EUTROPHICATION AND NUTRIENT CYCLING IN SAN ELIJO LAGOON: A SUMMARY OF BASELINE STUDIES FOR MONITORING ORDER R9-2006-0076

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Executive Summary

The purpose of this report is to summarize the findings of a SCCWRP study conducted to support the development of a eutrophication water quality model in San Elijo Lagoon. The study included measurement of primary producer biomass, sediment and particulate nitrogen and phosphorus deposition, benthic dissolved oxygen and nitrogen (N) and phosphorus (P) fluxes, and sediment bulk and pore water N and P.

The purpose of this report is two-fold:

- Provide a summary of SCCWRP study data that will be used to develop and calibrate the water quality model for San Elijo Lagoon (the Lagoon).
- Synthesize study data to inform management actions to address eutrophication and improve the efficiency of nutrient cycling in Lagoon.

Major Findings of This Study

The Lagoon is exhibiting symptoms of eutrophication, as documented by episodes of low dissolved oxygen. Macroalgae, a key indicator for eutrophication, was present in moderate amounts. Episodes of low DO and macroalgal biomass were that were highest the year of the 2008 TMDL field study relative to the Bight '08 Eutrophication Assessment (2008-2009).

- Dissolved oxygen concentrations found to be below 5 mg L^{-1} about 1 - 18% of the wintertime and 62 - 42% of the summertime at Segments 1 and 2 respectively during the 2008 TMDL field studies. This trend was repeated at Segment 1 the following year during the Bight study (5% winter versus 44% summer), but at a lower percentage than the previous year. Hypoxia (<2 mg L^{-1}) was more prevalent annually at Segment 2 (15%) versus Segment 1 (1%).

- Estimates of biomass and percent cover of macroalgae were moderate with averages of 251 g wet wt m^{-2} over the fall 2008 field studies and cover up to 67%. No established framework exists to assess adverse effects from by macroalgae, though a recent review (Fong *et al*. 2011) found studies documenting adverse effects of macroalgae on benthic infauna as low as 700 g wet wt m^{-2} and with cover greater than 30 - 70%. Dissolved oxygen concentrations measured during the Bight '08 study at Segment 1 site showed surface waters to be below 5 mg^{-1} about 19% of the wintertime and 23% of the summertime.

During the wet season (Nov-April), terrestrial TN and TP loads were the dominant source of nutrients to surface waters, but during the dry season benthic ammonium and SRP flux dominated measured sources to surface waters and provide nutrients in excess of that required to grow the abundance of macroalgae measured in the estuary. Three types of data are used to support this finding:

- With respect to relative sources, terrestrial TN and TP input overwhelmed all other sources[1] during the wet season (Nov-April), but during the summer and fall estimated terrestrial input

[1] The net exchange of groundwater is unknown.

only represented 25 and 6% of TN and TP loads to the surface waters respectively. Direct atmospheric deposition is a negligible source. In contrast, benthic flux ranged acted as a sink for about a large percentage of the terrestrial N during the winter index period but then became a dominant source of N and P during the summer and fall (>75%), the periods of peak primary producer biomass.

- Mixing diagrams show a source of dry season SRP and ammonium sources to the estuary which is not accounted for by measured terrestrial input from the mass emission station. Lateral inputs of groundwater or runoff from Orilla Creek are contributing an unquantified source of nutrients to the estuary.
- During peak periods of macroalgal blooms, benthic fluxes of ammonium and SRP are 10X the N and 5X the P required to grow the abundance of macroalgae observed. Macroalgae is an efficient trap for dissolved inorganic nutrients and can even increase the net flux by increasing the concentration gradient between sediments and surface. The storage of large quantities of N and P as algal biomass thus diverts loss from denitrification and burial and providing a mechanism for nutrient retention and recycling within the estuary.

The patterns of ammonium and nitrate fluxes suggest that denitrification (loss of nitrate to N gas) may be playing a large role during the winter and spring time when sediments are better flushed and oxygenated but that dissimilatory nitrate reduction (DNR), the conversion of nitrate to ammonium under anoxic sediment conditions, is clearly a dominant pathway during the summer time and is likely responsible for some portion of the large fluxes of ammonium observed during these periods. Thus in the winter and spring, the Lagoon is better able to assimilate external dissolved inorganic nitrogen (DIN) inputs through denitrification, but will be more likely to retain N inputs during the summer and fall as DNR-derived ammonium is incorporated into algal biomass and to some degree retained within the estuary.

Management Options to Reduce Eutrophication

Preliminary nutrient budgets for San Elijo Lagoon illustrate that internal recycling of N and P has a more important role than terrestrial runoff during peak periods of productivity. While exchange with the ocean is not well quantified and a great deal of uncertainty in these budgets exists, the relative magnitude of these inputs is not likely to change this conclusion. Sediment data indicate that the Lagoon has accumulated a large amount of organic matter in the sediments. Because benthic flux is the major source of N to the Lagoon, recycling of this organic matter to biologically available forms of nutrients will likely continue to cause problems with algal blooms and hypoxia, even with nutrient reductions, unless restoration is undertaken to flush the Lagoon of the fine-grained sediments and improve circulation.

Given the findings of this study, the following options for management of eutrophication in the Lagoon should be considered:

- Increase flushing and circulation within the Lagoon to decrease detention of fine-grain sediments and decrease water residence time. Restoration options which favor intertidal habitats over subtidal habitats will be an advantage over subtidal habitat, which will tend to plagued by hypoxia.

- Reduce terrestrial loads from the watershed, with emphasis on detention of fine-grained particles before it reaches the Slough. Emphasis should be placed on reducing both phosphorus as well as nitrogen from the watershed.

Disclosure

Funding for this project has been provided in full or in part through an agreement with the State Water Resources Control Board. The contents of this document do not necessarily reflect the views and policies of the State Water Resources Control Board, nor does mention of trade names or commercial products constitute endorsement or recommendation for use." (Gov. Code 7550, 40 CFR 31.20)

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1 Introduction

1.1 Background and Purpose of Report

San Elijo Lagoon (the Lagoon) is a 126 ha acre estuary located within the southern portion of the city of Encinitas in San Diego County, California. The Lagoon is part of a 400 acre reserve of estuarine, freshwater, riparian and upland open space habitat that supports a large number of functional habitats and wildlife, including populations of federally- or state-listed endangered species such as the Light Footed Clapper Rail, Willow Flycatcher, California Gnatcatcher, Western Snowy Plover, and Belding's Savannah Sparrow. The Lagoon drains the Escondido Creek watershed, which encompassed 200 km^2 and drains through two main tributaries: Escondido Creek and Orilla Creek. Urban and agricultural land uses in the watershed resulted in hydrological modifications to the Lagoon and have led to increased nutrient loading to the estuary.

Increased nutrient loads are known to fuel the productivity of primary producers such as macroalgae in the Lagoon, in a process known as eutrophication. Eutrophication is defined as the increase in the rate of supply and/or *in situ* production of organic matter (from aquatic plants) in a water body. While these primary producers are important in estuarine nutrient cycling and food web dynamics [Boyer, et al., 2004; Kwak and Zedler, 1997; Mayer, 1967; McGlathery, 2001; Pregnall and Rudy, 1985], their excessive abundance can reduce the habitat quality of a system. Increased primary production can lead to depletion of dissolved oxygen (DO) from the water column causing hypoxia (low O_2) or anoxia (no O_2; [Camargo and Alonso, 2006; Diaz and Rosenberg, 2008; Valiela, et al., 2002]), which can be extremely stressful to resident organisms. An overabundance of macroalgae or phytoplankton can also shade out or smother other primary producers and reduce benthic habitat quality through the stimulation of sulfide (S^{-2}) and ammonium (NH_4) production (Diaz 2001).

As a result of excessive algal abundance and low DO, the Lagoon was placed on the State Water Resources Control Board's (SWRCB) 303(d) list of impaired waterbodies. In order to establish Total Maximum Daily Loads (TMDL) of nutrients to the estuary, the San Diego Regional Water Quality Control Board (SDRWQCB) issued a Monitoring Order (R9-2006-0076) requiring stakeholders to collect data necessary to develop watershed loading and estuarine water quality models. Lagoon stakeholders contracted with MACTEC Inc. to collect data on nutrient loading, estuarine hydrology, and ambient sediment and water quality to address the requirements of Investigation Order R9-2006-0076. The Southern California Coastal Water Research Project (SCCWRP), Louisiana State University (LSU) and University of California Los Angeles (UCLA), supported by a Prop 50 grant from the State Water Resources Control Board (SWRCB), conducted studies to aid model development including monitoring of primary producer biomass, measurement of sediment and particulate nitrogen (N) and phosphorus (P) deposition, measurement of benthic DO and nutrient fluxes, and sediment bulk and porewater nutrients. During October 2007 through October 2008, SCCWRP and MACTEC conducted field studies to collect the necessary data.

The purpose of this report is two-fold:

- Provide a summary of SCCWRP study data that will be used to develop and calibrate the water quality model for the Lagoon.
- Synthesize study data to inform management actions to address eutrophication and improve the efficiency of nutrient cycling in the Lagoon.

Studies were conducted in order to address the following research objectives:

- Characterize the seasonal trends in surface water ambient nutrient concentrations, sediment solid phase and porewater nutrients, and primary producer communities.
- Estimate the seasonal and long-term annual deposition of sediments and particulate nutrients to the Lagoon
- Characterize the seasonal trends in N and P exchange between Lagoon sediments and surface waters (benthic nutrient flux).
- Assess the efficiency of nutrient cycling in the Lagoon by estimating, to the extent possible, N and P budgets.

1.2 Report Organization

This report is organized into an executive summary and four chapters:

Executive Summary

Chapter 1: Introduction, purpose, and organization of report, site description, and general study design

Chapter 2: Seasonal trends in Lagoon surface water and sediment nutrients and primary producer communities

Chapter 3: Seasonal trends in exchange of nutrients between surface waters and sediments

Chapter 4: Lagoon Nitrogen and Phosphorus Budgets

A summary of quality assurance results is provided in Appendix 1. Appendix 2 provides the data tables for summarized SCCWRP study data (as a complement to graphs used to present the data in Chapters 2 - 5) to facilitate use of data for modeling.

1.3 Site Description

The Lagoon is located of the 200 km^2 Escondido Creek Watershed in the southern edge of the City of Encinitas in San Diego County, California. Fifty-three percent of the estuarine habitat is dominated by mudflats, 38% by salt panes and salt marsh habitat, with the remaining 9% as subtidal habitat. It is divided into the Western, Central and Eastern basins by Highway 101, the railway, and Interstate 5 respectively. The lagoon is an intermittently tidal coastal lagoon whose inlet closes during winter storm swells. The San Elijo Lagoon Conservancy, which manages the Lagoon, has an endowment to dredge the inlet in the spring in order to maintain the mouth open to tidal flushing.

The primary source of freshwater input into the estuary is surface flow from the Escondido and Orilla Creeks, though ancillary freshwater input for the estuary comes from runoff and ground seepage. Analysis of land use in the watershed shows that urban areas cover approximately 44% of the watershed, while rural residential and agriculture encompass 15 and 10% respectively. The remaining is open or vacant space. Nutrient sources appear to be predominantly from the watershed and include agriculture, nursery operations, municipal wastewater discharges, urban runoff, septic systems, and golf course operations. Agriculture is found on the northern uplands of the eastern basin and drains into the eastern basin via a storm drain, so additional nutrient loading from infiltration and groundwater discharge into the estuary are also possible.

1.4 General Study Design

The general study design for all monitoring conducted to support TMDL modeling is based on a basic conceptual model developed to describe the sources, losses, and transformations of targeted constituents within the San Elijo Lagoon (McLaughlin *et al.* 2007). The three principal types of monitoring were conducted:

1. Continuous monitoring of hydrodynamic and core water quality parameters (salinity, temperature, etc.);
2. Wet weather monitoring, which was conducted during and immediately following a specified number of storm events at the mass emission (ME) site in the main tributary, targeted locations in the lagoon, and at the ocean inlet; and
3. Dry weather monitoring, which was conducted during "index" periods that were meant to capture representative seasonal cycles of physical forcing and biological activity in the estuary. During each index period, sampling was conducted at the ME site and the ocean inlet site, as well as two segment sites within the Lagoon. In the San Elijo Lagoon, the Ocean Inlet site represents the lower portion of the Lagoon, while the Segment sites one and two grade upward toward the upper estuary of the Lagoon.

In general, stakeholder monitoring was intended to cover: 1) continuous monitoring of hydrodynamic and core water quality parameters, 2) all wet weather monitoring, and 3) dry weather ambient monitoring of surface water nutrient concentrations within the lagoon and at points of exchange between the lagoon and the ocean inlet and watershed freshwater flows (ME site).

SCCWRP studies collected three types of data: 1) estimates of nutrients associated with sediments and primary producer biomass to complement stakeholder sampling during dry weather index periods, 2) measurements of key rates of exchange or transformation within or among sediments and surface waters, and 3) rates of net sediment and particulate N and P deposition to support sediment transport and estuary water quality modeling.

Sampling to develop the dataset occurred during four index periods in one year (Table 1.1). Each index period represents seasonal variations in the estuary: Storm season (January 2008), post-storm/pre-algal bloom (March 2008), high algal bloom (July 2008), and post-algal bloom/pre-storm (September 2008).

This sampling design aimed to provide a means to examine annual variability in estuary processes affecting nutrient availability and cycling. SCCWRP sampling was coordinated to coincide with stakeholder monitoring of dry weather ambient water quality (WestonSolutions 2009). Figure 1.1 summarizes the sampling locations for the different types of monitoring studies in San Elijo Lagoon.

Table 1.1. Summary of the different sampling activities in San Elijo Lagoon by time period, types of sampling event, organization and actual dates sampling occurred.

Period	Event	Organization	Date
Wet Weather Monitoring	Storm Sampling (3 storm events)	MACTEC	1/5-1/7/08 1/23-1/24/08 2/3-2/4/08
Wet Weather Monitoring	Post Storm Sediment Sampling	MACTEC	1/15/08
Continuous Monitoring	Water Quality Monitoring	MACTEC	1/1/08-10/23/08
Interim Period	Sediment Deposition	LSU	11/15/07
Interim Period	Sediment Deposition	LSU	12/13/07
Index Period 1	Ambient Sampling	MACTEC	1/14-1/16/08, 2/7- 2/8, 2/11/08
	Transect Sampling	MACTEC	1/15/08
	Benthic Chamber Study- SEG 1	SCCWRP	1/14/08
	Benthic Chamber Study- SEG 2	SCCWRP	1/15/08
	Porewater Peeper Deployment	SCCWRP	1/7-1/23/08
	Sediment Core	SCCWRP	1/23/08
	Macroalgae Monitoring	UCLA	1/22/08
	Sediment Deposition	LSU	1/23/08
Interim Period	Sediment Deposition	LSU	2/28/08
Index Period 2	Ambient Sampling	MACTEC	3/24-3/26/08, 3/31-4/1/08, 4/7/08
	Transect Sampling	MACTEC	3/26/08
	Benthic Chamber Study- SEG 1	SCCWRP	3/26/08
	Benthic Chamber Study- SEG 2	SCCWRP	3/27/08
	Porewater Peeper Deployment	SCCWRP	3/18-4/3/08
	Sediment Core	SCCWRP	4/3/08
	Macroalgae Monitoring	UCLA	4/11/08
	Sediment Deposition	LSU	4/3/08
Interim Period	Sediment Deposition	LSU	5/15/08
Index Period 3	Ambient Sampling	MACTEC	7/7-7/9/08, 7/14-7/16/08
	Transect Sampling	MACTEC	7/7/08
	Benthic Chamber Study- SEG 1	SCCWRP	7/8/08
	Benthic Chamber Study- SEG 2	SCCWRP	7/9/08
	Porewater Peeper Deployment	SCCWRP	7/3-7/23/08
	Sediment Core	SCCWRP	7/23/08
	Macroalgae Monitoring	UCLA	7/21/08
	Sediment Deposition	LSU	7/23/08
Interim Period	Sediment Deposition	LSU	8/20/08

Table 1.1. Continued

Period	Event	Organization	Date
Index Period 4	Ambient Sampling	MACTEC	9/22-9/24/08, 10/1-10/3/08
	Transect Sampling	MACTEC	9/24/08
	Benthic Chamber Study- SEG 1	SCCWRP	9/24/08
	Benthic Chamber Study- SEG 2	SCCWRP	9/25/08
	Porewater Peeper Deployment	SCCWRP	9/12-9/30/08
	Sediment Core	SCCWRP	9/30/08
	Macroalgae Monitoring	UCLA	9/29/08
	Sediment Deposition	LSU	9/30/08

Figure 1.1. Location of sampling activities in San Elijo Lagoon.

2 Patterns in Surface Water and Sediment Nutrients and Primary Producer Communities in the San Elijo Lagoon

2.1 Introduction

All estuaries exhibit distinct temporal and spatial patterns in hydrology, water quality and biology that are integral to the ecological services and beneficial uses they provide (Day *et al.* 1989, Loneragan and Bunn 1999, Caffrey 2004, Rountree and Able 2007, Shervette and Gelwick 2008, Granek *et al.* 2010). Characterization of seasonal and spatial patterns in surface water and sediment nutrient concentrations and aquatic primary producer communities provides valuable information about the sources, dominant transport mechanisms, and fate of nutrients in the San Elijo Lagoon and helps to generate hypotheses regarding the controls on biological response to nutrients.

The purpose of this chapter is to present a baseline characterization of the patterns in surface water and sediment nutrients and aquatic primary producers in San Elijo Lagoon. This work forms the foundation for interpretation of sediment porewaters and benthic fluxes (Chapter 3) and characterizing the efficiency of nutrient cycling through N and P budgets for the Lagoon (Chapter 4).

2.2 Methods

The following types of field data were collected and methods are explained in detail in this section:

- Longitudinal and seasonal trends in surface water ambient nutrient concentrations, conducted in conjunction with MACTEC
- Seasonal trends in aquatic primary producer biomass and/or percent cover and tissue nutrient content
- Seasonal variation in sediment bulk characteristics (grain size, solid phase N and P content)

A detailed presentation of the intent and field, analytical, and data analysis methods associated with each of these data types follows below.

When appropriate, ambient water quality data collected and analyzed by MACTEC are incorporated into the results and discussion. These data are cited when used and for a detailed explanation of methods, see MACTEC (2009).

2.2.1 Field Methods

2.2.1.1 Surface Water Nitrogen and Phosphorus along a Longitudinal Gradient

Longitudinal transects of surface water nutrient concentrations provide valuable spatial information about how concentrations vary along a gradient from the freshwater source to the ocean (or in this case river) end-member.

Surface water samples were collected by MACTEC at 18 sites along a longitudinal gradient of the San Elijo Lagoon (Figure 1.1; MACTEC 2009). Longitudinal transect sampling occurred on the fourth day of the first week of each index period. Transect sampling was performed using kayaks and grab-sampling techniques. Sampling occurred in the tidal channels and samples were collected once at ebb tide and once at flood tide.

The sample bottle was triple rinsed before filling completely. Sample bottles were open and closed under water to avoid contamination with surface films or stratified water masses. One liter sample bottles were returned to the shore for immediate filtering where appropriate. Ambient water samples were subsampled for a suite of analytes using a clean, 60 ml syringe. Each syringe was triple rinsed with sample water. Mixed cellulose ester (MCE) filters were used for nutrient analysis and polyethersulfone (PES) filters were used for dissolved organic carbon (DOC) and metals analysis. Each filter was rinsed with ~20 ml of sample water (discarded) before collection into vials.

2.2.1.2 Inventory of Aquatic Primary Producer Cover and Tissue Content

Aquatic primary producer communities include macroalgal and cyanobacteria mats, benthic algal mats, suspended phytoplankton, and submerged aquatic vegetation. The purpose of this study element was to characterize seasonal variation in the standing biomass, cover, and the tissue nutrient content of these communities. This information will be used to calibrate the component of the eutrophication water quality model that accounts for the storage and transformation of nutrients in primary producer community biomass.

Aquatic primary producer biomass was measured during the four index periods at Lagoon segment sites. At these sites, intertidal macroalgae were sampled along a 30 m transect parallel to the waterline and one meter down-slope from the vascular vegetation. Macroalgal abundance was determined by measuring percent cover and algal biomass; including both attached and detached mats. At five randomly chosen points along each transect, a 0.25 m^2 quadrat with 36 evenly spaced intercepts (forming a 6 x 6 grid) was placed on the benthos. The presence or absence of each macroalgal species in the top layer under each intercept was recorded. When present, algae were collected from a 530.9 cm^2 area circumscribed by a plastic cylinder placed on the benthos in the center of each quadrat. Each sample was placed in an individual ziplock bag in a cooler, transported to the laboratory and refrigerated. Algal samples were transferred to low nutrient seawater where they were cleaned of macroscopic debris, mud and animals. For each sample, algae were placed in a nylon mesh bag, spun in a salad spinner for one minute, wet weighed, rinsed briefly in deionized water to remove salts, and dried at 60° C to a constant weight. Macroalgal biomass was normalized to area (g wet wt m^{-2}). Fine macroalgal filaments that grow within the sediment may be visible but biomass cannot be collected quantitatively at this early growth stage, making percent cover in this case a more sensitive measurement. In addition, when there is 100% cover, and mats are different thicknesses, biomass will be a more useful measure to make distinctions between sites (Sfriso *et al.* 1987). Thus it is important to use both methods to estimate abundance. Samples were cleaned and weighed to determine wet and dry weights. Dried samples were analyzed for percent organic carbon (OC), percent organic N and percent P.

