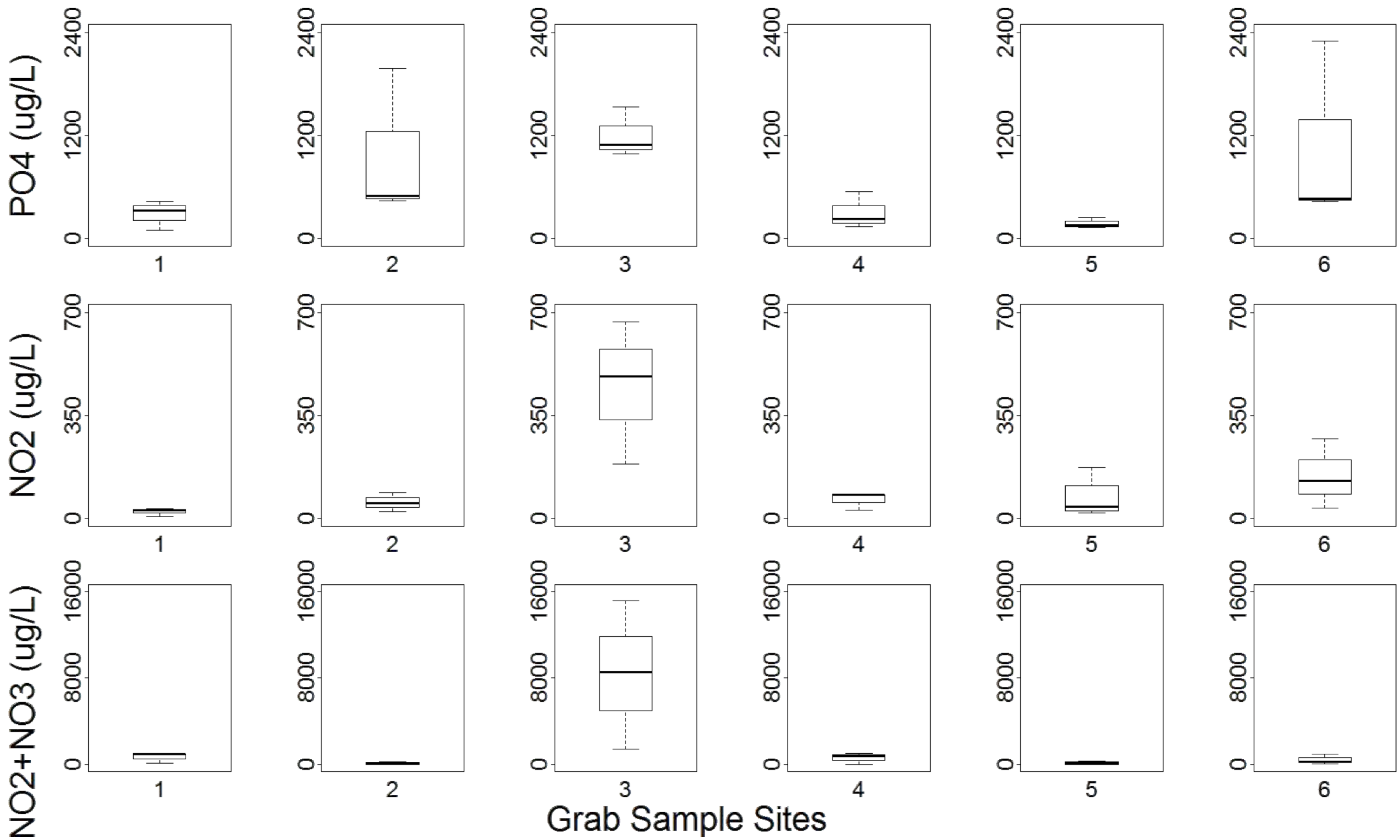

Figure 4. Phosphate, nitrite, and nitrite plus nitrate. Site 3, the downstream Castroville Slough site, had the highest values on average, though site 6, near the train trestle on the MCS, also had high values.