2.2.1.3 Sediment Bulk Characteristics and Solid Phase Nutrients

All sediments carry nutrients, either as organic matter or, in the case of P, associated with particles. When deposited in the estuary, these particulate nutrients may break down to biologically available forms and may build up in high concentrations in sediment porewaters. Sediment bulk characteristics control nutrient content; finer particle size fractions are associated with higher OC, N and P content (Sutula et al. 2006).

The purpose of this study element was to characterize the inventories of nutrients associated with sediments. Specifically, this involved measurement of the sediment solid phase bulk characteristics (grain size, porosity, etc.) and sediment OC, N and P concentrations.

Sediment bulk characteristics and solid phase nutrient concentrations were estimated for a vertical profile in one sediment core taken from each segment site per index period. For each sampling period, one sediment core was taken and vertically sectioned on site into 1 cm intervals from the sediment water interface until 6 cm depth and then sectioned every 2 cm down to 12 cm. Sediments were placed in plastic storage bags and stored on ice in the dark until they reached the laboratory. In the lab, sections were wet weighed, dried at 50 °C to a constant weight, and reweighed to determine percent solids and wet bulk density. A subsample of each section (~10 grams dry weight) was removed and ground to a fine powder for percent organic carbon, percent total nitrogen (TN) and percent total phosphorus (TP) analysis. The remainder of the section was utilized for grain size analysis (percent fines).

2.2.2 Analytical Methods

All water samples were assayed by flow injection analysis for dissolved inorganic nutrients using a Lachat Instruments QuikChem 8000 autoanalyzer for the analysis of ammonium (NH_4), nitrate (NO_3), nitrite (NO_2), and soluble reactive phosphate (SRP). Dissolved iron (Fe) and manganese (Mn) were measured by atomic adsorption spectrophotometry on a Varian Instruments AA400. Water samples were assessed for total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), total nitrogen (TN) and total phosphorus (TP) via two-step process: first water samples undergo a persulfate digest to convert all N from all N compartments into NO_3 and the P from all P compartments into orthophosphate; then the resulting digests are analyzed by automated colorimetry (Alpkem or Technicon) for nitrate-N and orthophosphate-P (Koroleff 1985). Water DOC was analyzed on a Shimadzu TOC-5000A Total Organic Carbon Analyzer with ASI-5000A Auto Sampler. Water total carbon dioxide (TCO_2) was analyzed on a UIC instruments carbon dioxide (CO_2) coulometer. Inorganic nutrients were run by the Marine Science Institute at the University of California, Santa Barbara and total dissolved and total nitrogen and phosphorus were run at the University of Georgia Analytical Chemistry Laboratory.

Dried sediment samples were subsampled and ground for analysis of percent organic carbon (%OC), percent total nitrogen (%TN), and percent total phosphorus (%TP). Samples for %OC were acidified to remove carbonates; %OC and %TN were measured by high temperature combustion on a Control Equipment Corp CEC 440HA elemental analyzer at the Marine Science Institute, Santa Barbara. Sediment

%TP were prepared using and acid persulfate digest to convert all P to orthophosphate, which was then analyzed by automated colorimetry (Technicon) at the University of Georgia Analytical Chemistry Laboratory.

To determine percent fines, a portion of sediment from each interval was weighed dry (total dry weight), then wet sieved through a 63 µm sieve, dried at 50 °C to a constant weight, and reweighed as sand dry weight. Percent sand was calculated as a function of the sand dry weight divided by the total dry weight of the sample. Percent fines were calculated as the total weight minus the percent sand.

2.2.3 Data Analysis

Analysis of variance (ANOVA) tests were used to test for differences in concentration by index period and, where relevant, by ebb and flood tide (SAS Proc GLM, 2008). Data were transformed to correct for unequal variance and mean and standard errors were generated from Tukey's pairwise comparisons.

Standing biomass of aquatic primary producers groups (phytoplankton, macroalgae, microphytobenthos, and cyanobacteria mats) were converted to carbon per meter squared in order to make comparisons among the groups. The following assumptions were used in this conversion:

- Phytoplankton- Average 1.5 m depth of water, Chl a: C ratio of 30 (Cloern *et al.* 1995)
- MPB – Chl a: C ratio of 30:1 (Sundbäck and McGlathery 2005)
- Cyanobacteria: 50% C by dry wt (study data)
- Macroalgae: 22% C by dry wt (study data)

Porosity, fractions of water and sediment, and wet bulk density were used to estimate seasonal and annual sediment deposition rates and to evaluate changes in sediment nutrient and radioisotope inventories. These values are calculated from parameters measured in the laboratory.

The difference between wet and dry weights was used to calculate the fraction water (f_{wet}) and fraction sediment (f_{dry}):

$$f_{wet} = \frac{W_{wet} - W_{dry}}{W_{wet}}$$

$$f_{dry} = 1 - f_{wet}$$

Eq. 2.1, 2.2

where W_{wet} and W_{dry} are the wet and dry sediment weights, respectively. Subsequently, when enough sample was present, a small known fraction of the initial dried sample was weighed, and dry grain density was determined gravimetrically using Archimedes principle, *i.e.,*by volume displacement. The weighed sediment divided by the displaced volume yielded the dry grain density of each sediment core sample section. The dry grain density and fractions wet and dry were used in turn to calculate the porosity and bulk density. Often the shallowest sections of the cores did not contain enough material for a complete sediment physical properties analysis. We took extra cores near the end of the project to complete any missing sediment physical property data needed for future calculations. Porosity is a measure of the amount of "empty space" in the sediment, defined by the ratio of the volume of voids to the total volume of a rock or unconsolidated material. Porosity was calculated using the following equation:

$$\phi = \frac{\frac{f_{wet}}{\rho_{water}}}{\frac{f_{wet}}{\rho_{water}} - \frac{f_{dry}}{\rho_{drygrain}}} \qquad \textbf{Eq. 2.3}$$

where ϕ is the porosity; ρ_{water} and $\rho_{drygrain}$ are the density of ambient water and dry sediment grains, respectively. Bulk density, $\rho_{wetbulk}$ or $\rho_{drybulk}$, was calculated based on the total mass of each core section divided by the core section interval volume. Thus both a wet and a dry bulk sediment density could be determined on deeper samples more often when a larger mass of sample was available for the different analyses. Wet bulk density (ρ in g cm^{-3}) is given by the Equation 2.4.

$$\rho = \frac{W_{SEDwet\,(i)}}{V_i} \qquad \textbf{Eq. 2.4}$$

Where $W_{SEDwet\,(i)}$ is the wet weight of each sediment core section interval and V is the volume of the sediment core section interval.

2.3 Results

2.3.1 Seasonal and spatial trends in physiochemical parameters and nutrients

Water quality and primary producer biomass would be expected to change as a function of estuary hydrology, salinity, pH and temperature. Figure 2.2 shows Lagoon water level, salinity and DO at Segment 1 (at I-5 Bridge) as a function of freshwater flow into the estuary during the 2008 field study. During the period of January-April 2008), freshwater base flow at the mass emission station averaged 35.8 cfs, with five medium to large storms (peaks of 424 - 1140 cfs) occurring in January through March. Tidal range during this time period is 1.4 m, and while Segment 1 specific conductivities indicate this site is fresh, conductivities measurements at Segment 2 fluctuates from 5 - 50 mS cm^{-1}, indicating that the estuary mouth is open and fully tidal. During early March the ocean inlet appears to be restricted, and the mouth closed from March 28 through April 4, then again from April 15 through April 28.

With the onset of the dry season (May –October 2009), freshwater base flow gradually reduces to 3 - 7 cfs. Specific conductivity at the Segment 1 continues to show influence of this freshwater input, with a range of ~ 5 - 40 mS cm^{-1}, while Segment 2 is more marine in character, with conductivities ranging from 5 - 50 mS cm^{-1}. Between study years, total freshwater flow was 25% higher in 2007-2008 then in 2008-2009 (Table 2.1).

Table 2.1. Annual (Dec-Nov), wet season (Dec-April), and dry season (May-Nov) total freshwater discharge at the Escondido Creek Mass Emission Station.

Period	2007-2008 Discharge (cf)	2008-2009 Discharge (cf)
Annual	6.45E+08	4.81E+08
Wet Season	5.63E+08	4.09E+08
Dry Season	8.24E+07	7.26E+07

Dissolved oxygen concentrations at Segments 1 and 2 averaged 6.1 - 6.4 mg L^{-1} during the 2008 TMDL field study respectively, while concentrations averaged 7.1 mg L^{-1} during the 2008-2009 Bight study. Instantaneous concentrations below 5 mg L^{-1} approximately 38 and 32% of the time during the period of record (January 2008-October 2008) for Segments 1 and 2 respectively for the TMDL study, while DO concentrations at Segment during the 2008-2009 Bight study were below 5 mg L^{-1} 24% of the time (Figure 2.2).

The percentage of time below 5 mg L^{-1} was much higher during the summer (62% and 43% for Segment 1 and 2 respectively) versus winter (1% and 18% respectively), coincident with higher water temperatures, decreased freshwater flow, and peak primary productivity (Figure 2.1). This trend was repeated at Segment 1 the following year during the Bight study (5% winter versus 44% summer), but at a lower percentage than the previous year. Hypoxia (<2 mg L^{-1}) was more prevalent annually at Segment 2 (15%) versus Segment 1 (1%).

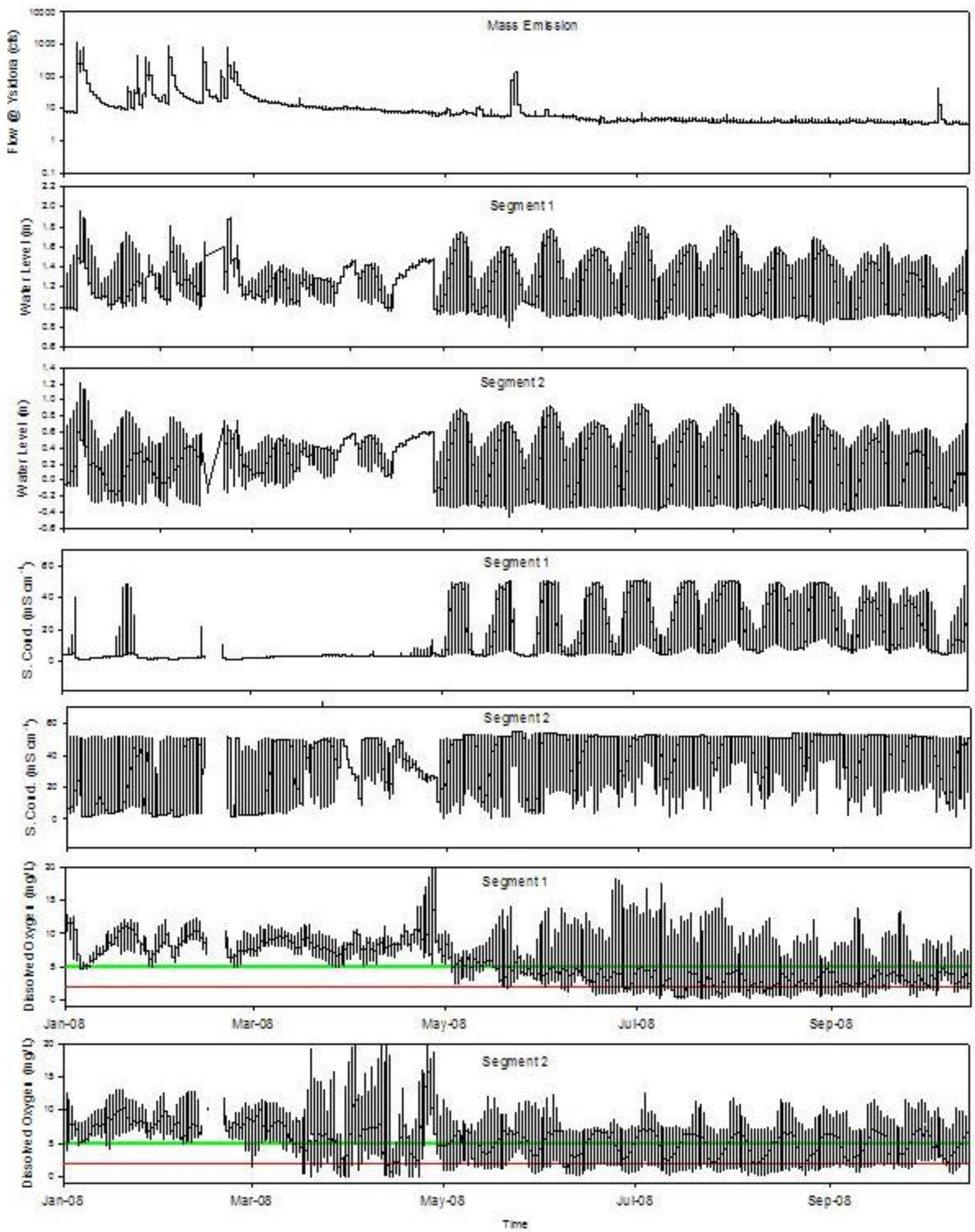


Figure 2.2. Continuous freshwater flow (cfs, log10 scale at Escondido Creek Mass Emission Station) and Segment 1 and 2 water level (m), specific conductivity (mS cm^{-1}), and dissolved oxygen (mg L^{-1}) during 2008 TMDL field studies (MACTEC 2009). Green and red lines in dissolved oxygen graph show the SDRWQCB 5 mg L^{-1} basin plan objective and the 2 mg L^{-1} definition of hypoxia (Diaz 2001), respectively.

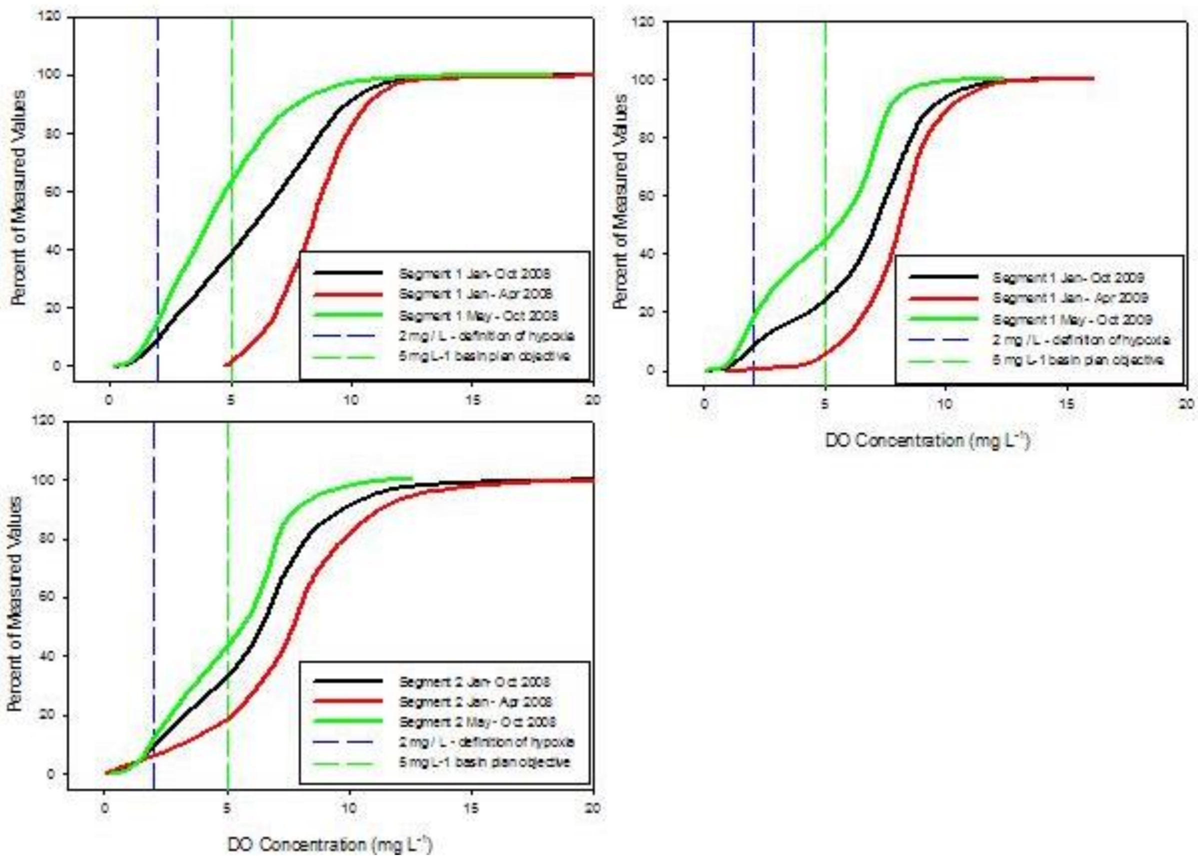


Figure 2.3. Cumulative frequency distribution of dissolved oxygen concentration annually (black line), during wet season (Jan-Apr) and during dry season (May-Oct) at Segment 1 site and Segment 2 during the TMDL study (2008) and at Segment 1 during the Bight '08 study (2009).

Concentrations of < 5 mg L^{-1} typically occurred in nighttime through early morning hours and coincided with periods of low tidal flushing during neap tidal cycles (Figure 2.4). Spatially, periods of low O_2 (< 5 mg L^{-1}) were more likely to extend through a 24 hour period at Segment 1 during neap tides. At Segment 2, mouth closure during late March and early April caused periods of hypoxia that were not observed at Segment 1.

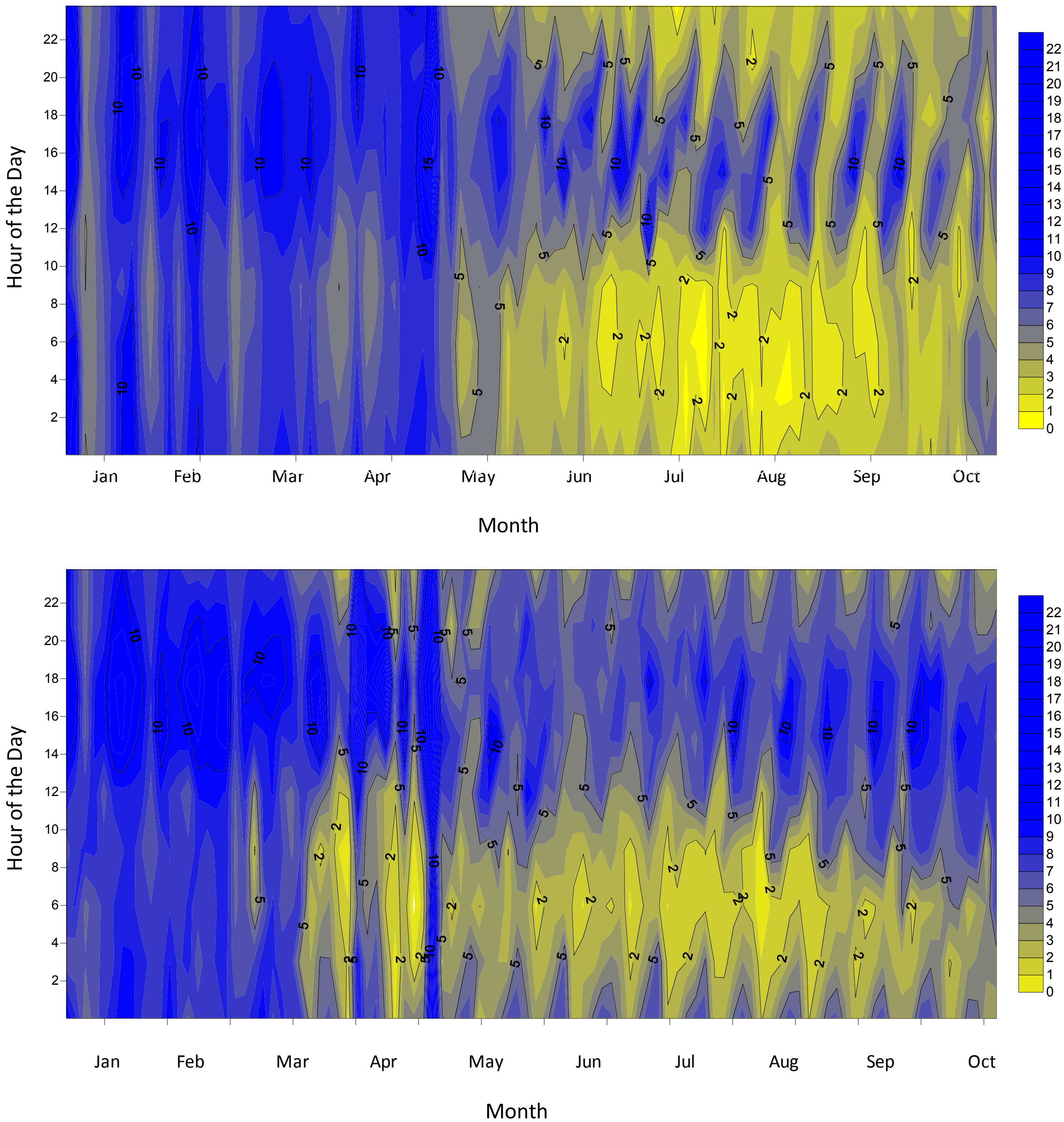


Figure 2.4. Contour plot (top panel) of Segment 1 (top panel) and Segment 2 (bottom panel) DO by month (x axis) and time of day (y-axis) during the 2008 TMDL field study. Legend on right shows color key for DO concentrations.

During the 2007-2008 field study, several consistent patterns emerged with respect to wet and dry weather N and P concentrations (Tables 2.2 - 2.3). First of all, wet weather ME concentrations were almost always greater than Segment 1 or 2 concentrations. During this time, the mass emission station generally had higher NH_4 content (8%) than the estuary segment sites (5%), while NO_3+NO_2 concentrations generally ranged from 20 - 80% of TN among mass emissions and estuary sites. Soluble reactive phosphorus content in TP was highly variable during wet weather events.