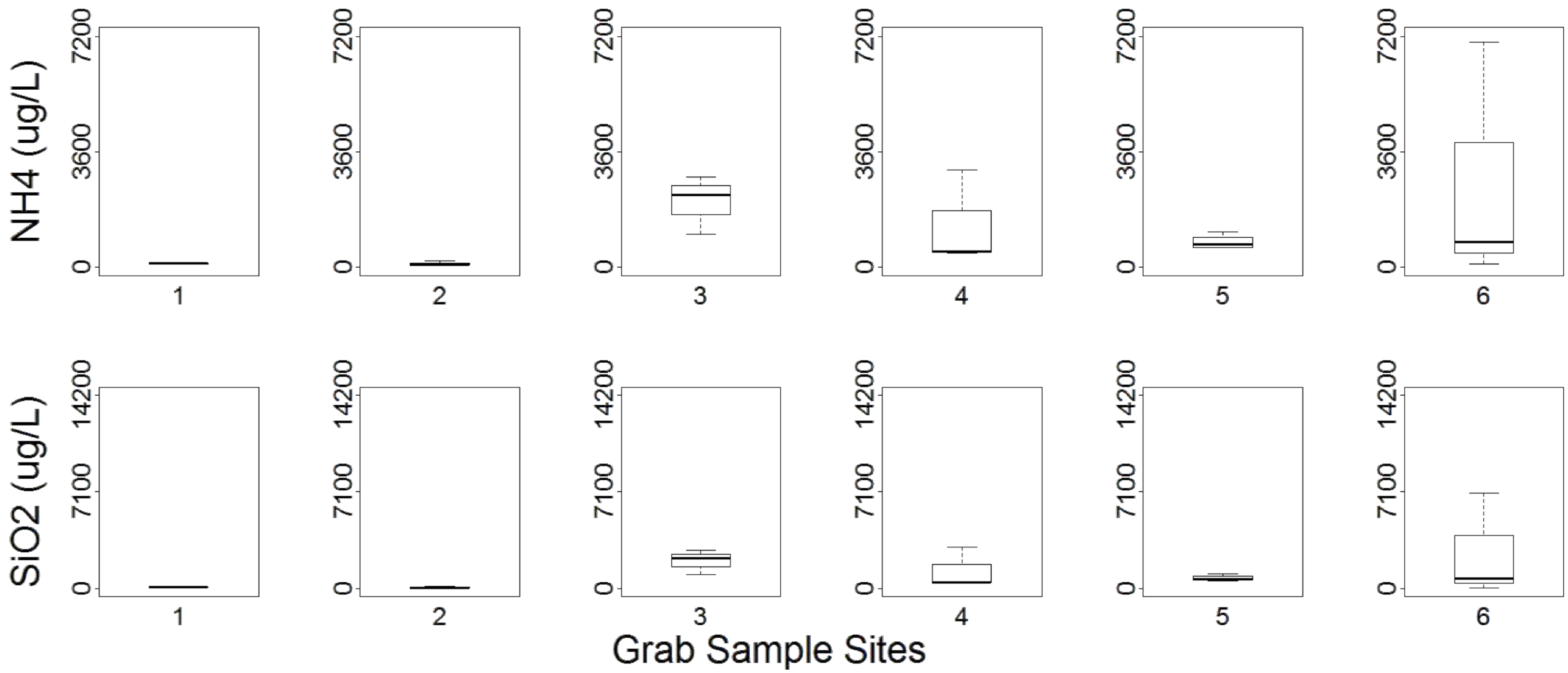

Figure 5. Ammonium and silica for all grab sample sites during the study period. Samples from site 3 and site 6 revealed the highest values for both water quality parameters.