During winter dry weather, mean ME TN was the highest of any other wet or dry weather period (223 µM TN. Segment 1 and 2 TN concentrations were typically higher than ME concentrations during the winter and spring index periods. In contrast, summer and fall dry weather concentrations of TN were greatest at the ME station and decreased toward the ocean inlet. This pattern was also generally the same for NH_4 and NO_3 +NO_2. Dry weather ME and estuary Segment 1 stations generally had lower NH_4 content (3 - 6% of TN) relative to Segment 2 (23% of TN), while NO_3 +NO_2 concentrations ranged from 33 - 65% of TN among ME and estuary sites. In general, the highest NH_4 concentrations were observed at Segment 1 during the spring, summer and fall index periods relative to the ME and Segment 2 stations. During dry weather, Segment 1 and 2 sites were almost always higher than the ME site, indicating that additional sources of P may be entering the Lagoon. SRP generally represented 50% or greater of the TP during dry weather.

Table 2.2. Mean and standard deviation of TN, $NH_4$and NO_3 +NO_2 concentrations in wet (storm) and dry (index) weather periods at Mass Emission Station, Segment 1 (Upstream) and Segment 2 (Downstream). All concentrations are in µM.

Event		Date	TN	NH4	NO_3 +NO_2
Storm 1	ME	1/5/2008	116.4±114.5	9.3±3.1	98.6±65.8
	Seg 1	1/5/2008	78.9±77.3	4.3±5.0	14.3±18.2
	Seg 2	1/5/2008	65.4±24.7	4.3±2.9	20.0±19.2
Storm 2	ME	1/23/2008	238.5±131.7	9.3±4.7	192.8±189.3
	Seg 1	1/23/2008	162.5±18.7	3.2±0.5	152.5±97.1
	Seg 2	1/23/2008	43.9±39.9	2.1±1.0	42.9±59.6
Index 1	ME	1/14/2008	223.3±221.0	6.7±2.9	179.9±230.0
	Seg 1	1/14/2008	291.1±70.4	4.2±1.4	231.8±37.8
	Seg 2	1/14/2008	199.2±143.1	4.4±2.1	149.9±89.7
Index 2	ME	3/24/2008	38.4±17.4	6.9±0.8	10.5±11.4
	Seg 1	3/24/2008	107.8±41.8	8.6±2.6	76.7±15.2
	Seg 2	3/24/2008	67.8±41.6	1.9±1.8	11.5±12.8
Index 3	ME	7/7/2008	114.5±36.2	2.7±0.5	87.3±46.8
	Seg 1	7/7/2008	55.1±20.4	9.6±10.3	4.2±6.0
	Seg 2	7/7/2008	27.0±16.6	4.1±2.1	2.4±4.6
Index 4	ME	9/22/2008	163.4±29.7	2.2±0.5	99.8±33.2
	Seg 1	9/22/2008	55.7±25.6	12.2±6.5	6.1±2.7
	Seg 2	9/22/2008	28.8±17.6	4.6±3.7	1.1±0.6

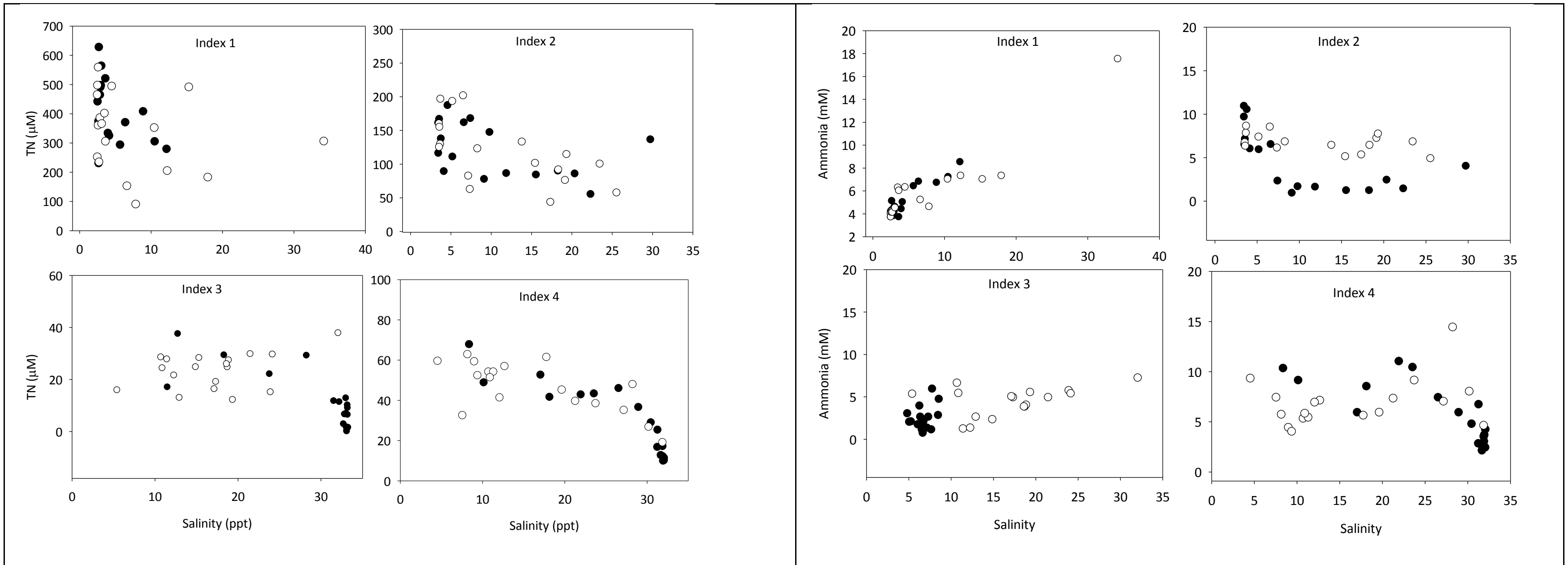
Table 2.3. Mean and standard deviation of TP and SRP concentrations in wet (storm) and dry (index) weather periods at Mass Emission Station, Segment 1 (Upstream) and Segment 2 (Downstream). All concentrations are in μM.

Event	Station	Date	TP	SRP
Storm 1	ME	1/5/2008	7.7±4.5	6.2±3.9
	Seg 1	1/5/2008	2.6±3.2	0.8±0.7
	Seg 2	1/5/2008	1.8±1.6	0.8±0.7
Storm 2	ME	1/23/2008	23.9±17.2	4.2±3.2
	Seg 1	1/23/2008	4.7±0.2	2.6±0.0
	Seg 2	1/23/2008	1.3±0.9	1.0±0.9
Index 1	ME	1/14/2008	2.5±1.3	1.6±1.4
	Seg 1	1/14/2008	7.4±1.4	4.7±0.8
	Seg 2	1/14/2008	5.8±3.5	3.3±1.5
Index 2	ME	3/24/2008	1.0±0.6	0.6±0.2
	Seg 1	3/24/2008	5.5±2.5	3.9±1.0
	Seg 2	3/24/2008	3.7±2.5	1.1±0.9
Index 3	ME	7/7/2008	1.7±0.4	1.4±0.6
	Seg 1	7/7/2008	7.0±2.4	3.3±2.9
	Seg 2	7/7/2008	2.7±1.9	2.0±1.9
Index 4	ME	9/22/2008	3.3±0.7	2.2±0.2
	Seg 1	9/22/2008	5.5±1.6	3.5±0.7
	Seg 2	9/22/2008	2.2±1.5	1.4±1.0

Mixing diagrams (plots of salinity relative to nutrient concentrations) are helpful in interpreting the extent to which freshwater versus marine endmembers are the primary source of nutrient and to what extent within estuary sources (e.g., storm drains, groundwater, benthic flux, biological release) or sinks (benthic flux, denitrification, biological uptake) are visible. Mixing diagrams show a source of a NH_4, TP and SRP within the estuary during the winter, summer and fall index periods and a sink for these constituents during the spring index period. With respect to NO_3, the Lagoon appears to be sink for NO_3 $+NO_2$ during the spring, summer and fall index periods, with the winter index period inconclusive. Patterns for the TN mixing diagrams are driven by the dominant DIN constituent, which varied among index periods.

Table 2.4. Nutrient data for the estuary site and mass emission station taken during the Bight 08 monitoring.

Sample Date	Site	Analyte (µM)							
		SRP	NO2	NO2+ NO3	NH4	TN	TP	TDN	TDP
11/24/08	Estuary	1.5	0.3	4.3	5.1	32.2	2.3	26.4	1.6
1/20/09		2.5	1.4	86.8	12.7	119.9	6.4	118.7	4.9
3/23/09		0.9	0.1	2.1	2.3	17.8	5.1	15.6	9.2
5/13/09		6.9	1.1	5.6	38.8	31.2	6.8	92.7	13.2
6/17/09		1.9	0.1	1.8	7.9	29.4	9.1	26.2	9.6
10/1/09		2.2	0.1	0.4	2.4	28.7	10.8	21.2	11.1
11/24/08	Creek					354.3	3.3		
1/20/09						374.9	3.4		
3/23/09						410.6	2.0		
5/13/09						40.0	5.1		
6/17/09						198.9	3.7		
10/1/09		3.0	0.4	66.2	3.0	108.3	4.4	98.2	5.2



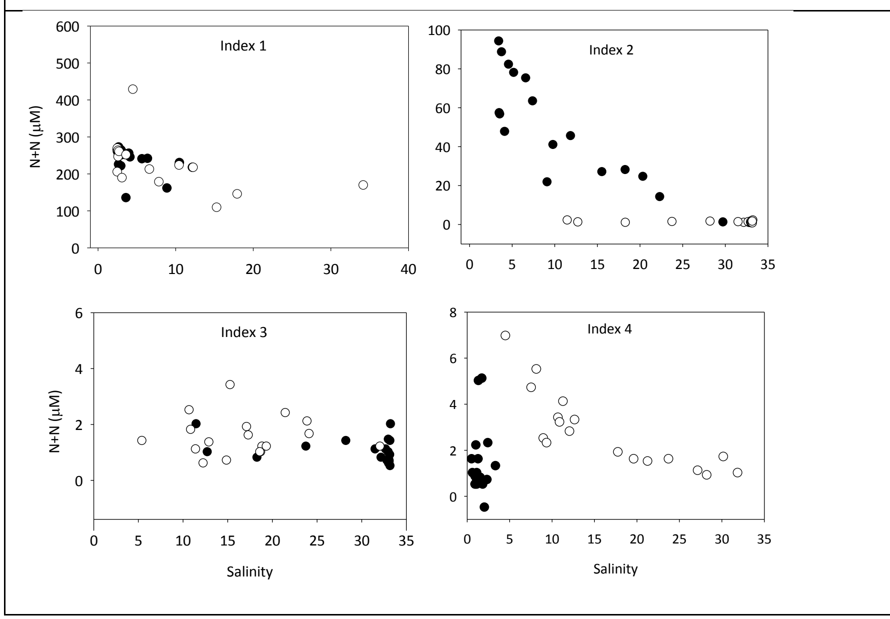


Figure 2.5. Mixing diagrams (concentration as a function of salinity) of TN (top left), Ammonium (top right), and Nitrate+Nitrate (bottom left) during each of the four index periods. All concentrations are given in µM. Black fill circles indicate transect samples taken during the flood tide, while white fill circles indicate those taken during ebb tide. A linear trend indicates conservation behavior of the constituent with salinity, while a concave shape represents production (a source) and a convex shape represents consumption (a sink) of the constituent.

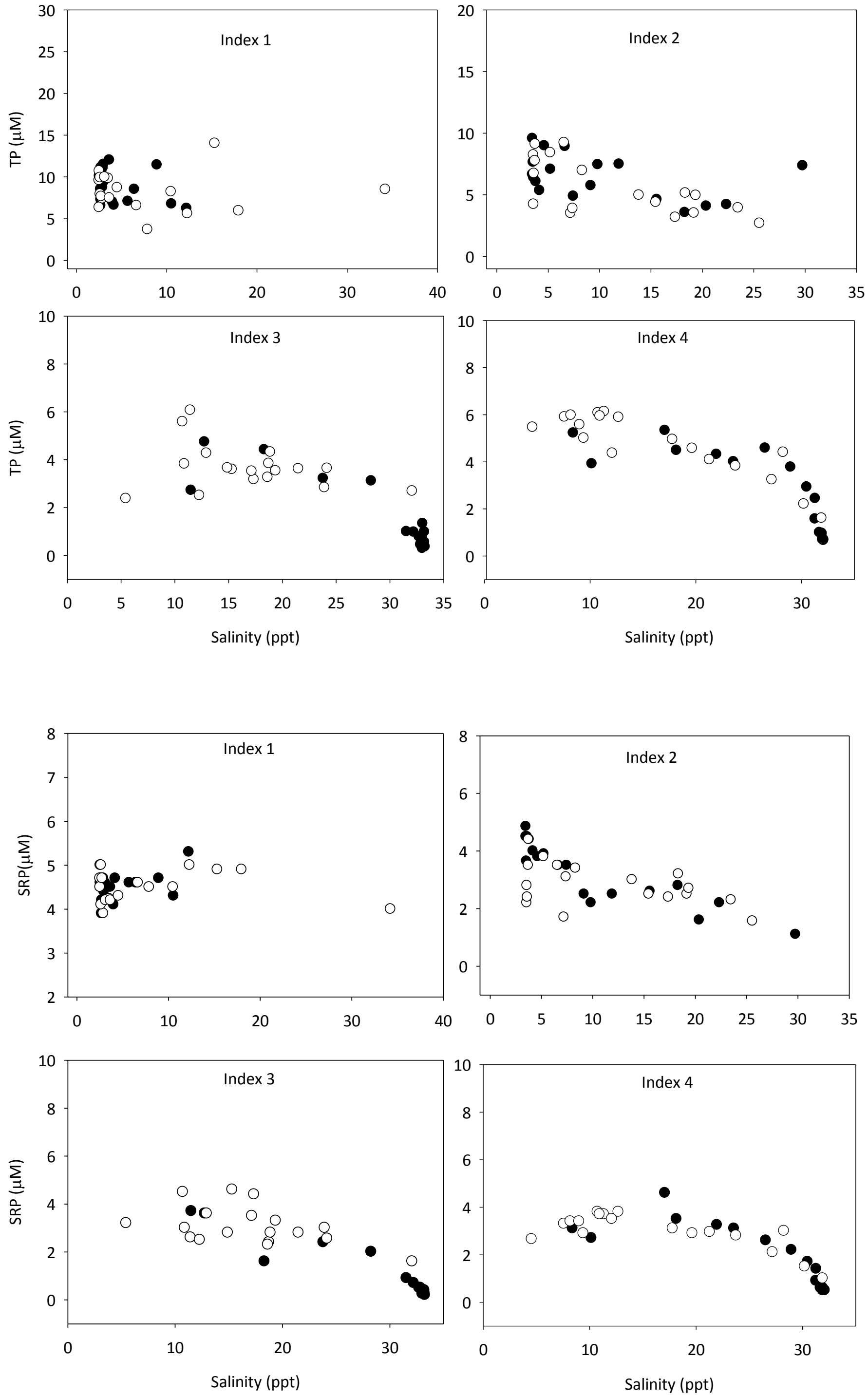


Figure 2.6. Mixing diagrams of TP (top) and SRP (bottom) concentration (µM) during each of the four index periods. Black fill circles indicate transect samples taken during the flood tide, while white fill circles indicate those taken during ebb tide. A linear trend indicates conservative mixing of the constituent with salinity, while a concave shape represents production (a source) and a convex shape represents consumption (a sink).

2.3.2 Seasonal Trends in Primary Producers

This study assessed seasonal trends in biomass and or percent cover of three aquatic primary communities:

- phytoplankton (measured as suspended chlorophyll a)
- macroalgae and cyanobacterial mats (biomass and percent cover)
- microphytobenthos (measured as benthic chlorophyll a)

A fourth community, submerged aquatic vegetation, was not observed in the San Elijo Lagoon.

Figure 2.7 shows the comparative biomass of phytoplankton, macroalgae and microphytobenthos, standardized to mass of carbon (C) per unit area by 2008 sampling period for Segment 1 and 2; Figure 2.8 shows interannual variation in carbon biomass between TMDL and Bight 08 studies. Overall, carbon attributable to phytoplankton biomass was insignificant relative to macroalgal and MPB biomass. During the winter index period, no biomass or cover of macroalgae was observed. By the spring index period, microphytobenthos dominated the aquatic primary producers. A shift towards dominance by macroalgae and cyanobacterial mats occurred during summer and fall, with peak macroalgal biomass (50 ± 27 g dry wt m^{-2} or 251 ± 123 g wet wt m^{-2}) and percent cover (100%) at Segment 1 during the July 2008 index period and peak biomass (43 ± 10 g dry wt m^{-2} or 183 ± 56 g wet wt m^{-2}) at Segment 2 during July 2008 (Figure 2.7). This pattern was generally repeated during the 2008-2009 Bight 08 field survey (Figure 2.8, albeit with lower concentrations of macroalgae during summer 2009 (17 ±16 g dry wt m^{-2}).

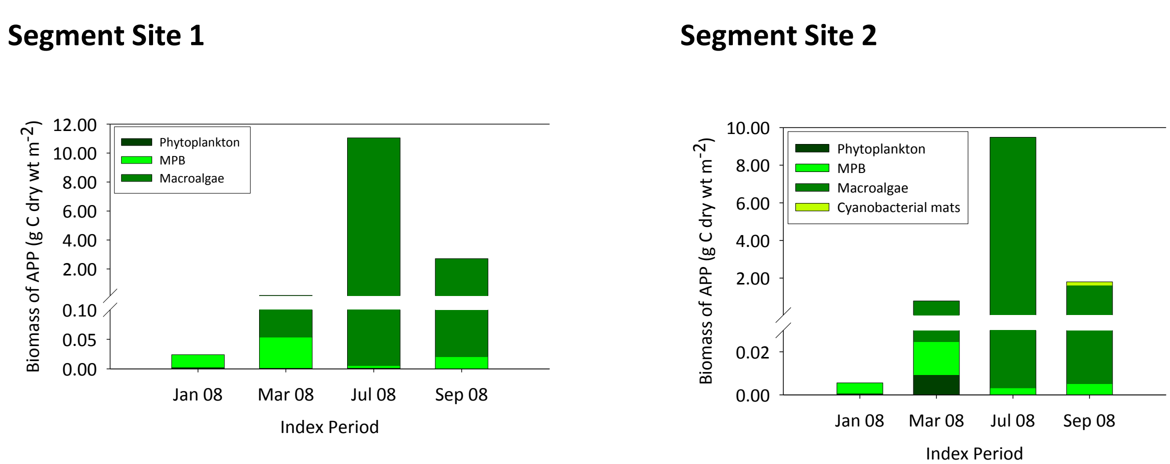


Figure 2.7. Mass of carbon associated with the four types of primary producers observed in San Elijo Lagoon segment sites 1 and 2.

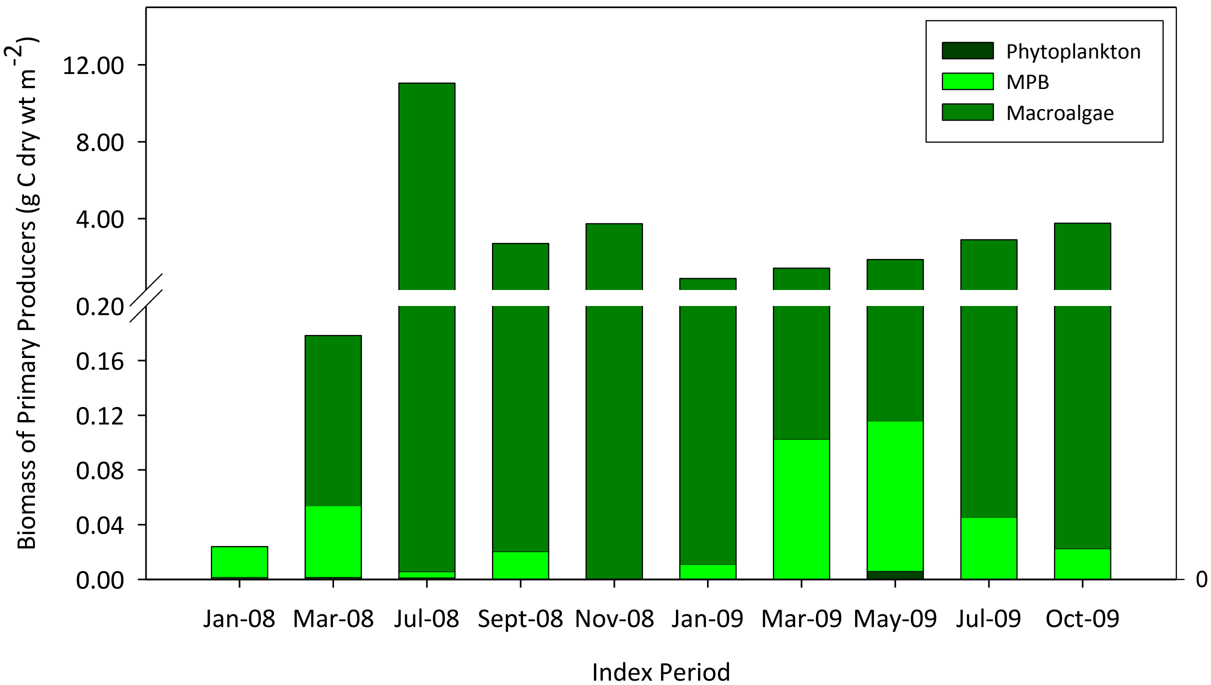
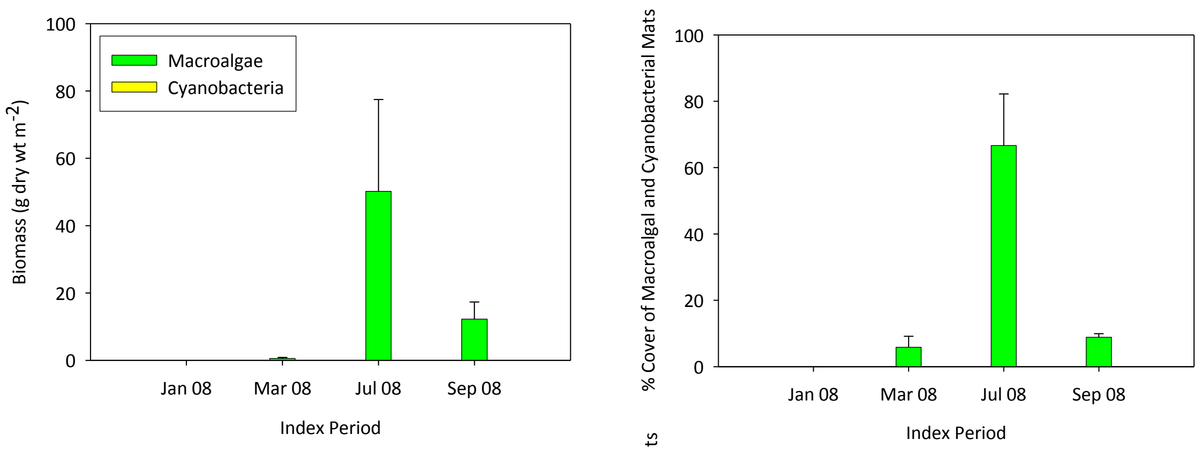


Figure 2.8. Comparison of areal mass of carbon associated with three types of primary producers observed at Segment 1 during TMDL and Bight 08 Field studies (Jan 2008 - October 2009). Note that microphytobenthos (MPB) were sampled at different elevations during the TMDL field studies (100 cm below MLLW) and Bight 08 study (30 cm above MLLW). Macroalgal biomass and phytoplankton biomass were sampled in using comparable methods.