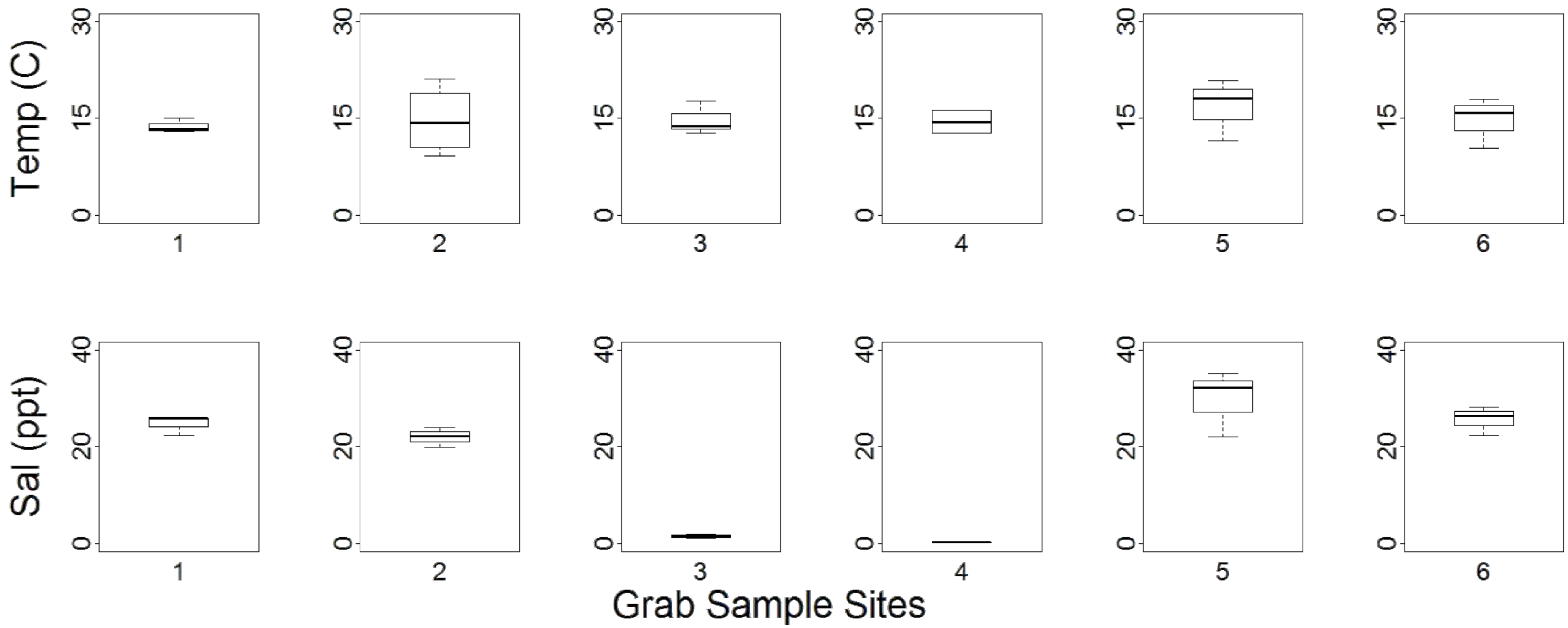

Figure 6. Temperature and salinity for all grab sample sites during the study period. Temperatures were relatively consistent for all sites. Salinity was observed in the Moro Cojo Slough, but not at either of the Castroville Slough sites. The furthest upstream Moro Cojo Slough site was hypersaline, likely due to tidal influence and lack of freshwater inflow.

4 Discussion

Salinity is currently a major problem facing the Moro Cojo Slough. Results of the salinity transect show that seawater has encroached throughout the slough, most notably seen in the 36.7 ppt salinity concentration found at the furthest upstream location. This problem stems from the tide gate failure. Without action resolving that failure, the salinity problem will persist. Should the extremely saline water continue to dominate the slough, Moro Cojo may undergo a habitat conversion into a salt marsh. This would adversely affect species which rely on the slough. The Moro Cojo provides habitat to several endangered and threatened amphibians, including California tiger salamander (*Ambystoma californiense*), California red-legged frog (*Rana draytonii*), and Santa Cruz Long Toed Salamander (*Ambystoma Macrodactylum Croceum*) and is an essential location for migratory birds (Pers. Com. Dr. Robert Burton, November 12, 2015). In addition, the damage resulting from elevated salinity may spread beyond the slough to neighboring agricultural fields, resulting in decreased crop yields.

Nutrient loading from neighboring agricultural fields is also a potential threat facing Moro Cojo Slough. High concentrations of phosphate, nitrate, ammonium, and silicate could potentially cause eutrophication within the slough. The impact of nutrient loading can be seen by site S7, which contained high nutrient concentrations along with low dissolved oxygen saturation. The extensive fertilizer use in neighboring fields is likely the cause of elevated nutrient levels create observed at site S7 which may spread throughout the slough. Additionally, we observed that adding freshwater to the system can lower nutrient concentrations, as was observed following the mid-November rain events. Drought conditions may be compounding the problem of nutrient loading in the Moro Cojo slough.

5 Conclusion

The Moro Cojo Slough is designated as impaired for a number of water quality criteria, and is currently facing the added potential impact of increasing salinity associated with the tide gate failure (CCRWQCB 2013). This report and the associated data imply that the salinity has increased in the MCS since the previous observed salinity study in 2005, and that the water at the furthest upstream end of the MCS is hypersaline. This is likely due in part to the tide gate failure and the lack of substantial amounts of freshwater influence over the past 3 years during the drought. Without these freshwater inflows, the hypersaline water can't be flushed out of the system. This increased salinity might impact organisms in the system, including federally threatened and endangered species present within the MCS.

Nutrient data from this sampling period imply that elevated nutrient concentrations occur within the entire sub-watershed; however, the highest values are in the Castroville Slough where most water contained within comes directly from field runoff. Phosphate trends showed higher concentrations upstream compared to downstream. Sampling events subsequent to rain events highlighted decreased nutrient values, which makes sense due to an increase of runoff diluting these constituents. Continued study of the restored wetlands that are present in the wetlands and their effectiveness, combined with critical fertilizer management, might assist the systemic nutrient problems in the MCS.

6 References

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7 Appendix

R code for nutrient box plots and t-tests

```
#envs 660 - module c, moro cojo slough grab sample box whisker plots and t-tests, started 12/3/2015 by a henson
rm(list=ls())
graphics.off()
#run t-test between furthest upstream (5) and furthest downstream (1) sampling points on the MCS
N_UP      = c( 13.8, 315, 40.7, 209 )
N_DN      = c( 957, 1380, 100 )
t.test( N_UP, N_DN )
#run t-test between freshwater above halocline and saltwater below in the MCS b/w sites 1 and 5
N_INSalt  = c( 412, 11, 10.7, 10.8, 22.4, 5.5, 129, 18.8, 47.8, 35.2, 56.4, 56.5 )
N_OUTSalt = c( 379, 13.1, 20.8, 8.3, 28, 5, 32.7, 47, 26, 42.3, 18.6, 52.2 )
t.test( N_INSalt, N_OUTSalt )
#create vectors for parameters and make box plots
(DAT = read.csv("ENVS660_MCSGrabSampleData_Fall2015.csv"))
PO4_1 = DAT$PO4[DAT$Sample=="1"]
PO4_2 = DAT$PO4[DAT$Sample=="2"]
PO4_3 = DAT$PO4[DAT$Sample=="3"]
PO4_4 = DAT$PO4[DAT$Sample=="4"]
PO4_5 = DAT$PO4[DAT$Sample=="5"]
PO4_6 = DAT$PO4[DAT$Sample=="6"]
NO2_1 = DAT$NO2[DAT$Sample=="1"]
NO2_2 = DAT$NO2[DAT$Sample=="2"]
NO2_3 = DAT$NO2[DAT$Sample=="3"]
NO2_4 = DAT$NO2[DAT$Sample=="4"]
NO2_5 = DAT$NO2[DAT$Sample=="5"]
NO2_6 = DAT$NO2[DAT$Sample=="6"]
NO3NO2_1 = DAT$NO3NO2[DAT$Sample=="1"]
NO3NO2_2 = DAT$NO3NO2[DAT$Sample=="2"]
NO3NO2_3 = DAT$NO3NO2[DAT$Sample=="3"]
NO3NO2_4 = DAT$NO3NO2[DAT$Sample=="4"]
NO3NO2_5 = DAT$NO3NO2[DAT$Sample=="5"]
NO3NO2_6 = DAT$NO3NO2[DAT$Sample=="6"]
NH4_1 = DAT$NH4[DAT$Sample=="1"]
NH4_2 = DAT$NH4[DAT$Sample=="2"]
NH4_3 = DAT$NH4[DAT$Sample=="3"]
NH4_4 = DAT$NH4[DAT$Sample=="4"]
NH4_5 = DAT$NH4[DAT$Sample=="5"]
NH4_6 = DAT$NH4[DAT$Sample=="6"]
SiO2_1 = DAT$SiO2[DAT$Sample=="1"]
SiO2_2 = DAT$SiO2[DAT$Sample=="2"]
SiO2_3 = DAT$SiO2[DAT$Sample=="3"]
SiO2_4 = DAT$SiO2[DAT$Sample=="4"]
SiO2_5 = DAT$SiO2[DAT$Sample=="5"]
SiO2_6 = DAT$SiO2[DAT$Sample=="6"]