Table 2.5. Comparison of wet macroalgal biomass and percent cover at Segment 1 during TMDL and Bight 08 study.

Study	Time Period	Wet Macroalgal Biomass (Mean ± SD) g m^{-2}	% Cover (Mean ± SD)
TMDL Field Study	**Jan-08**	0±0	0±0
	Mar-08	2±1	6±3
	Jul-08	251±123	67±15
	Sept-08	85±34	9±1
Bight 08 Study	**Nov-08**	141±69	37±27
	Jan-09	139±0	6±8
	Mar-09	39±16	13±18
	May-09	74±47	21±20
	Jul-09	144±94	42±27
	Oct-09	194±79	26±33

Segment Site 1



Segment Site 2

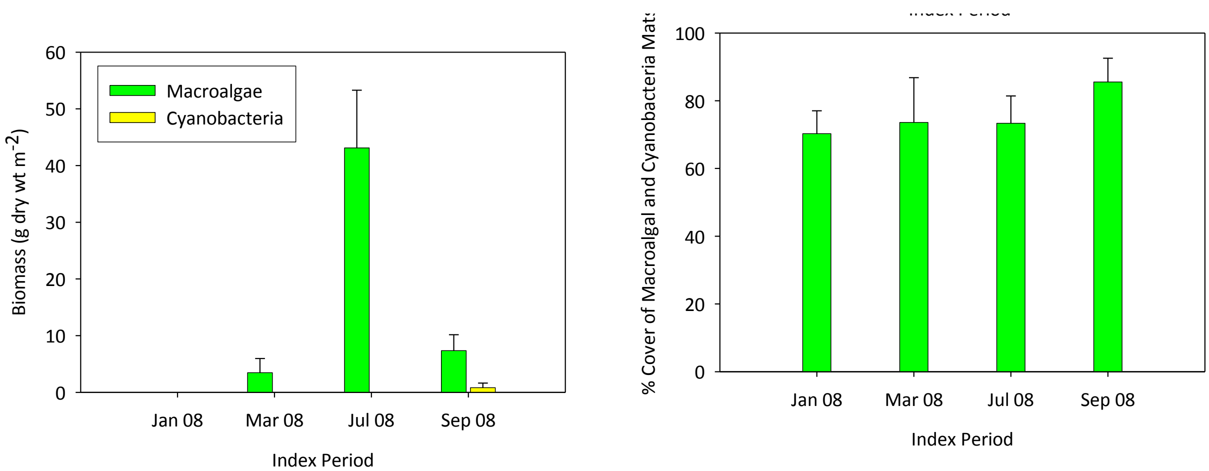
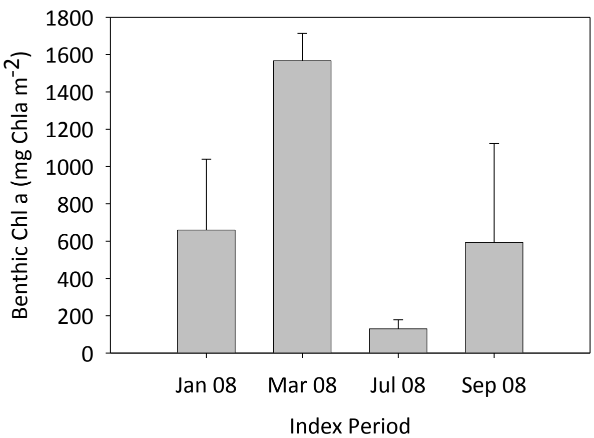


Figure 2.9. Segment Sites 1 and 2 mean and standard deviation of macroalgal biomass and % cover for each index period.

Microphytobenthos biomass appeared to be higher during the Bight 08 study (peak biomass of 3295 mg chl a m^{-2}) than during the TMDL field study (peak biomass of 1657 mg chl a m^{-2}) , though sampling methods among the two studies were conducted at different water depths, making a true comparison difficult (Figure 2.10).

During the 2008 TMDL studies, phytoplankton biomass was highest during spring 2008, with mean values of 19 mg m^{-3} and 112 mg m^{-3} at Segments 1 and 2 respectively (Fig. 2.11). During the Bight 08 study, phytoplankton biomass peaked in May 2009 (73 mg m^{-3}), but remained fairly constant throughout the rest of the year.

Segment Site 1



Segment Site 2

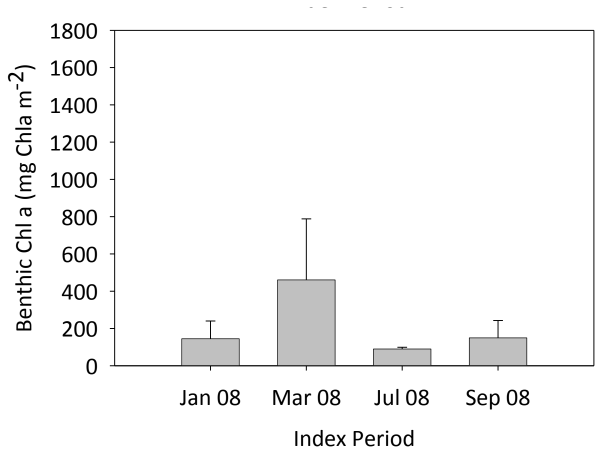
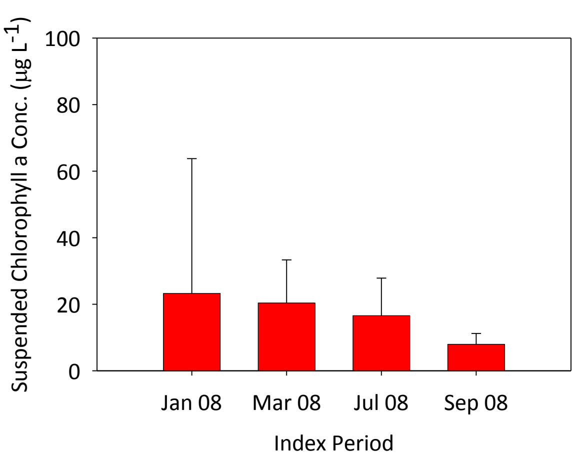


Figure 2.10. Segment Sites 1 and 2 mean and standard deviation of benthic chlorophyll a concentrations for each index period.

Segment Site 1



Segment Site 2

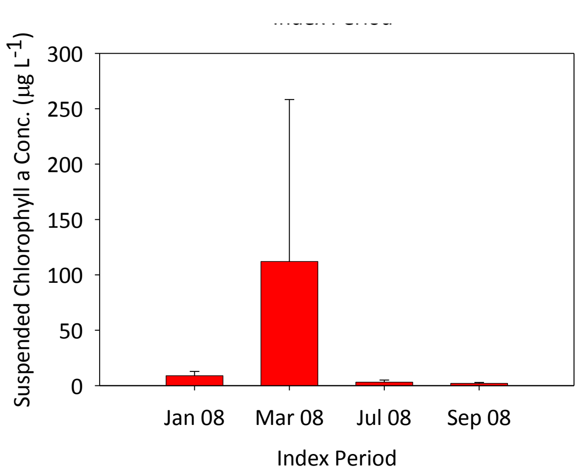


Figure 2.11. Segment Sites 1 and 2mean and standard deviation of suspended chlorophyll a concentrations for each index period (MacTech 2009).

2.3.3 Seasonal Variation in Sediment Grain Size and Total Organic Carbon, Nitrogen and Phosphorus Characteristics by Index Period

Differences were observed in sediment grain size, total organic carbon, and total nutrient between Segment Sites 1 and 2 (Figure 2.11). Segment 1 sites generally had higher fractions of fine-grained sediments, with surface sediments ranging from 10 - 80% fines. In contrast, Segment Site 2 sediments were coarser, with surface sediments ranging from 0 - 20% fines. As a result, sediment % OC and sediment total nutrients also followed this general trend. No consistent vertical trends with depth were observed.

2.3.4 Seasonal Trends in Sediment Deposition

Sediment deposition and removal events were measured using the particle tracer, ^{7}Be. This cosmogenic radionuclide is produced in the upper atmosphere by spallation of O_2 and N atoms. Because ^{7}Be is particle reactive, it will adsorb to any aerosols or dust present in the atmosphere at the time of formation. These particles are scrubbed from the atmosphere during rain events or fall out slowly as dry deposition. The ^{7}Be particles can then act as particle tracer proxies for all internal sediment movement, and track the downstream flow of sediment in streams and calculate the mass accumulation of sediment in the system.

Sediment mass fluxes can be compared to discharge and precipitation events to identify important events. Mass fluxes are presented as a material inventory (g cm^{-2}; Fig. 2.12) and indicate the San Elijo Lagoon is primarily a depositional environment throughout the year. While transport during rainfall events is possible, the fact that deposition is recorded throughout the year may be due to the resuspension of surface sediments in the Lagoon. Alternatively or in addition to resuspension, primary producer biomass can incorporate ^{7}Be particles into their biomass and consequently, when they senesce and are deposited onto the sediments, surface sediments will show a “new” inventory of ^{7}Be.

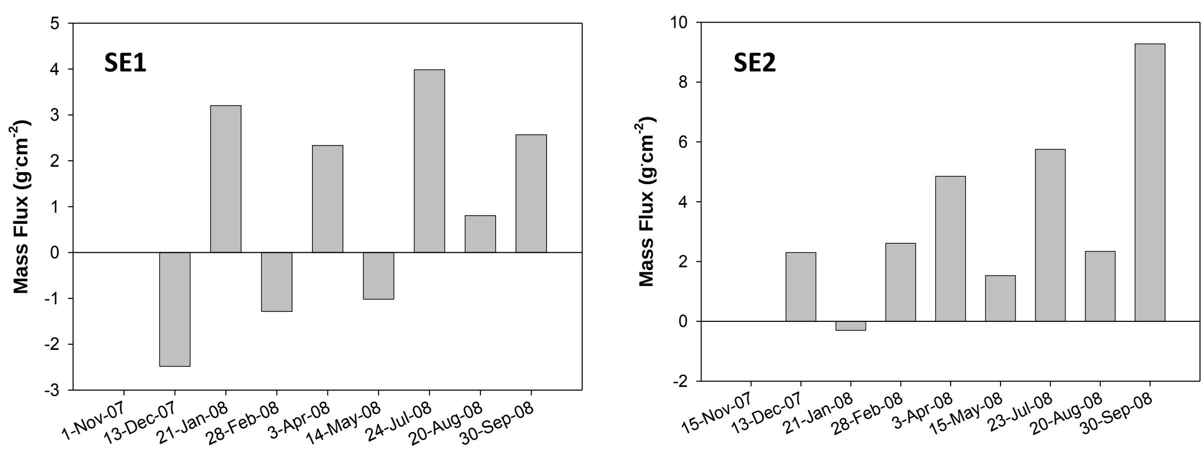


Figure 2.12. Mass flux is given as an inventory of material deposited (+) or removed (-) through time (red bars) and accumulated monthly rainfall (blue bars).

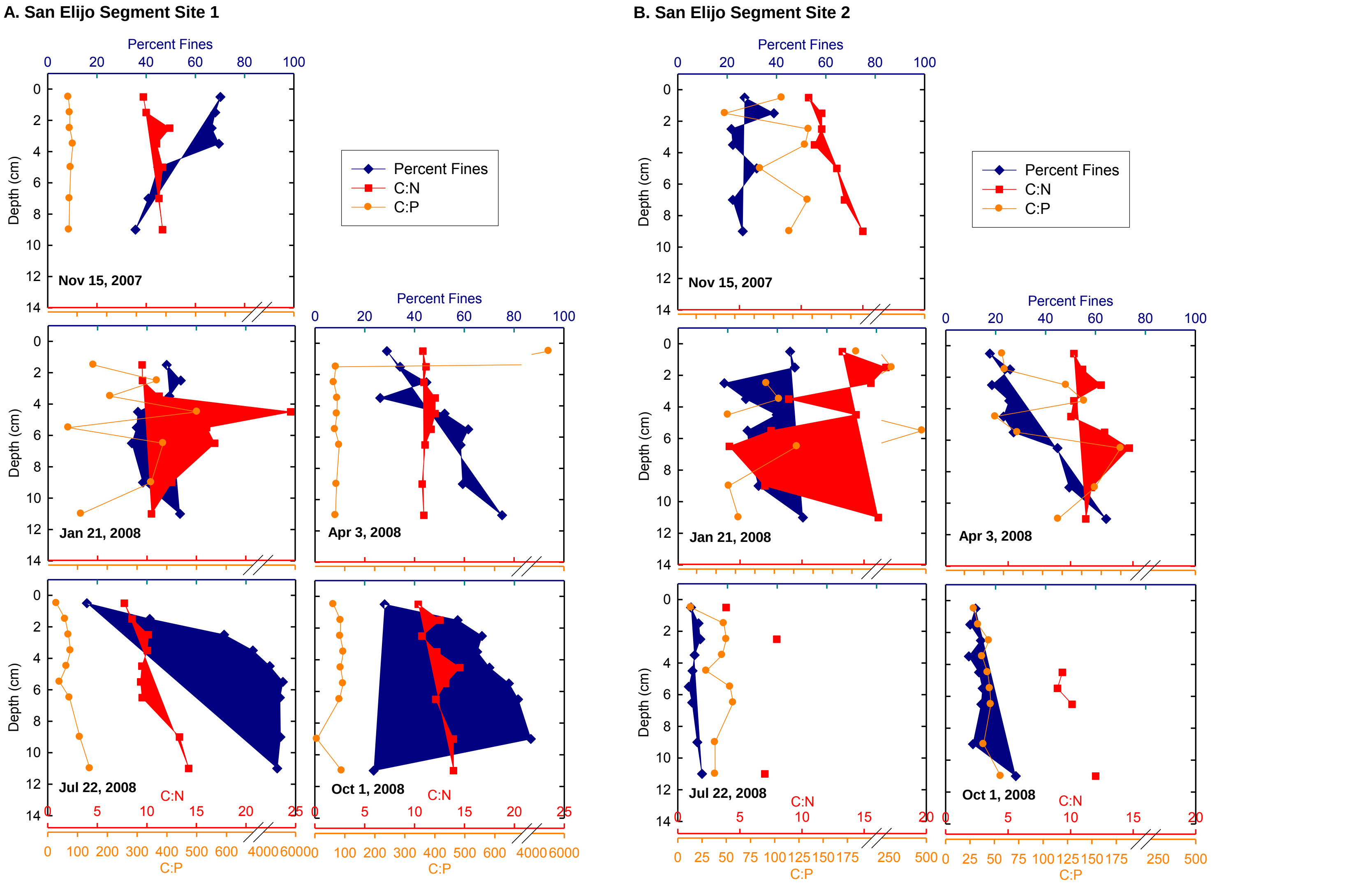


Figure 2.11. Sediment grain size (as percent fines, ♦), carbon: nitrogen (C:N, ■), and carbon: phosphorus (C:P, ●) ratios of cores taken in Segment Sites 1 and 2 of the Lagoon during each index period.

2.4 Discussion

2.4.1 Summary of Findings

This component of the study documented three major findings:

1. The Lagoon is exhibiting symptoms of eutrophication, as documented by episodes of low DO and moderate coverages of macroalgal cover and biomass. Episodes of low DO and macroalgal biomass were that were highest the year of the 2008 TMDL field study relative to the Bight '08 Eutrophication Assessment (2008-2009).

   - Estimates of biomass and percent cover of macroalgae were moderate with averages of 251 g wet wt m^{-2} over the fall 2008 field studies and cover up to 67%. No established framework exists to assess adverse effects from by macroalgae, though a recent review (Fong et al. 2011) found studies documenting adverse effects of macroalgae on benthic infauna as low as 700 g wet wt $m\text{-}^{2}$ and with cover greater than 30 - 70%.

   - Dissolved oxygen concentrations found to be below 5 mg L^{-1} about 1 - 18% of the wintertime and 62 - 42% of the summertime at Segments 1 and 2 respectively during the 2008 TMDL field studies. This trend was repeated at Segment 1 the following year during the Bight study (5% winter versus 44% summer), but at a lower percentage than the previous year. Hypoxia (<2 mg L^{-1}) was more prevalent annually at Segment 2 (15%) versus Segment 1 (1%).

2. Dry season concentrations of dissolved inorganic nutrients indicate anthropogenically-enriched nutrient sources. During the summer and fall, estuarine ambient dry season SRP and NH_4 was highest in Segment 1 (10 - 12 µM NH_4 and 3 - 4 µM SRP). Mixing diagrams (plots of salinity relative to nutrient concentrations) of transect data indicate dry season sources of phosphate and $NH4_3$, not associated with direct freshwater input.

3. Sediments in the Lagoon in general were a mixtures of sands, silt clays, with C:N ratios of 10 - 15:1. Segment 1 site generally had higher fractions of fine-grained sediments while Segment 2. Beryllium-7 analysis show the Lagoon to be largely deposition at Segments 1 and 2.

2.4.2 Significance of Macroalgae in Lagoon

Opportunistic macroalgae are highly successful in nutrient–rich freshwater and estuarine systems. These algae typically have filamentous or sheet-like growth forms (e.g., Cladophora or *Ulva* spp.) that can accumulate in extensive, thick mats over the seagrass or sediment surface. Although macroalgae are a natural component of these systems, their proliferation due to nutrient enrichment reduces habitat quality in four ways: 1) increased respiration at night and large O_2 demand from decomposing organic matter, 2) shading and out-competing submerged aquatic vegetation and microphytobenthos (Fong et al. 2011), 3) impacts on the density of benthic infauna, which are a principle food source for birds and fish, and 4) development of poor aesthetics and/or odor (Fong *et al.* 1998, Kamer *et al.* 2001, Kennison *et al.* 2003).

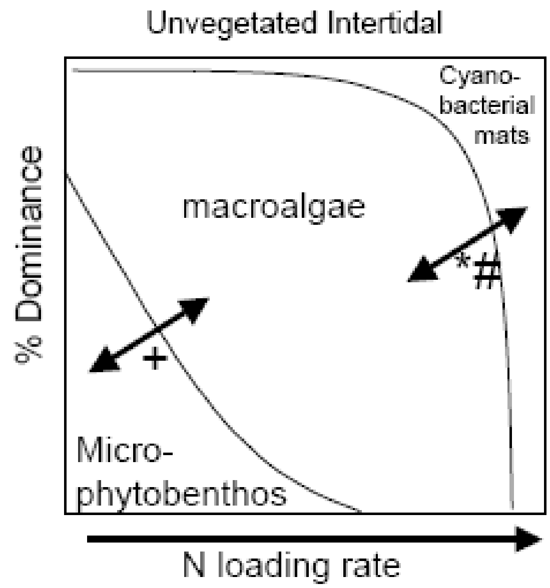


Figure 2.12. Conceptual model of the relationships between N loading rate and the community composition of primary producers in unvegetated shallow subtidal and intertidal habitat in California estuaries.

As nutrient availability increases, it has been well-documented in many parts of the world that blooms of green or red macroalgae become dominant in shallow subtidal and intertidal estuaries and lagoons, replacing seagrass or MPB (e.g., Sfriso et al. 1987, 1992, Raffaelli et al. 1989, Valiela et al. 1992, 1997, Geertz-Hansen et al. 1993, Peckol et al. 1994, Marcomini et al. 1995, Page et al. 1995, Hernández et al. 1997, Hauxwell et al. 1998, Kamer et al. 2001). Figure 2.12 shows that as N availability increases, macroalgae become increasing dominant, eventually outcompeting microphytobenthos. Under extreme nutrient availability and in particular with higher P availability, cynanobacterial mats appear (Fong et al. 2011).