Temp_1 = DAT$Temp[DAT$Sample=="1"]
Temp_2 = DAT$Temp[DAT$Sample=="2"]
Temp_3 = DAT$Temp[DAT$Sample=="3"]
Temp_4 = DAT$Temp[DAT$Sample=="4"]
Temp_5 = DAT$Temp[DAT$Sample=="5"]
Temp_6 = DAT$Temp[DAT$Sample=="6"]
Sal_1 = DAT$Sal[DAT$Sample=="1"]
Sal_2 = DAT$Sal[DAT$Sample=="2"]
Sal_3 = DAT$Sal[DAT$Sample=="3"]
Sal_4 = DAT$Sal[DAT$Sample=="4"]
Sal_5 = DAT$Sal[DAT$Sample=="5"]
Sal_6 = DAT$Sal[DAT$Sample=="6"]
```

```
windows( 20, 4 )
par( mfrow = c( 1, 6 ))
par( mai = c( 0.6, 1.7, 0.55, 0.1 ))
ylim = c( 0, 2400 )
boxplot( PO4_1, xlab = "1", ylab = "", cex.axis = 4, cex.lab = 4, ylim = ylim, yaxt = "n"  )
mtext(side=2,text = "PO4 (ug/L)",line=8,cex=4)
axis(2,at=seq(0,2400,1200),cex.axis=4)
boxplot( PO4_2, xlab = "2", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,2400,1200),cex.axis=4)
boxplot( PO4_3, xlab = "3", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,2400,1200),cex.axis=4)
boxplot( PO4_4, xlab = "4", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,2400,1200),cex.axis=4)
boxplot( PO4_5, xlab = "5", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,2400,1200),cex.axis=4)
boxplot( PO4_6, xlab = "6", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,2400,1200),cex.axis=4)
dev.copy( png, width = 2000, height = 400, 'GrabSamples_PO4.png' )
dev.off()
windows( 20, 4 )
par( mfrow = c( 1, 6 ))
par( mai = c( 0.6, 1.7, 0.55, 0.1 ))
ylim = c( 0, 700 )
boxplot( NO2_1, xlab = "1", ylab = "", cex.axis = 4, cex.lab = 4, ylim = ylim, yaxt = "n"  )
mtext(side=2,text = "NO2 (ug/L)",line=8,cex=4)
axis(2,at=seq(0,700,350),cex.axis=4)
boxplot( NO2_2, xlab = "2", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,700,350),cex.axis=4)
boxplot( NO2_3, xlab = "3", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,700,350),cex.axis=4)
boxplot( NO2_4, xlab = "4", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,700,350),cex.axis=4)
boxplot( NO2_5, xlab = "5", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,700,350),cex.axis=4)
boxplot( NO2_6, xlab = "6", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,700,350),cex.axis=4)
dev.copy( png, width = 2000, height = 400, 'GrabSamples_NO2.png' )
dev.off()
windows( 20, 4 )
par( mfrow = c( 1, 6 ))
par( mai = c( 1.3, 1.7, 0.55, 0.1 ))
ylim = c( 0, 16000 )
boxplot( NO3NO2_1, xlab = "1", ylab = "", cex.axis = 4, cex.lab = 4, ylim = ylim, yaxt = "n"  )
mtext(side=2, adj=1, text = "NO2+NO3 (ug/L)",line=8,cex=4)
mtext(side=1,at=5,text = "Grab Sample Sites",line=8,cex=4)
axis(2,at=seq(0,16000,8000),cex.axis=4)
boxplot( NO3NO2_2, xlab = "2", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,16000,8000),cex.axis=4)
boxplot( NO3NO2_3, xlab = "3", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,16000,8000),cex.axis=4)
boxplot( NO3NO2_4, xlab = "4", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,16000,8000),cex.axis=4)
boxplot( NO3NO2_5, xlab = "5", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,16000,8000),cex.axis=4)
boxplot( NO3NO2_6, xlab = "6", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,16000,8000),cex.axis=4)
dev.copy( png, width = 2000, height = 400, 'GrabSamples_NO3NO2.png' )
dev.off()
windows( 20, 4 )
par( mfrow = c( 1, 6 ))
par( mai = c( 0.6, 1.7, 0.55, 0.1 ))
ylim = c( 0, 7200 )
boxplot( NH4_1, xlab = "1", ylab = "", cex.axis = 4, cex.lab = 4, ylim = ylim, yaxt = "n"  )
mtext(side=2,text = "NH4 (ug/L)",line=8,cex=4)
```

```
#mtext(side=1,at=5,text = "Grab Sample Sites",line=8,cex=4)