In the Lagoon, the relative biomass of benthic primary producers followed a seasonal trend typical of eutrophic coastal lagoons (Fong *et al.* 1993, Fong *et al.* 1998, Kamer *et al.* 2001). During the winter index period (January 2008), flushing and scouring during storm events act together with low temperatures and light levels to inhibit growth of macroalgae. Microphytobenthos (MPB) biomass peaked during the winter and spring index periods, with relatively high concentrations (1657 mg chl a m^{-2}). By the summer index period, however, microphytobenthos appear to be out-competed by macroalgae (*Ulva sp.)* at both segment sites and cyanobacteria mats appeared in Segment 2 in the fall. Biomass and percent cover of macroalgae were moderate with a mean averages of 251 - 194 g wet wt m^{-2} over the fall 2008 and 2009 TMDL and Bight field studies and cover up from 46 - 67%. This dominance and standing biomass macroalgae and cyanobacteria during the summer and fall suggest that the Lagoon is moderately disturbed with respect to nutrient over-enrichment (Fong *et al.* 1993).

While primary producer biomass and percent cover are useful for understanding the extent of eutrophication in estuaries, there is currently no established assessment framework to determine whether an estuary has become “adversely affected” by macroalgae. A recent review (Fong et al. 2011) found studies documenting adverse effects of macroalgae on benthic infauna found thresholds as low as 700 g wet wt m^{-2} (Bona 2006) and adverse effects with cover greater than 30 - 70% (Jones and Pinn 2006, Pihl et al. 1995). Ongoing studies being conducted by SCCWRP and UCLA will help to provide additional data which which to select macroalgal management endpoints for the estuary, if desired.

Macroalgal mats can rapidly deplete dissolved inorganic nutrients from the water column (Pedersen and Borum 1997, McGlathery *et al.* 2007). This depletion of nutrients increases the rate of benthic flux of nutrients from the sediments by creating a concentration gradient, thus diverting N loss from denitrification and providing a mechanism for N retention and recycling within the estuary (Krause-Jensen *et al.* 1999, Fong and Zedler 2000). In the Lagoon, the peak in macroalgae productivity coincided with the reduced freshwater flow. Increased residence time of water during this time period would result in greater residence time, enhancing availability of nutrients that can promote the productivity of macroalgal blooms. Concentrations of NO_2+NO^3 varied from 0 - 8 µM during the summer and fall, indicating that available sources are being drawn down to near non-detectable levels.

The presence of macroalgae in estuarine environments can alter DO concentrations significantly on a diurnal scale. High rates of respiration from elevated biomass may reduce DO content of estuarine waters at night (e.g., Peckol and Rivers (1995)), while decomposition of accumulated organic matter may cause a large microbial O_2 demand both day and night (Sfriso *et al.* 1987). Dissolved oxygen concentrations found to be below 5 mg L^{-1} about 1 - 18% of the wintertime and 42 - 62% of the summer and fall, indicating that a combination of macroalgal biomass and sediment O_2 are driving factors in depressed DO concentrations; sediment O_2 demand as well as flux of degraded organic matter may also play a role; observations of tidal height relative to DO show low O_2events were associated with neap tide cycles, indicating that water residence time is likely a controlling factor. During neap tides, exchange with oxygen-rich ocean waters is at a minimum and sediment O_2 demand and autotrophic and heterotrophic respiration will act to deplete surface waters of O_2. Factors affecting dissolved oxygen flux are explored further in Chapter 3.

2.4.3 Patterns in the Lagoon Surface Water, Porewater Nutrient Concentrations and Sediment Bulk Characteristics

Ambient nutrient concentrations within an estuary are the integration of various pathways of sources, sinks and transformations, including both uptake and release (Valiela *et al.* 1992, Valiela *et al.* 1997, Dalsgaard 2003, Bergamasco *et al.* 2004, Paerl 2009). The relative ratios of the different species can provide some insight into the dominant processes controlling nutrient availability within the estuary.

Surface water nutrient concentrations measured at the mass emission site and within the estuary show the surface waters to be enriched, with winter dry weather TN (199 - 291 µM) slightly higher or on par with wet weather concentrations (43 - 238 µM) and wet weather TP approximately equal to dry weather (1.8 - 24 µM TP). During winter index and wet weather periods, NO_3 +NO_2 and SRP comprised the largest fractions of TN and TP respectively, typical of surface waters enriched with anthropogenic sources of nutrients. During the summer and fall, less freshwater was delivered to the estuary, and DON, NH_4, SRP dominated estuarine TN and TP respectively.

Mixing diagrams (plots of salinity relative to nutrient concentrations) of surface water transect data were particularly instructive as to whether freshwater versus marine endmembers are the primary source of nutrients and to what extent within estuary sources (e.g., storm drains, groundwater, benthic flux, biological release) or sinks (benthic flux, denitrification, biological uptake) are visible (Day et al. 1989, Boyton et al. 2006, Sutula et al. 2006, REFS). Mixing diagrams show that for the Lagoon, sources or production of NH_4, TP, and SRP appears in the of the estuary during the winter, summer and fall index periods, consistent with the concept that additional sources of these constituents may be entering surface waters from benthic flux (see chapter 3) or non-point source inputs such as agricultural runoff, groundwater, or storm drains (Valiela et al. 2006). Nitrate+nitrite was consistently lower throughout the summer and fall index periods then in the winter and spring, with very low concentrations in the upper estuary and higher concentrations at the ME station. These very low concentrations of NO_3 +NO_2 indicate that either denitrification (the process of converting NO_3 to N gas) or plant uptake may be responsible for drawing down concentrations to near detectable values.

Sediment organic matter can be decomposed by microorganisms via a series of biogeochemical reactions which result in the release of mineral forms of nutrients to sediment porewaters (Berner 1966). The grain size and organic matter content of the sediment set the capacity of the sediment to produce porewaters of various concentrations, since low organic matter content, associated with sands and coarse substrates, generally have low %OC, %N and %P content (Sutula et al. 2002). Segment 1 sites generally had higher fractions of fine-grained sediments (20 - 80% fines) and higher %OC, %N and %P, while Segment 2 sediments were 0 - 20% fines with lower %OC and %N.

2.4.4 Significance of the Lagoon Sediment Characteristics and Transport

Sediments are a potentially significant internal source of N and P to surface waters in estuarine systems such as the Lagoon (see Chapter 3). Watershed-derived sediments deposited in estuaries during the wet season carry an associated particulate N and P load (Sutula et al. 2002). When deposited in the estuary, the particulate N and P can be mineralized to biologically-available forms and may build up in high concentrations in sediment porewaters. Such mechanism depends on new sources of particulate N and P associated with fined-grained sediment deposition. Mass fluxes estimated based on ^{7}Be show Segment 1 and 2 to be net depositional, with some erosion appeared to occur at Segment 2 in between wet weather events, but the net balance was a net deposition. Sediment transport in San Elijo Lagoon was the subject of a Louisiana State Master's thesis (CITATION), which explores seasonal and interannual deposition rates in greater detail and develops a dynamic simulation model of sediment transport for San Elijo Lagoon.

3 Estimates and Factors Influencing Benthic Oxygen, Carbon Dioxide and Nutrient Fluxes

3.1 Introduction

Sediments are a potentially significant internal source of N and P to surface waters in estuarine systems. Watershed-derived sediments, deposited in estuaries during the wet season, carry an associated particulate N and P load (Sutula *et al.* 2004, Sutula *et al.* 2006). When deposited in the estuary, particulate nutrients can be mineralized to biologically-available forms and may build up in high concentrations in sediment porewaters. These porewaters can diffuse into the overlying water column or be released through advective processes such as bioturbation by benthic infauna, forced flow of water through sediments by bioirrigation or tidal pumping, or physical resuspension of sediments through scouring or resuspension during strong tidal currents or storm flows (Boynton *et al.* 1980, Grenz *et al.* 2000, Jahnke *et al.* 2003). Once released to the water column, these particulate-derived nutrients are available for uptake by primary producers, including macroalgae, microphytobenthos, and submerged aquatic vegetation.

Primary producer abundance is often limited by availability of nutrients (Howarth 1988, Valiela *et al.* 1997, Kamer *et al.* 2004, Paerl 2009). Macroalgae generally obtain nutrients directly from the water column, though studies have shown that algae may intercept nutrients fluxing out of sediments (Lavery and McComb 1991, McGlathery *et al.* 2007). In Southern California, wet-season particulate-nutrient loads deposited in lagoons where shown to provide a significant source of nutrients that fueled excessive growth of submerged aquatic vegetation and macroalgae during the dry season (Boyle *et al.* 2004, Sutula *et al.* 2004, Sutula *et al.* 2006). Thus, sediment-derived nutrients may cause algal blooms to persist even when nutrient loading from the watershed is reduced to levels calculated to limit macroalgal biomass (Sutula *et al.* 2004, Neto *et al.* 2008).

The principal methods of estimating sediment contribution of nutrients (benthic flux) include benthic chambers (Hammond *et al.* 1985, Clavero *et al.* 2000, Berelson *et al.* 2003), sediment-core incubations (Risgaard-Petersen and Ottosen 2000, Welsh *et al.* 2000) and porewater profiles (Hammond *et al.* 1999, Qu *et al.* 2005). Vertical fluxes of solutes diffusing between the sediment and overlying waters can be calculated from Fick's law of diffusion (i.e., porewater diffusive fluxes). The major controls on diffusive fluxes are sediment porosity and the diffusive boundary layer (DBL). However, diffusive fluxes generally underpredict true fluxes. Benthic chambers and sediment-core incubations are direct measurements and may integrate diffusive and advective transport of porewater by means of bioturbation/or bioirrigation processes (Berelson *et al.* 1999).

In addition to nutrients, the fluxes of O_2 and total inorganic carbon (TCO_2) and trace metals provide valuable information the biogeochemical functioning of the sediments. In particular, O_2 and TCO_2 fluxes provide insight on the rates and dominant pathways of organic matter mineralization and benthic community metabolism, which are of primary interest in understanding ecosystem functioning and disturbances caused by eutrophication (Ferguson *et al.* 2003, Ferguson *et al.* 2004, Qu *et al.* 2005). The production of total inorganic C, measured as the release of TCO2 from the sediment to the overlying water, has been used to interpret the balance between aerobic and anaerobic mineralization since both yield CO_2 as the ultimate oxidation product of carbon (Berelson *et al.* 1998, Hammond *et al.* 1999). Measurement of dissolved iron (Fe) and manganese (Mn) pore concentrations and fluxes provide valuable information about the redox chemistry of the benthic boundary layer, since these constituents are only released if the environment has a sufficiently low redox potential (hypoxic).

This component of SCCWRP studies had two objectives:

- Measurement of porewater N, P, TCO_2, S^{-2}, Fe and Mn concentrations to provide information about the sediment biogeochemistry and redox status of San Elijo Lagoon sediments.
- Estimation of *in situ* flux of nutrients, DO, and TCO_2 fluxes between sediments and surface waters. Benthic fluxes were estimated via direct *in situ* measurements of nutrient flux and sediment O_2 demand using benthic flux chambers. Data were also collected on some of the key factors (sediment characteristics and nutrient content, primary producer biomass) known to control fluxes in order to understand key drivers on the magnitude and direction of flux.

3.2 Methods

3.2.1 Field Methods

3.2.1.1 Porewater Concentrations

Sediment porewaters were sampled within two segments of the estuary using porewater equilibrators (peepers: (Hesslein 1976)) during each index period (Figure 3.1). When the peepers are placed into the sediment, solutes from the porewaters come into contact with the filter and a concentration gradient is established between the cell water (no solute) and the porewaters. This causes solutes to diffuse into the cells and, over time, equilibrium is established between the peeper cells and the porewaters whereby the concentrations on both sides of the filter paper are equal. Each peeper was constructed from a 50 x 18 cm solid plexiglass frame into which cells (0.5 x 3.0 x 13 cm) were milled in at a spacing of approximately 1 cm, which are used to sample a depth profile of the sediment porewaters. Each cell is filled with distilled, deionized water that had been bubbled with N gas for 24 hours to remove the O_2 and covered with a 0.45 µm polycarbonate filter paper. The filter is held in place by an outer plexiglass frame secured with Teflon screws. Peepers are kept under a N atmosphere until deployment. Peepers were pushed by hand into the subtidal sediment, making sure that the peeper is vertical and the top of the sediment surface was flush with the top well of the peeper. Peepers were secured with a 30 m cable attached to a stake driven into the upper intertidal zone to facilitate recovery and the location was recorded using GPS coordinates. After a two-week equilibration period (Hesslein 1976, Brandl and Hanselmann 1991), the peepers were retrieved. Peeper recovery was coordinated with the collection of the sediment core and a collection of ambient bottom water (Chapter 2). Sediment cores for bulk characteristics and nutrients, described above, were collected within 2 feet of the peeper location.

Immediately following retrieval, the peepers are placed inside large format ziploc bags that were purged with N gas to minimize artifacts from oxidation of porewater fluids. Porewater samples were extracted from each well using a repeater pipette, dispensed into vials and immediately frozen for analysis. Wells sampled represent porewater depths of: 0 - 1, 1 - 2, 2 - 3, 3 - 4, 4 - 5, 5 - 6, 7 - 8, 10 - 11, and 13 - 14 cm. Each peeper is processed within 15 minutes of recovery. Following sub-sampling of the peeper, ambient bottom water samples were also filtered, collected into vials and frozen for analysis. All water samples were analyzed for the following: S^{-2}, NH_4, NO_3, NO_2, soluble reactive P, TDN, N, TDP, dissolved Fe, dissolved Mn, TCO_2, and DOC. Before freezing S^{-2} samples were preserved with zinc acetate. One field blank was collected for each porewater analyte, and a field blank and a duplicate were collected for each ambient sample. Surface water samples were collected at the time of peeper retrieval.

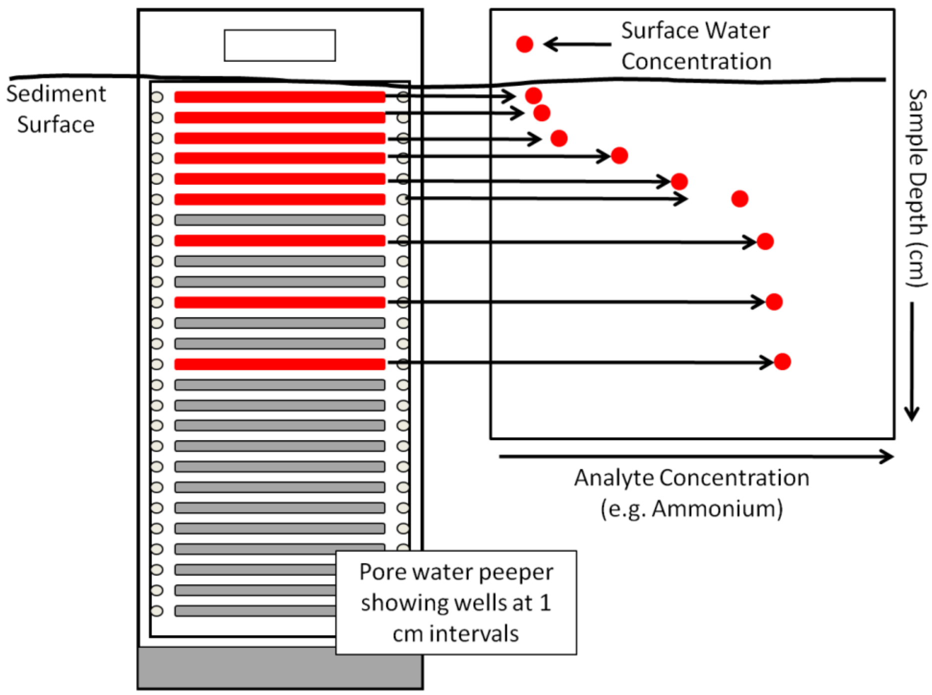


Figure 3.1. Graphic depicting of how porewater profiles are generated from porewater peepers.

3.2.1.1 Measurement of In Situ *Benthic Fluxes*

In situ sediment nutrient, trace metal, and DOC fluxes and sediment O_2 demand were measured using benthic flux chambers (Burdige *et al.* 1999, Berelson *et al.* 2003, Elrod *et al.* 2004). A minimum of two replicate chamber deployments were conducted in each of the Segment sites of Lagoon per index period and were incubated for three to five hours during a neap tidal cycle. Water samples were periodically drawn from the chamber as O_2 levels within the chamber decline (Figure 3.2). These samples, when analyzed, yield the change in concentration of the targeted analyte over time. The surface area of the chamber is known and the volume of water contained with the chamber can be calculated, therefore, a flux rate can be derived.

Four identical benthic flux chambers were built based on a modified design from Webb and Eyre (Webb and Eyre 2004). The chamber is made of clear acrylic measuring 25 cm x 25 cm x 26 cm (l x w x h) mounted to an aluminum frame and is designed such that 10 cm of the chamber height is submerged in the sediment (leaving a height of 16 cm above the sediments) (Figures 3.3 and 3.4). The chamber frame is placed on top of an acrylic “skirt”, a thin sheet of acrylic measuring 24” x 36” with a hole cut in the center. This “skirt” allowed for the acrylic chamber to sink into the sediments but prevented the frame from also sinking into the sediments and thus changing the chamber height over the deployment time. When properly deployed the total chamber volume is 10 liters. Two of the chambers were left clear and open to variations in ambient light throughout the deployment (light chambers, Figure 3.5); the other two chambers were covered in aluminum foil to prevent ambient light from penetrating the chambers (dark chambers).

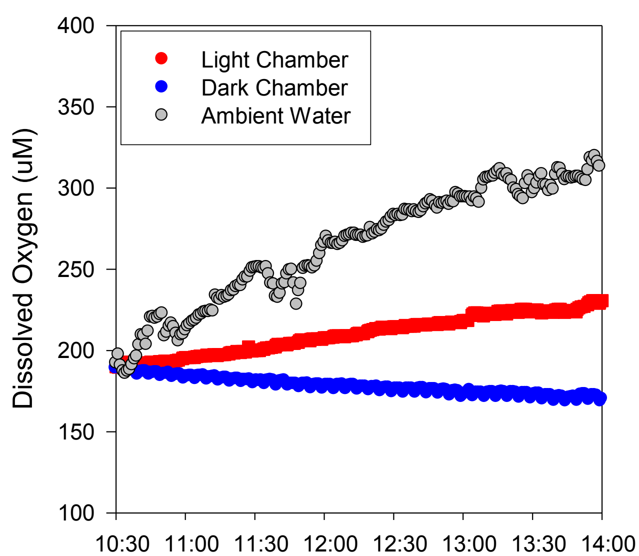


Figure 3.2. Typical chamber time series of dissolved oxygen concentration within the light and dark chambers relative to ambient surface water (Segment Site 2, July 2008). Oxygen concentrations in both the light and dark chambers steadily decreased over the incubation. Flux calculations were made during the most linear part of the curve.

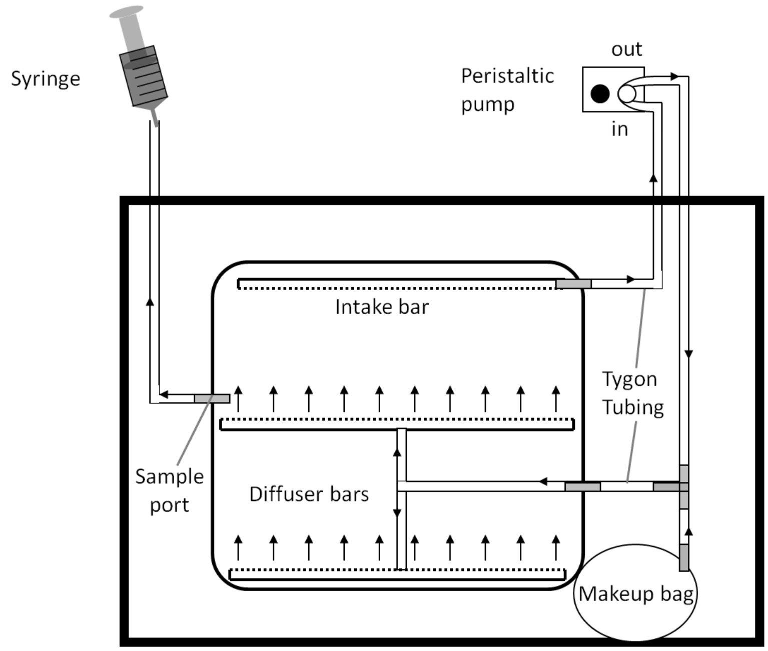


Figure 3.3. Schematic of benthic chamber design as viewed from above.

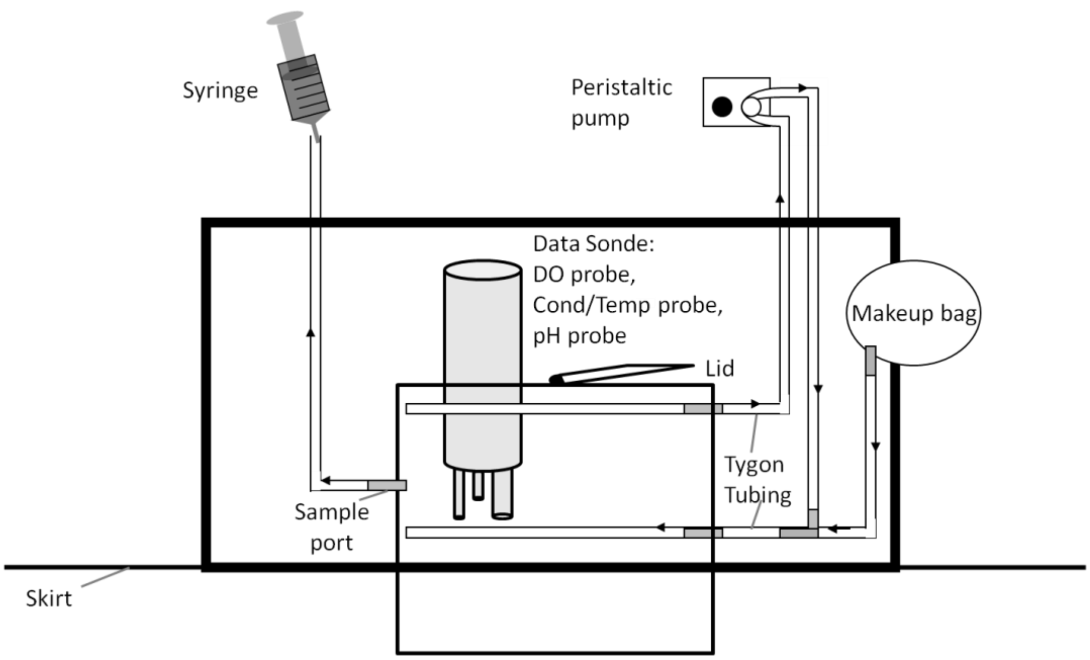


Figure 3.4. Schematic of benthic chamber design as viewed from side.

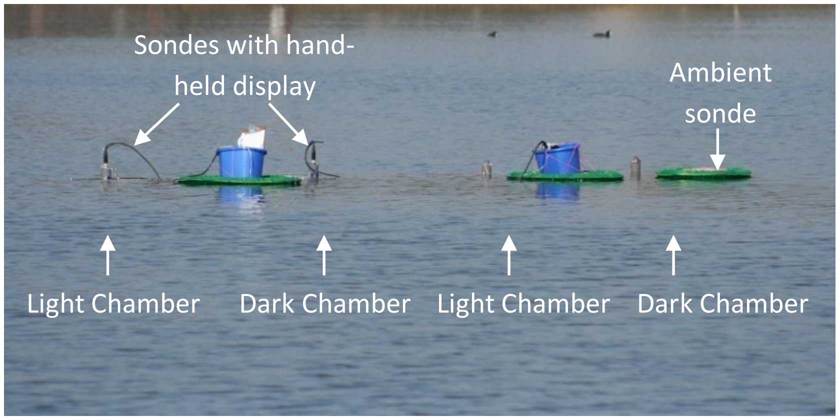


Figure 3.5. Flux chambers during deployment.

Each chamber is equipped with a YSI 6920 data sonde containing a temperature/conductivity probe, optical dissolved O_2 probe, and pH probe allowing for continuous measurements within each chamber and of ambient water every minute. All probes were calibrated in the laboratory before deployment. Two of the chamber probes were connected to a YSI 650 hand-held data display unit allowing for real-time monitoring of DO levels within each chamber. Such a set up allowed the field team to set the timing of chamber samplings to insure that all five samplings were evenly spaced in time and that no sampling would occur after the chamber DO levels fell below 2 mg L^{-1}.

The chamber is "plumbed" with tubing from the chamber to a peristaltic pump which keeps water circulating through the chamber, preventing the development of a benthic boundary layer which would alter the benthic-flux rate (Webb and Eyre 2004). An additional tube is connected to a clean 60 ml syringe which is used to pull water samples from the chamber at the designated intervals. There were five sample draws from each chamber and each sample draw removed approximately 130 ml of water from the chamber (two syringes plus 10 ml of rinse). In order to maintain consistent chamber volume, water from a "make-up" bag is drawn into the chamber as the sample water is withdrawn. The two syringes used to draw chamber water at each sampling port are immediately taken to the shoreline for processing.

Sediments were mildly disturbed during deployment, so chambers were allowed to equilibrate with surroundings before the tops were closed. Chambers were closed when the turbidity measurement in chamber 1 returned to baseline. Dissolved oxygen, temperature, salinity and pH were measured continuously in each chamber and the surface water directly adjacent to the chambers with data sondes. Dissolved oxygen concentrations in the chambers were monitored during the incubation and observed to steadily decline in both the light and dark chambers over the course of the experiment relative the ambient DO concentration (Figure 3.2). Samples were pulled from the chamber at evenly spaced intervals to measure the change in concentration within the chambers as a function of time; these data were used to calculate the flux from the sediments. The interval between samplings was determined based on the rate at which the real-time measurements of DO decreased; the aim of the experiments was to collect five distinct samplings before the DO levels fell below 2 mg L^{-1} (62 µM).

Chamber water and ambient surface water samples were analyzed for TDN, TDP, NH_4, SRP, NO_2, NO_3, DOC, Fe, Mn and TCO_2. One unfiltered split was collected for TN and TP, and then the syringe was fitted with an MCE filter, which was rinsed with 10 ml of sample water, and splits were collected for dissolved nutrients (NO_2, NO_3, NH_4, and SRP), and total dissolved nitrogen and phosphorus (TDN/TDP). The second syringe was fitted with a PES filter, which was rinsed with 10ml of sample water, and splits collected for DOC, dissolved metals (Fe and Mn), and TCO_2. All samples were placed in the dark on ice while in the field. Total carbon dioxide samples were analyzed in the laboratory within 6 hours of collection. The remaining samples were frozen upon return to the laboratory until analysis within their respective holding times.

After the deployment was completed, surface sediment samples were collected and analyzed for grain size, OC, organic N, and TP content, and sediment chlorophyll a. Algal biomass and SAV biomass were comprehensively harvested from the chamber whenever applicable, sorted, cleaned and weighed.

Ambient water samples were collected by SCCWRP during both the benthic chamber deployment (surface waters) and the porewater peeper extraction (bottom waters). The protocol for sampling and processing was the same as given above for the transect sampling (Section 2.3.1).

3.2.1.2 Benthic Infauna

Benthic infauna cores (5 cm diameter, 10 cm deep) were collected from each benthic flux chamber following deployment in each index period. Individuals were identified and counted by genus and extrapolated to estimate the number of infauna of each genus in the top 10 cm of each square meter of subtidal sediment.

3.2.2 Analytical Methods

All water samples were assayed by flow injection analysis for dissolved inorganic nutrients using a Lachat Instruments QuikChem 8000 autoanalyzer for the analysis of NH_4, NO_3, NO_2, and SRP. Dissolved Fe and Mn were measured by atomic adsorption spectrophotometry on a Varian Instruments AA400. Water samples were assessed for TDN, TDP, TN and TP via two-step process: first water samples undergo a persulfate digest to convert all N from all N compartments into NO_3 and the P from all P compartments into orthophosphate; then the resulting digests are analyzed by automated colorimetry (Alpkem or Technicon) for nitrate-N and orthophosphate-P (Koroleff 1985). Water DOC was analyzed on a Shimadzu TOC-5000A Total Organic Carbon Analyzer with ASI-5000A Auto Sampler. Water TCO_2 was analyzed on a UIC instruments carbon dioxide coulometer. Sulfide samples were allowed to react with N,N-dimethyl-p-phenylenediamine and ferric chloride under acidic conditions to yield the product methylene blue, and the concentration of methylene blue was determined spectrophotometrically at 668nm. Concentration of S^{-2} in the sample was calculated by reference to a standard curve (absorbance vs. S^{-2} concentration). Inorganic nutrients and trace metals were run by the Marine Science Institute at the University of California, Santa Barbara and total dissolved and total nitrogen and phosphorus and DOC were run at the University of Georgia Analytical Chemistry Laboratory. Sulfide and TCO_2 were measured by SCCWRP.

3.2.3 Data Analysis

Flux rates (F) for each constituent (dissolved nutrients, metals, TCO_2, and O_2) are calculated from the chamber height (h) and the change in constituent concentration within the chamber over time (dC/dt):

$$\mathbf{F = h * (dC/dt).} \quad \textbf{Eq. 3.1}$$

Concentration versus time was platted as a linear gradient using all data that passed a quality assurance check. Use of the linear portion of the incubation curve assumes that the flux of a constituent is constant during the incubation interval (Figure 3.1).

Productivity at the sediment/water interface can be estimated from the fluxes of TCO_2 and O_2 as carbon fixation and gross primary productivity (GPP) respectively. Carbon fixation is a measure of the amount of inorganic carbon (CO_2) converted to autotrophic biomass and is calculated from the difference between light (with photosynthesis) and dark (without photosynthesis) TCO_2 fluxes:

$$\text{Carbon Fixation} = \text{Flux } TCO2_{light} - \text{Flux } TCO2_{dark} \quad \textbf{Eq. 3.2}$$

Gross Primary Productivity is the rate at which primary producers capture and store chemical energy as biomass and can be calculated from the difference between light (with photosynthesis) and dark (without photosynthesis) O_2 fluxes:

$$\text{GPP} = \text{Flux } O2_{light} - \text{Flux } O2_{dark} \quad \textbf{Eq. 3.2}$$

3.3 Results

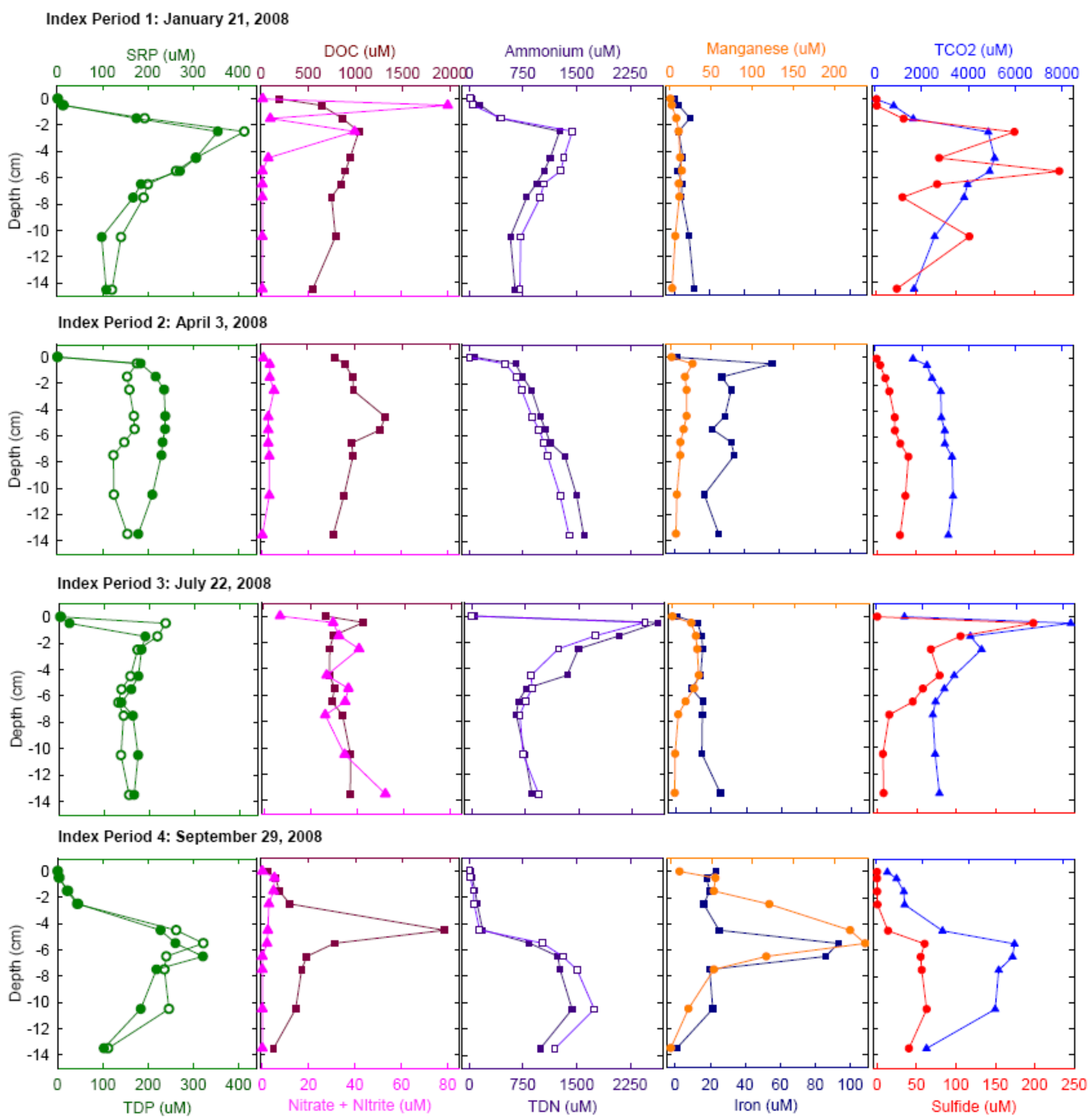
3.3.1 Sediment Porewater Concentrations

Porewater N and P concentrations showed distinct differences among index periods (Figure 3.6). With respect to N, Segment Site 1 TDN mean concentration were roughly equal to that of Segment 2, though peak concentrations varied by index period and each segment had very different vertical profiles. The mean TDN concentrations of the top 6 cm in Segment 1 ranged from 221 µM TDN during September 2008 to 1271 µM TDN in July 2008, while that of Segment 2 ranged from 461 µM TDN during March 2008 to 1321 µM TDN in July 2008. At both segments, NH_4 typically comprised 80% or greater of the TDN. Nitrate+nitrite typically had concentrations of 0 - 40 µM in the top 4 cm at Segment 1 and 0 to 150 µM at Segment 2.

As with N, mean porewater TDP concentrations at Segment 1 and Segment 2 were comparable in magnitude, with slightly higher peak concentrations of TDP at Segment 1 (247 µM TDP) versus Segment 2 (367 µM TDP). As with TDN, SRP generally comprised 70 - 90% of TDP at Segment 1 and 2 throughout all index periods.

Seasonally, the porewater concentrations at the two segment sites peaked during different index periods. At Segment 1, NH_4 concentration in the top 6 cm were highest during the January and July index periods (1497 µM and 2250 µM respectively). Peak concentrations of these constituents coincided with peak S^{-2} (240 µM) and SRP concentrations (375 µM) and near non-detectable concentrations of NO_3 $+NO_2$. Peak S^{-2} concentrations in combination with low Mn and Fe indicate that the sediments during these periods were anoxic. Segment 2 sediment showed the highest concentrations of NH_4 during January (2013 µM), coinciding with peak S^{-2} (12,760 µM) and high SRP (137 µM), indicating that sediments during this time period were anoxic. Sediment at Segment 2 appears better flushed, with profiles that indicate loss of ammonium sulfide during the March, July and September index periods. Segment 1 and 2 mean DOC concentrations generally were of the same order of magnitude and followed a similar seasonal trend. Peak concentration occurred during the January and March index period (1005 to 1246 µM and the lowest concentrations (~400 µM DOC) during the September 2008 index period. At both segment sites, vertical profiles of SRP, NH_4, and TCO_2 concentrations tended to covary, showing peaks at mid-depths of the core and declines further down core. DOC and to a lesser extent NO_3 $+NO_2$ tend to covary with reduced Mn and Fe.

A) San Elijo Segment Site 1



B) San Elijo Segment Site 2

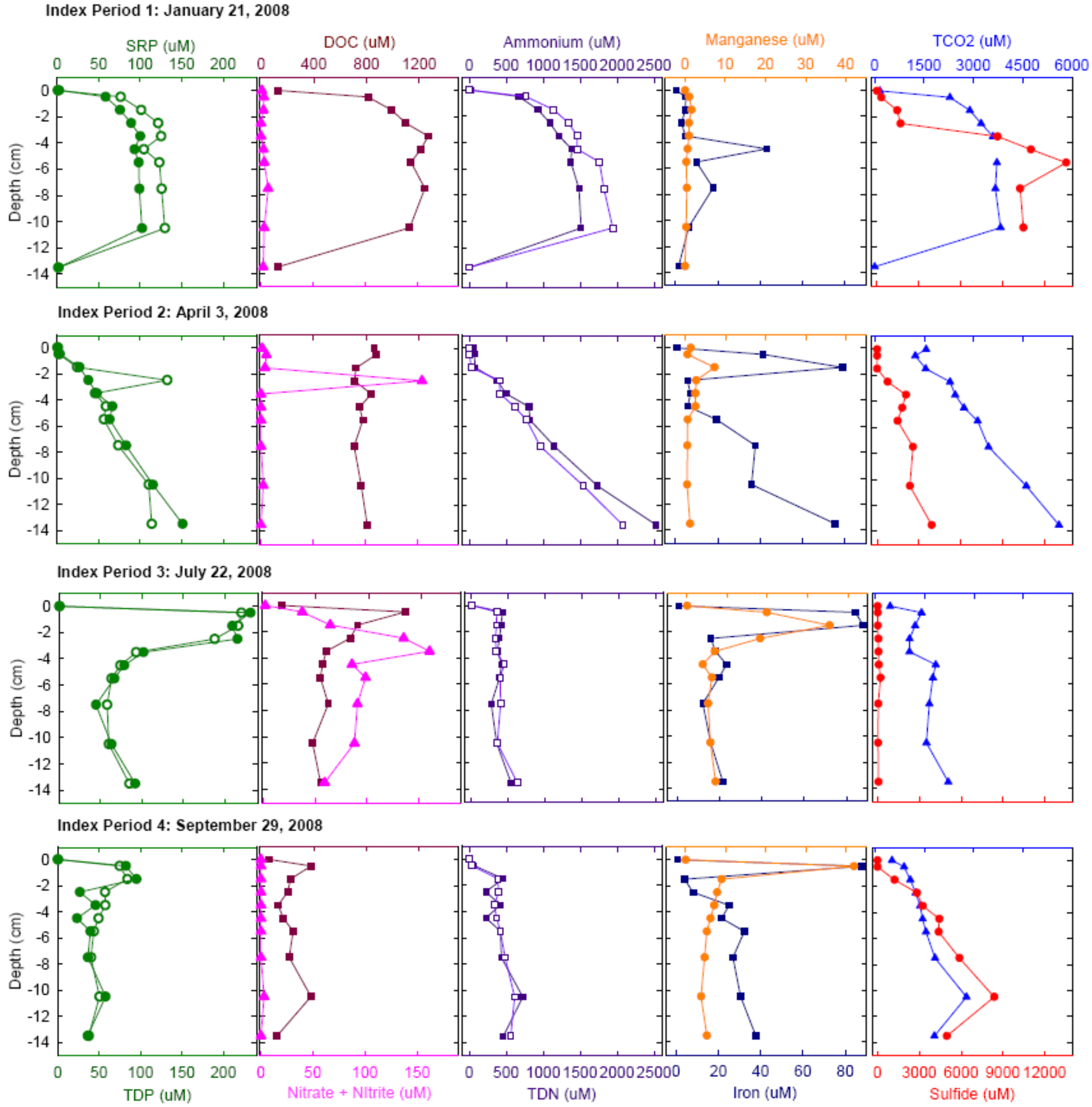


Figure 3.6. Results of sediment porewater sampling in San Elijo Lagoon Segment Sites 1 and 2 (panels A and B respectively) during each index period. Each row represents an index period: the first column shows total dissolved phosphorus (●) and soluble reactive phosphate (○), the second column nitrate + nitrite (▲) and dissolved organic carbon (■), the third column total dissolved nitrogen (■) and ammonium (□), the fourth column iron (■) and manganese (●), and the fifth column shows sulfide (▲) and total carbon dioxide (●). The same scale applies to each column.

3.3.2 Dissolved Oxygen and Carbon Dioxide Fluxes

Overall, sediment O_2 and TCO_2 fluxes in Segments 1 and 2 showed a similar picture of strong O_2 demand in the summer and fall (Table 3.1, Figures 3.7 and 3.8). Segment 1 sediments showed a small net release of O_2 (5 mmol m^{-2} d^{-1}) and uptake of TCO_2 during the winter (3 mmol m^{-2} d^{-1}) and a small uptake of oxygen during the spring (-3 mmol m^{-2} d^{-1}), indicating that during these time periods the sediments were slightly autotrophic or balanced (respiration equaled primary production; Figure 3.7). From summer through fall, however, net oxygen fluxes were into the sediment and net TCO_2 fluxes were strongly positive, indicating net heterotrophy (-12 to -94 mmol m^{-2} d^{-1} O_2 and 42 mmol m^{-2} d^{-1} TCO_2). In Segment 2, the sediments were net heterotrophic during all index periods (Figure 3.8), with net oxygen fluxes ranging from -23 mmol m^{-2} d^{-1} O_2 in the spring to -94 mmol m^{-2} d^{-1} O_2 in the fall index period. TCO2 effluxes were high at this, with ranges of 53 mmol m^{-2} d^{-1} in the spring to 146 mmol m^{-2} d^{-1} during the summer index period. There was good correspondence bewteeen the DO and TCO_2 data, showing similar trends between both data types.

Among co-factors measured in all chamber incubations at Segments 1 and 2, DO flux was positively correlated with sediment C:N ratio and negatively correlated with TCO_2 and TDN fluxes (Table 3.2). TCO_2 flux positively correlated with infaunal abundance and negatively correlated with sediment C:N ratio (Table 3.2).

Table 3.1. Mean and standard deviation of Segment 1 and 2 DO fluxes by index period.

Index Period	Net	Std. Dev
Jan 2008	-16.0	21.3
Mar 2008	-13.3	10.3
July 2008	-72.2	22.2
Sept 2008	-53.6	41.3

Table 3.2. Spearman's Rank Correlation among DO, TC02, nutrient fluxes and factors known to influence flux (Temperature – Temp, sediment C:N Ratio (CN), sediment C:P (CP), total infaunal abundance (Infauna), sediment % fines, benthic chl a within chambers (chl a)). No macroalgal biomass was present in chambers. Table gives correlation (r) and p-value for α = 0.05). Bolded values are significant at p-value<0.05.