axis(2,at=seq(0,7200,3600),cex.axis=4)
boxplot( NH4_2, xlab = "2", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,7200,3600),cex.axis=4)
boxplot( NH4_3, xlab = "3", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,7200,3600),cex.axis=4)
boxplot( NH4_4, xlab = "4", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,7200,3600),cex.axis=4)
boxplot( NH4_5, xlab = "5", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,7200,3600),cex.axis=4)
boxplot( NH4_6, xlab = "6", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,7200,3600),cex.axis=4)
dev.copy( png, width = 2000, height = 400, 'GrabSamples_NH4.png' )
dev.off()
windows( 20, 4 )
par( mfrow = c( 1, 6 ))
par( mai = c( 1.3, 1.7, 0.55, 0.1 ))
ylim = c( 0, 14200 )
boxplot( NH4_1, xlab = "1", ylab = "", cex.axis = 4, cex.lab = 4, ylim = ylim, yaxt = "n"  )
mtext(side=2,text = "SiO2 (ug/L)",line=8,cex=4)
mtext(side=1,at=5,text = "Grab Sample Sites",line=8,cex=4)
axis(2,at=seq(0,14200,7100),cex.axis=4)
boxplot( NH4_2, xlab = "2", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,14200,7100),cex.axis=4)
boxplot( NH4_3, xlab = "3", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,14200,7100),cex.axis=4)
boxplot( NH4_4, xlab = "4", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,14200,7100),cex.axis=4)
boxplot( NH4_5, xlab = "5", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,14200,7100),cex.axis=4)
boxplot( NH4_6, xlab = "6", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,14200,7100),cex.axis=4)
dev.copy( png, width = 2000, height = 400, 'GrabSamples_SiO2.png' )
dev.off()
windows( 20, 4 )
par( mfrow = c( 1, 6 ))
par( mai = c( 1.3, 1.7, 0.55, 0.1 ))
ylim = c( 0, 30 )
boxplot( Temp_1, xlab = "1", ylab = "", cex.axis = 4, cex.lab = 4, ylim = ylim, yaxt = "n"  )
mtext(side=2,text = "Temp (C)",line=8,cex=4)
axis(2,at=seq(0,30,15),cex.axis=4)
boxplot( Temp_2, xlab = "2", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,30,15),cex.axis=4)
boxplot( Temp_3, xlab = "3", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,30,15),cex.axis=4)
boxplot( Temp_4, xlab = "4", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,30,15),cex.axis=4)
boxplot( Temp_5, xlab = "5", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,30,15),cex.axis=4)
boxplot( Temp_6, xlab = "6", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,30,15),cex.axis=4)
dev.copy( png, width = 2000, height = 400, 'GrabSamples_Temp.png' )
dev.off()
windows( 20, 4 )
par( mfrow = c( 1, 6 ))
par( mai = c( 1.3, 1.7, 0.55, 0.1 ))
ylim = c( 0, 40 )
boxplot( Sal_1, xlab = "1", ylab = "", cex.axis = 4, cex.lab = 4, ylim = ylim, yaxt = "n"  )
mtext(side=2,text = "Sal (ppt)",line=8,cex=4)
mtext(side=1,at=5,text = "Grab Sample Sites",line=8,cex=4)
axis(2,at=seq(0,40,20),cex.axis=4)
boxplot( Sal_2, xlab = "2", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,40,20),cex.axis=4)
boxplot( Sal_3, xlab = "3", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
```

```
axis(2,at=seq(0,40,20),cex.axis=4)
boxplot( Sal_4, xlab = "4", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,40,20),cex.axis=4)
boxplot( Sal_5, xlab = "5", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,40,20),cex.axis=4)
boxplot( Sal_6, xlab = "6", cex.axis = 4, cex.lab = 4, ylim = ylim,yaxt = "n" )
axis(2,at=seq(0,40,20),cex.axis=4)
dev.copy( png, width = 2000, height = 400, 'GrabSamples_Sal.png' )
dev.off()
```