Metric	Statistic	Total Infauna	Sediment C:N Ratio	% Fines	Benthic Chl a	Macroalga Biomass	DO Flux	TCO2 Flux	NH4 Flux	TDN Flux	TDP Flux	NO3 Flux	SRP Flux
Total Infauna Abundance	Corr.	1	-0.27	**-0.53**	0.25	-0.07	-0.29	**0.36**	0.24	0.26	***0.38***	0.29	0.10
	p-value		0.15	**0.00**	0.17	0.70	0.12	**0.05**	0.19	0.16	***0.03***	0.11	0.58
Sediment C:N Ratio	Corr.		1	**0.53**	-0.13	-0.13	**0.49**	**-0.35**	-0.33	-0.22	-0.18	0.02	-0.26
	p-value			**0.00**	0.49	0.48	**0.01**	**0.05**	0.07	0.24	0.33	0.90	0.15
Sediment % Fines	Corr.			1	**-0.34**	**0.46**	0.29	-0.34	**-0.55**	**-0.37**	-0.28	0.07	-0.11
	p-value				**0.05**	**0.01**	0.12	0.06	**0.00**	**0.04**	0.12	0.69	0.54
Benthic Chl a	Corr.				1	**-0.41**	0.04	-0.10	-0.17	-0.07	0.24	-0.20	-0.16
	p-value					**0.02**	0.84	0.58	0.34	0.70	0.19	0.26	0.38
Macroalgal Biomass	Corr.					1	-0.31	0.14	-0.19	0.18	-0.07	0.30	0.11
	p-value						0.10	0.46	0.29	0.33	0.70	0.10	0.54
DO Flux	Corr.						1	**-0.83**	-0.27	**-0.43**	-0.15	-0.24	-0.27
	p-value							**<.0001**	0.15	**0.02**	0.44	0.21	0.16
TCO2 Flux	Corr.							1	0.28	0.32	0.12	0.21	0.32
	p-value								0.12	0.08	0.50	0.24	0.07
NH4 Flux	Corr.								1	**0.48**	**0.54**	0.03	**0.51**
	p-value									**0.01**	**0.00**	0.87	**0.00**
TDN Flux	Corr.									1	**0.38**	**0.52**	0.30
	p-value										**0.04**	**0.00**	0.10
TDP Flux	Corr.										1	0.00	**0.43**
	p-value											0.99	**0.01**
NO3 Flux	Corr.											1	0.03
	p-value												0.88
SRP Flux	Corr.												1
	p-value												

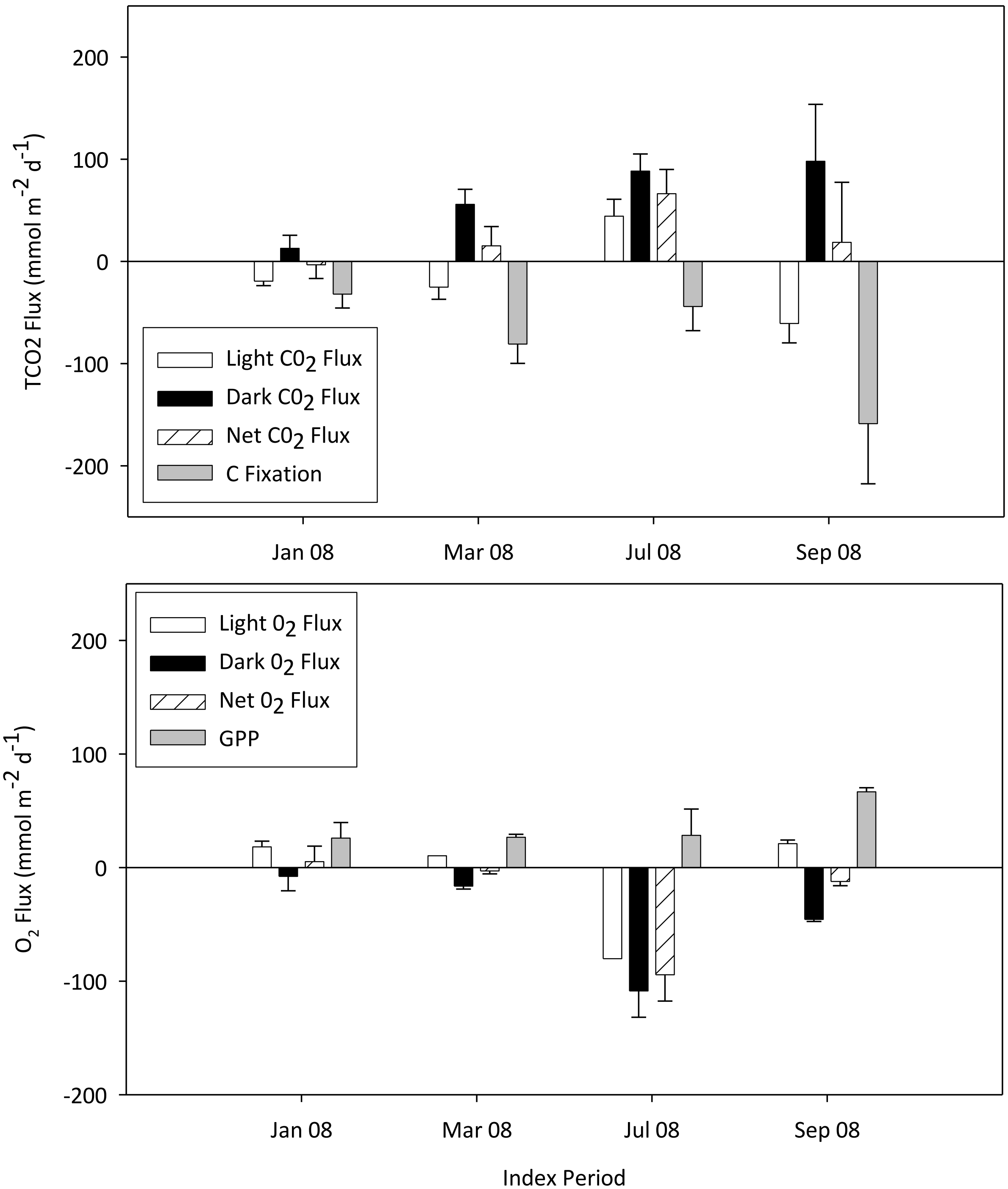


Figure 3.7. Segment Site 1 light, dark, and net (24-hour average of light and dark), TCO2 fluxes and estimated C fixation (top); andO2 fluxes and Gross Primary Productivity (GPP; bottom). Error bars represent the standard deviation between replicates.

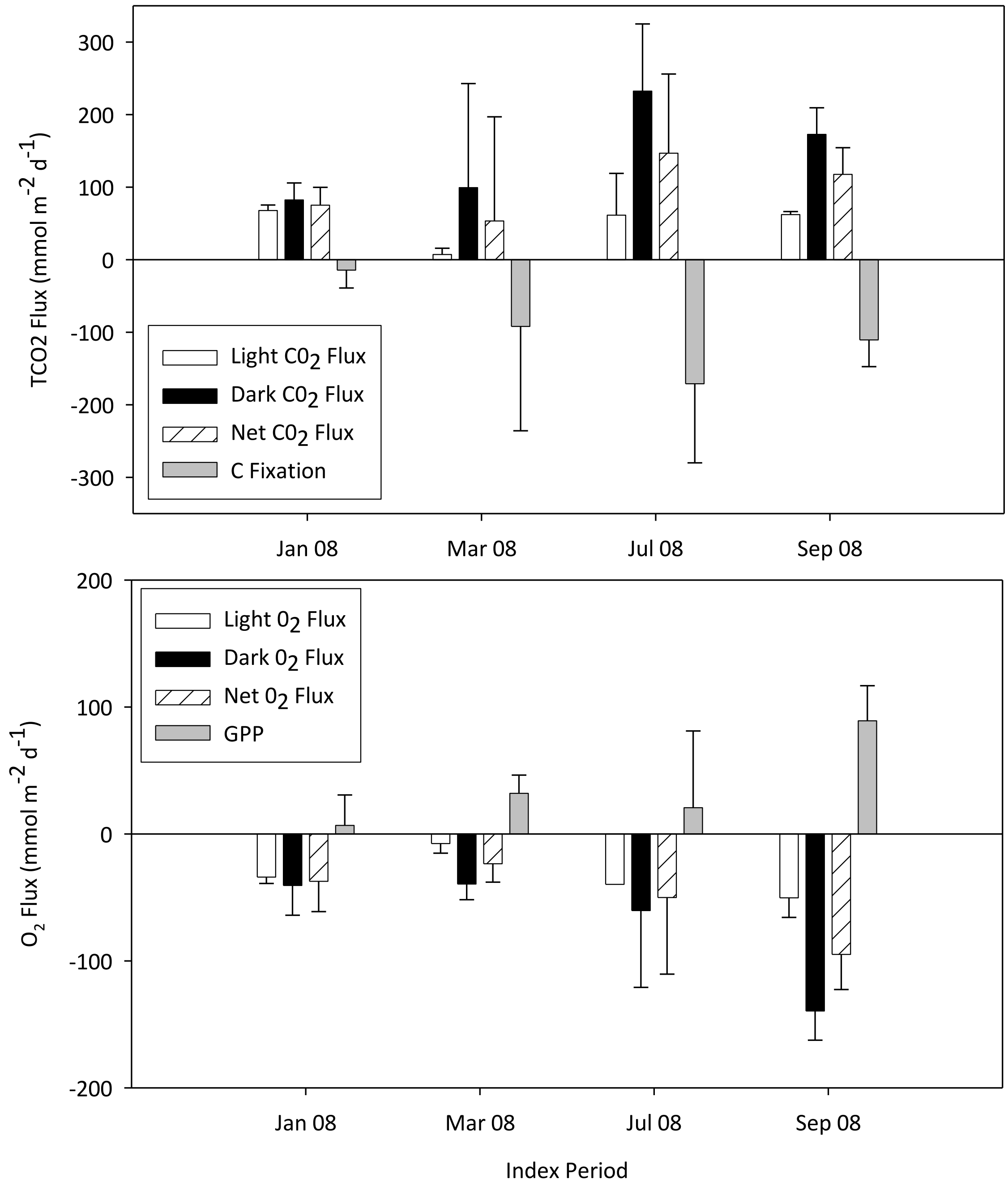


Figure 3.7. Segment Site 2 light, dark, and net (24-hour average of light and dark), TCO2 fluxes and estimated C fixation (top); and O2 fluxes and Gross Primary Productivity (GPP; bottom). Error bars represent the standard deviation between replicates.

3.3.2.1 Nitrogen Fluxes

Net fluxes (mean of light and dark incubations) of N (NH_4, NO_3 and TDN) exhibited some clear patterns with respect to season and Segment site (Table 3.3, Figure 3.9). Net fluxes across light and dark chambers show Segment 1 and Segment 2 was a consistent source of NH_4 and sink for NO_3 during all index periods. The balance of NH_4versus NO_3 fluxes drove the overall TDN fluxes, with the net fluxes showing a TDN influx during the winter and spring index periods (-32 to -5 mmol m^{-2} d^{-1}) and an efflux of TDN during the summer and fall index periods (0.8 to 24 mmol m^{-2} d^{-1}) Summer and fall NH_4fluxes were an order of magnitude higher at Segment 2 than at Segment 1. Nitrate influxes were comparable in magnitude during January 2008, but an order of magnitude higher at Segment 1 than at Segment 2 during the March index period, closer to the dominant source of NO_3 to the system. No significant differences existed between light and dark incubations for TDN, NH_4, or NO_3 fluxes (p-value>0.04; Figure 3.9).

Table 3.3. Nitrogen net fluxes and standard deviations from light and dark chamber fluxes (n = 4) by index period. All fluxes are in mmol N m^{-2} d^{-1}.

Index Period	Segment	TDN	NH4	NO3
Jan-08	Segment 1	-17.1±18.5	0.7±1.1	-18.3±13.7
Mar-08		-28.8±23.5	0.7±0.4	-13.3±20.8
Jul-08		3.0±1.2	0.8±0.5	-0.5±0.4
Sep-08		3.7±5.3	1.2±0.4	-0.3±0.5
Jan-08	Segment 2	-13.1±31.2	2.0±1.7	-13.2±6.9
Mar-08		-5.0±7.5	-1.0±0.3	-1.7±1.5
Jul-08		15.3±13.9	22.2±5.7	-0.6±0.5
Sep-08		20.1±7.0	24.0±7.1	-2.1±0.6

Of the co-factors measured in benthic chamber incubations at Segments 1 and 2, NH4 and TDN flux had significant positive correlations with total sediment % fines, TDP and SRP fluxes (Table 3.2). Nitrate fluxes had a significant correlation with TDN flux.

3.3.2.2 Phosphorus Fluxes

Net fluxes (mean of light and dark incubations) of TDP and SRP exhibited some clear patterns with respect to season and segment site (Table 3.4; Figure 3.9). Net fluxes across light and dark chambers show Segments 1 and 2 to be a consistent source of TDP during the summer and fall index periods (1.5 to 3.6 mmol TDP m^{-2} $d^{-1}$and 0.6 to 2.2 mmol SRP m^{-2} d^{-1}). In contrast, in contrast, fluxes of TDP and SRP were more variable, with a small magnitude.

Of the co-factors measured in benthic chamber incubations at Segments 1 and 2, TDP flux had significant positive correlations with total benthic infaunal abundance, TDN and TDP fluxes; Table 3.2), while SRP fluxes were correlated with NH4 and TDP fluxes.

Table 3.4. Phosphorus net fluxes and standard deviations from light and dark chamber fluxes (n = 4) by index period. All fluxes are in mmol P m^{-2} d^{-1}.

Index Period	Segment	TDP	SRP
Jan-08	Segment 1	-0.2±1.5	0.8±1.2
Mar-08		-0.3±1.7	0.04±1.2
Jul-08		1.5±0.6	0.9±0.6
Sep-08		1.5±0.7	0.6±0.3
Jan-08	Segment 2	-0.2±0.8	0.8±0.9
Mar-08		0.6±1.3	-0.8±0.3
Jul-08		2.4±0.9	0.9±1.0
Sep-08		3.6±2.1	2.2±1.1

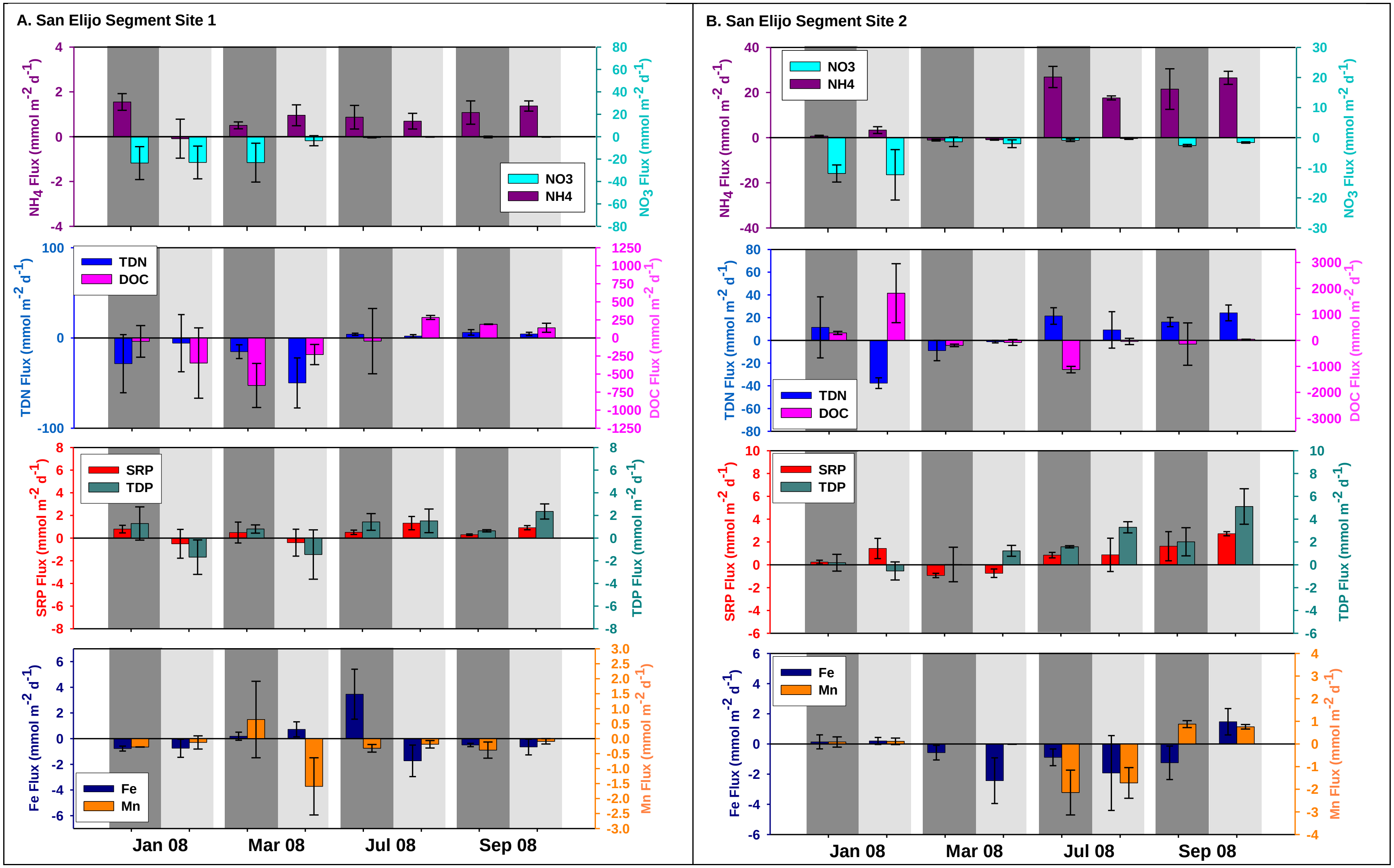


Figure 3.9. Segment Sites 1 (left) and 2 (right) benthic fluxes for dark (dark grey bands) and light (light grey bands) for each of the index periods. Error bars represent the standard deviation between replicate chambers.

3.3.3 Benthic Infaunal Diversity and Abundance

In San Elijo Lagoon, the benthic infauna community appears to be dominated by polychaetes and capitelids at densities exceeding 5000 individuals m^{-2} at Segment 2, indicative of organically enriched sediments (Figure 3.10). Diversity of organisms was generally much higher at Segment 2 than Segment 1. Abundances stayed relatively high during all index periods at Segment 2, whereas abundances were depressed during the first two index periods of the year at Segment 1.

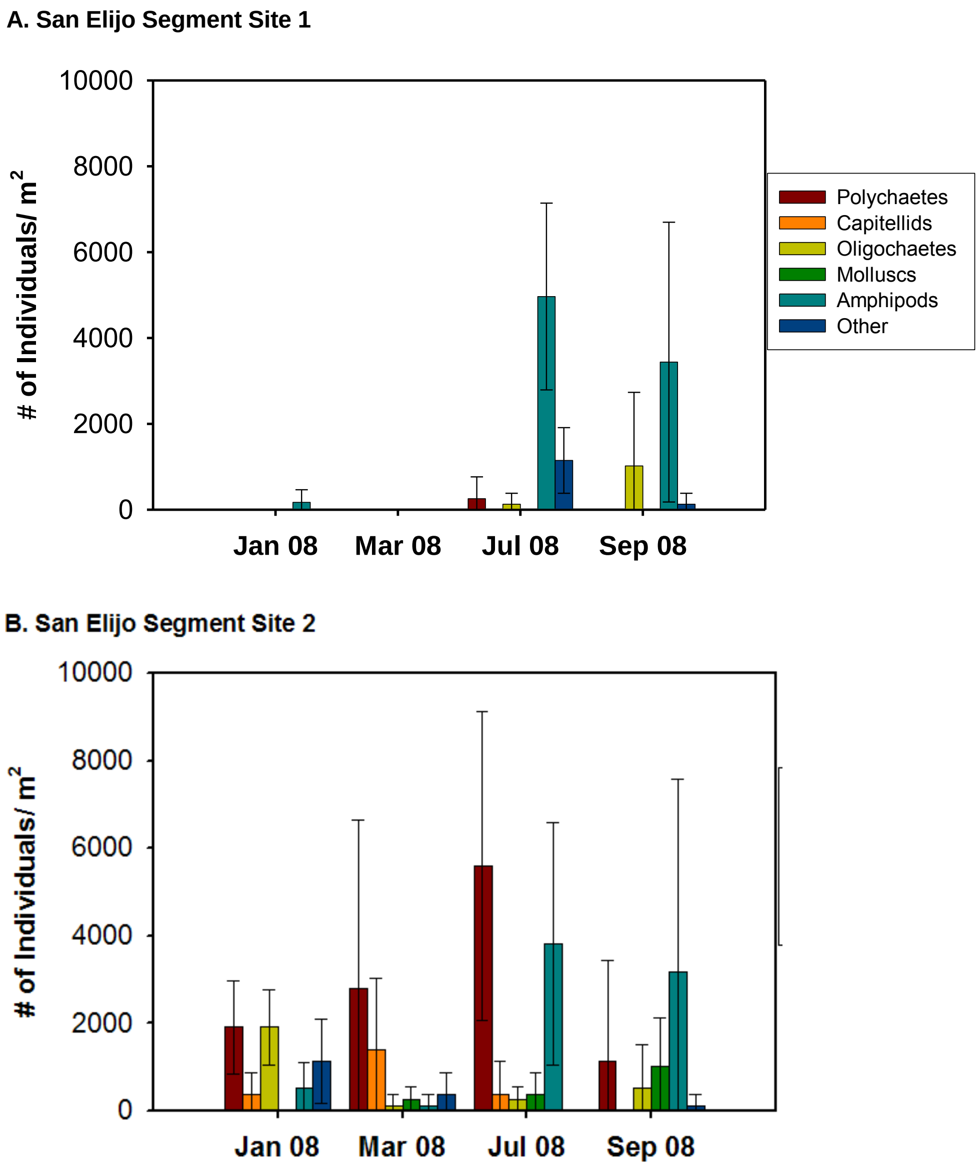


Figure 3.10. Mean and standard deviation of the abundance of benthic infauna taxa in San Elijo Lagoon in benthic chambers by index period.

3.4 Discussion

Estuaries, at the terminus of watersheds, are typically subject to eutrophication due to high inputs of anthropogenic nutrient loads and hydromodification. Primary production in estuaries can be fueled by either “new” nutrients entering the system from the watershed or from “recycled” nutrients from the remineralization of particulate and dissolved organic matter that is brought into the estuary during rain events and transported to the water column via benthic flux. Shallow coastal lagoons with natural or anthropogenic muting of the tidal regime are particularly susceptible, because restricted exchange increases the residence time of water and thus the amount of time nutrients are available for uptake by primary producers (Sundbäck and McGlathery 2005).

Overall, this component of the study documented two principal findings:

1. Averaging over season and segment, benthic flux appears to provides net source of NH_4 (6.3 mmol NH_4 m^{-2} hr^{-1}) and SRP (0.6 mmol SRP m^{-2} hr^{-1}) to surface waters. Mean annual influx of NO_3 into the sediment was high (-9 mmol m^{-2} hr^{-1}). Measured rates of denitrification were 2 orders of magnitude lower than this rate (T. Kane, UCLA Dissertation) and thus can only partially explain the fate of this influx of NO_3 into the sediments. A more likely explanation is that some portion of this NO_3 is being reduced to NH_4through dissimilatory NO_3 reduction and is cycling back up to surface waters as ammonium. Dissimilatory NO_3 reduction is a pathway that is favored under anoxic sediment conditions.

2. On average, estuary metabolism tends to be net heterotrophic (net uptake of O_2 by sediments) year round, with peak mean rates of -72 mmol O_2 m^{-2} hr^{-1} occurring during July 2008. The fluxes, measured with benthic chambers, are supported by continuous DO data, which showed the estuary to be below 5 mg L^{-1} 42 - 62% of the time during the summer and fall at Segment 2 and 1 respectively. These rates of oxygen uptake were comparable to other depositional environments in eutrophic/hypereutrophic estuaries. The Lagoon exhibited high net TCO_2 effluxes, which are typically driven by respiration of accumulated dead or decaying biomass (organic matter accumulation) as well as redox processes in the sediments that produce TCO_2, such as sulfate reduction. Correlations of TCO_2 flux with infaunal abundance indicate that advective processes such as bioirrigation are increasing the fluxes across the sediment water interface.

3.4.1 Significance of Rates of Benthic O2 and TCO2 Fluxes in San Elijo Lagoon

Eutrophication produces excess organic matter that fuels the development of hypoxia (i.e., low surface water DO concentration) as the organic matter is respired (Diaz 2001). When the consumption of O_2 exceeds the rate of resupply (decomposition of excessive amounts of organic matter exceeds diffusion/mixing of O_2 to bottom waters), O_2 concentrations can decline below the limit for survival and reproduction of organisms (Stanley and Nixon 1992, Borsuk *et al.* 2001, Diaz 2001). The consequence of this is often a cascade of effects including loss of habitat and biological diversity, development of foul odors and taste, and altered food webs (Sutula *et al.* 2007). Dissolved oxygen levels that fall below 5 mg

L^{-1} can be a stressor to aquatic life and levels below 1-2 mg L^{-1} for more than a few hours can be lethal to both fish and benthic invertebrates (USEPA 2000, 2003). The basin plan water quality objective for the San Elijo Lagoon states that DO shall be greater than or equal to 5 mg L^{-1}.

Comparison of the magnitude of O_2 and TCO_2 fluxes to *in situ* measurements in other systems indicate that the Lagoon is of equal or greater magnitude to most well-documented eutrophic estuaries (Table 3.5). The net O_2 and TCO_2 fluxes show that Segment 2 sediment were net heterotrophic year round and Segment 1 sediment were net heterotrophic in the summer and fall, indicating that the Lagoon is decomposing more organic matter than producing it at the time of sampling (Berelson et al. 1998, Eyre and Ferguson 2005, McGlathery et al. 2007). DO fluxes are supported by continuous DO data, which found DO concentrations below 5 mg L^{-1} approximately 42 - 62% of the year with brief periods of hypoxia (<2 mg L^{-1}), coinciding with muted tidal hydrology during neap tides. This study found that O2 were positively correlated and TCO_2 negatively correlated with sediment C:N ratio, indicating that sediment O_2 demand and TCO_2 effluxes are typically higher in sediments with greater organic matter and nutrient content. Lagoonal environments are more likely to be susceptible to hypoxia than river mouth estuaries because they have a tendency to deposit fine-grain, organic matter rich sediments (Schubel and Kennedy 1984, Paerl *et al.* 1998, Bate *et al.* 2004). Thus lagoonal estuaries such as Buena Vista, Famosa Slough and San Elijo Lagoon have higher sediment O_2 demand than river mouth estuaries such as Santa Margarita River and Loma Alta Slough (Table 3.5). TCO2 and DO fluxes were higher at Segment 2, which is a site more subject to advective transport as evidenced by correlations of fluxes with total infaunal abundance and depleted porewater profiles.

Shallow estuaries such as San Elijo Lagoon can develop low O_2 typically through one of three main processes: 1) as episodic events driven by primary producer blooms and their subsequehnt decomposition (McGlathery *et al.* 2007), 2) chemical O_2 demand driven by sediment heterotrophic bacteria or redox reactions, and/or 3) during density-driven stratification which develops during intermittent closure to tidal exchange when the estuaries "trap salt" and preclude diffusion and mixing of O_2 to bottom waters (Largier *et al.* 1991). In San Elijo Lagoon, surface water DO appears to be driven by high sediment O_2 demand during the summer and fall, time periods which coincide with peak macroalgal biomass and high temperatures, which would drive increases in microbial activity associated with organic matter decomposition, sulfate reduction, and other sediment redox processes. Density-driven stratification may be contributing to low surface water DO, particularly during neap tides when turbulent mixing is least likely to contribute to the breakdown of stratification. However, because the data sondes were only placed in bottom waters, no information on stratification is available for this estuary.

Table 3.5. Comparison of fluxes from the San Elijo Lagoon to other estuarine environments . All units are in mmol m^{-2} d^{-1}.

Site	O_2	TCO_2	SRP	NH_4	NO_3
Santa Margarita (this study)					
Segment One	4.5±66.5	-4.2±14.7	0.5±1.3	8.5±11.2	-13.9±14.3
Segment Two	-6.5±33.1	-3.1±23.8	0.1±0.4	0.2±0.9	-6.4±10.4
Loma Alta Slough (this study)	46.0±63.8	-6.7±58.0	0.1±0.2	1.8±4.9	-0.6±2.9
San Elijo Lagoon (this study)					
Segment One	-12.3±17.9	28.6±21.7	0.4±0.3	0.9±0.3	-8.1±8.5
Segment Two	-51.5±26.8	98.1±36.4	0.8±0.3	11.8±2.3	-4.4±2.8
Buena Vista Lagoon (this study)					
I-5 Basin	-7.5±34.5	3.6±13.2	-0.3±0.2	-0.4±0.4	-0.1±5.9
PCH Basin	-137.9±38.0	76.7±43.0	0.2±0.4	-2.2±6.2	-1.3±1.8
Famosa Slough (this study)	-43.8±17.7	58.9±46.4	-0.2±0.2	1.0±1.4	-0.2±0.5
Shallow SE Australian Lagoons (Eyre and Ferguson 2002)	-50 to 0	10 to 100		-3.4 to 0.3	0 to -60
Hog Island Bay (Tyler et al. 2003)	-0.003 to +0.012			-0.33 to + 0.42	-0.12 to +0.009
Shallow NE Australian Lagoons (Ferguson et al 2004)				-0.2±0.3	-0.4 ± 0.3
Newport Bay (Sutula *et al.* 2006)	-43 ± 20	107 ± 81	0.36 ± 0.52	5.7 ± 2.7	-3.0 ± 5.3
Los Angeles Harbor (Berelson unpublished)	-18.9 ± 6.3	39 ± 29	0.33 ± 0.40	3.9 ± 2.9	-0.19 ± 0.18
San Francisco Bay (Hammond *et al.* 1985)	-30 ± 7	24 ± 8	0.10 ± 0.50	1.1 ± 0.1	-0.5 ± 0.6
Monterey Bay (Berelson *et al.* 2003)	-9.1 ± 2.4	9.9 ± 2.7	0.11 ± 0.07	0.56 ± 0.24	-0.57 ± 0.48
Chesapeake Bay (Callender and Hammond 1982, Cowan and Boynton 1996)	-49		0.8	10.2	-2.9 – 0.2
San Quentin Bay, Baja CA (Ibarra-Obando *et al.* 2004)	-23.4 ± 10.7	31 ± 22.9	0.114 ± 0.140	2.15 ± 1.39	
Tomales Bay (Dollar *et al.* 1991)	-9.37 ± 9.56	20.7 ± 24.4	0.24 ± 0.40	1.96 ± 2.39	-0.01 ± 0.17
Plum Island Sound (Hopkinson *et al.* 1999)	-33 – -170	23 – 167	-0.25 – 1.5	4.8 – 21.2	

3.4.2 Seasonal Patterns of Nutrient Fluxes and Benthic Metabolism in the San Elijo Lagoon

In shallow coastal lagoons such as the San Elijo Lagoon, trends in benthic metabolism and nutrient flux are typically regulated by temporal changes in the primary producer community as well as process of diagenesis and cycling within the sediments (Sundbäck and McGlathery 2005). Porewater nutrient concentrations are controlled by a variety of factors, including exchange via the sediments, denitrification, nitrification, dissimilatory NO_3 reduction, decomposition and uptake by organisms (Figure 3.11). Exchange with the surface waters can be driven by diffion, or advective processes such as tidal pumping, groundwater input, etc. Thus interpretation of porewater profiles and *in situ* benthic fluxes can yield rich information about the redox status and dominant processes controlling nutrients cycling within the sediments and the degree to which they provide a net source of nutrients to support primary producers in the surface waters (Figure 3.12).

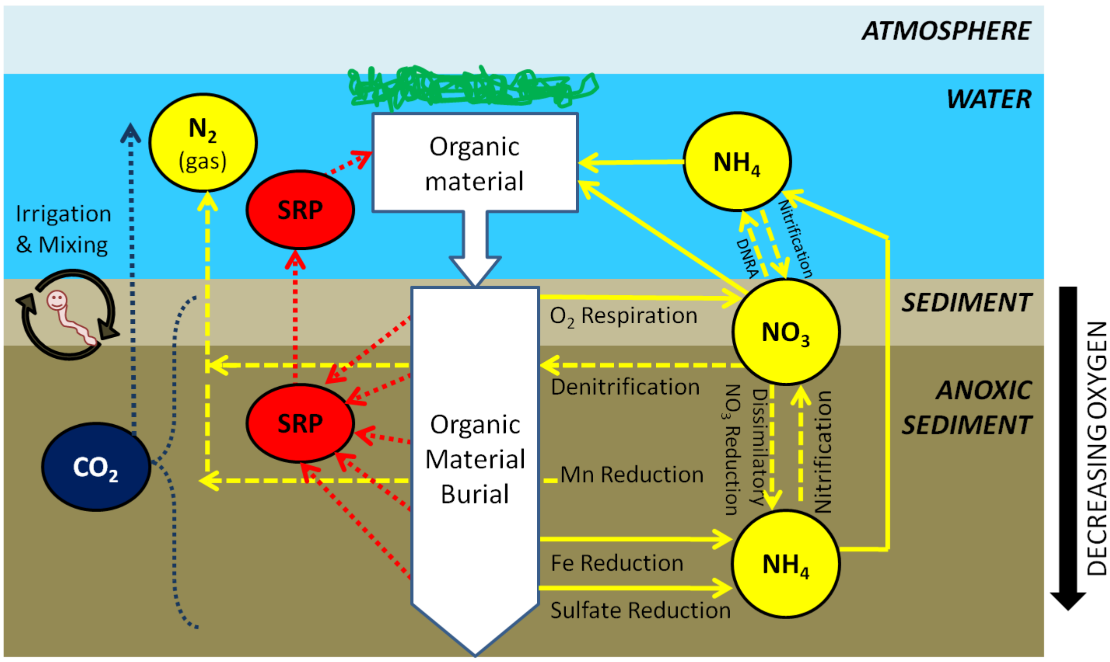


Figure 3.11. Pathways for nutrient cycling and decomposition of organic matter in the sediments.

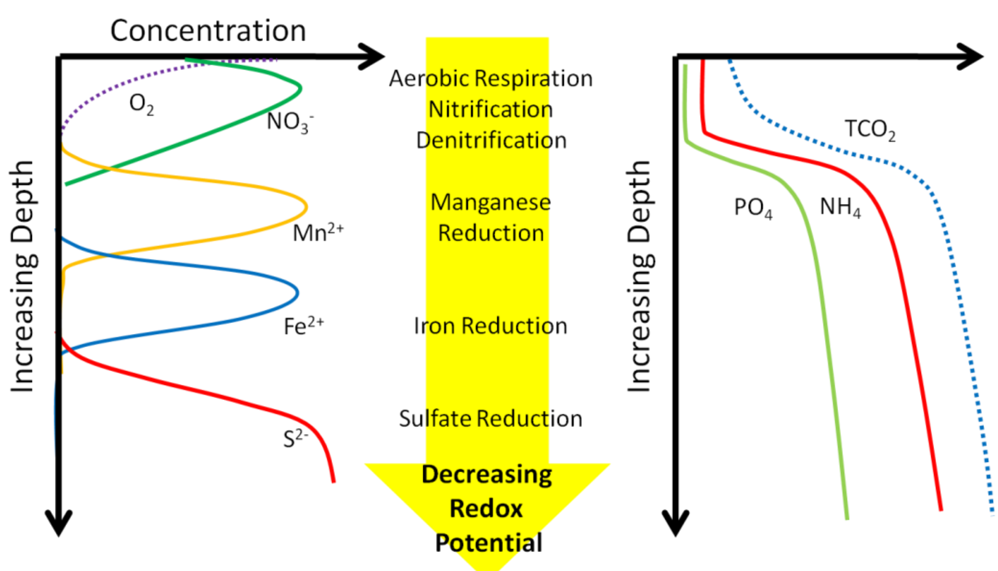


Figure 3.12. Sediment porewater profiles reflect redox status of the sediment.

For estuaries with high inputs of nitrate, the balance between denitrification and dissimilatory NO_3 two processes is important for the efficiency of N cycling and eutrophication in an estuary. Denitrification is the microbially mediated conversion of NO_3 to N gas, a process that occurs in moderately reduced (low O_2) sediments and represents an important permanent loss of nitrogen from an estuary (Seitzinger 1988). Dissimilatory nitrate reduction (DNR) is the microbially mediated conversion of NO_3 to NH_4, a process which occurs in anoxic sediments (An and Joye 2006) and by which N can be recycled to surface waters and available for biological uptake. Averaging over segments and seasons, mean benthic flux appears to provide net source of NH_4 (6 mmol NH_4 m^{-2} hr^{-1}) to surface waters. The magnitude of these NH_4 fluxes are among the highest documented in the literature (Table 3.5). This suggests that one source of this sediment NH_4flux is DNR. Mean influx of NO_3 into the sediment was high (-9 mmol m^{-2} hr^{-1}), with peaks occurring the in winter and spring index periods. Measured rates of denitrification in slurried cores were 1 - 2 orders of magnitude lower than this rate (0.02 - 0.2 mol m^{-2} hr^{-1}, T. Kane, UCLA Department of Biology Doctoral Dissertation; Table 3.6), within the range of published rates in eutrophic estuaries (0.05 - 0.25 mmol m^{-2} hr^{-1}, Seitzinger 1988) and thus can only partially explain the fate of this influx of NO_3 into the sediments. A more likely explanation is that a portion of this NO_3 is being reduced to NH_4 through DNR and cycling back up to surface waters as NH_4. The porewater profiles provide additional evidence of DNR; with depth, NH_4 increases, with a corresponding decrease in NO_3, signaling the DNR (conversion of NO_3 to NH_4) may be a dominant process (An and Gardner 2002, Brock 2006, Porubsky *et al.* 2009). This may be a dominant process in sediments of Segment 1 and Segment 2 during the summer and fall. Peak NH_4 values coincided with higher SRP values and often with peaks in S^{-2} concentrations up to 12000 µM, signaling that sediments in an anoxic state and thus would favor DNR over denitrification. Denitrification may be playing a large role during the winter and spring time when sediments are better flushed and oxygenated (Seitzinger 1988). Thus in the winter and spring, the Lagoon is better able to assimilate external DIN inputs through denitrification, but as the estuary becomes more eutrophic during summer and fall, the efficiency of N loss is greatly reduced.

Table 3.6. Denitrification rates measured in San Elijo Lagoon subtidal sediments on slurried cores. All rates in µmol m^{-2} hr^{-1} (T. Kane, UCLA Dissertation 2011).

Segment	March 2008	July 2008	August 2008
Segment 1	247.2±12.6	0.3±0.1	0.3±2.1
Segment 2	20.2±3.8	0±0	0±0

Averaging over index periods, sediments of the Lagoon appear to be source of SRP (0.6 mmol SRP m^{-2} hr^{-1}). During winter and spring, net fluxes of SRP are low, particularly Segment 1. Sediments in this area appear more oxic, thus trapping P in particulate form associated with Fe and aluminum oxides (Roden and Edwards 1997). During the summer and fall index periods, sediments appear to act as a source to surface waters. The consequences of sulfate reduction for P cycling and fluxes, as indicated by peak S^{-2} concentrations, is important. As sulfate is reduced, Fe(II) is converted to FeS_2 (Roden and Edmonds 1997). Because FeS_2cannot bind SRP, SRP adsorbed to Fe(II) are released, producing high porewater concentrations and net effluxes to surface waters. These measurements are supported by mixing diagrams of surface water SRP and TDP, which indicate a net source of SRP to surface waters.

Patterns of benthic nutrient cycling shifted seasonally, as can be observed from data representing the four index periods. The winter and spring index periods were characterized by frequent storm events. Peak flows during storm events in the winter index period would be expected to provide a subsidy of nutrients and particle-or organic matter-bound nutrients as well as an environment dominated by physical mixing of the surface waters and sediments (Smith *et al.* 1996, Correll *et al.* 1999, Paerl 2006). As evidence of this, surface sediments at both segment sites during the winter period contained the highest % fines and C:N ratios of any of the four index periods. As a result, primary producer biomass was low thus fluxes may have been controlled to a greater extent by advective processes (Sutula *et al.* 2004, Sutula *et al.* 2006).

During the spring sampling period, sediments appear were well flushed, as demonstrated by flat or sloping profiles of SRP, NH_4, and S^{-2} (Froelich *et al.* 1979), and thus sediment O_2 demand was moderate. Nitrate fluxes are large and negative (into the sediment), suggesting denitrification may occurring. This concept is supported by independent measures of denitrification in Lagoon sediments, which showed peak rates in the spring (Table 3.6), particularly at Segment 1, the site proximal to the largest input of NO_3. The MPB, which is the dominant primary producer during the spring can act to decouple nutrient turnover in the sediments from the overlying water column by acting as a “filter” for nutrient efflux from the sediments, at times completely intercepting nutrient fluxes across the sediment-water interface (McGlathery *et al.* 2004, McGlathery *et al.* 2007). Low fluxes of $NH_4$and SRP during the spring are an indication that this phenomenon may be occurring (Table 3.4).

During the summer and fall index periods, macroalgae replaced MPB as the dominant primary producer. Macraolgae have been shown to control the biomass of other primary producer communities, including MPB, because of a competitive advantage in nutrient uptake rate (Fong *et al.* 1993, Fong *et al.* 2003). While MPB has been shown to enhance the O_2 penetration of sediments, macroalgal biomass is known to deplete sediment O_2 and shallow the depth of Fe, Mn and sulfate reduction, resulting in high porewater concentrations near the surface (Tyler et al. 2005). Sulfide reached peak concentrations in Segment 1 surface sediments during July, coinciding with locations of peak macroalgal biomass measured in the estuary. Previous studies have suggested that macroalgae can drive an increased efflux of dissolved inorganic nutrients from sediments by drawing down surface water concentration, thereby increasing the concentration gradient (Tyler *et al.* 2003, Sutula *et al.* 2006). As these nutrients are trapped as biomass, macroalgae become an effective mechanism to retain and recycle nutrients within an estuary, diverting loss from denitrification or tidal outflow. This concept is supported by low to non-detectable rates of denitrification in the Lagoon during this index period. Both NO_3 uptake associated with primary production (microphytobenthos or macroalgae) as well as DNR may have limited denitrification through competition for NO_3 (Rysgaard *et al.* 1995, An and Joye 2001,(Dalsgaard 2003, McGlathery *et al.* 2007). Denitrification is thought to be an unimportant sink for N in shallow coastal lagoons because primary producers typically outcompete bacteria for available NO_3 (McGlathery *et al.* 2007).

4 San Elijo Lagoon Nitrogen and Phosphorus Budgets

4.1 Introduction

Nutrient cycling is one of the critical functions of estuaries (Day *et al.* 1989). The net balance of nutrient sources, transformations and losses from the estuary dictate the biomass and community structure of primary producers and bacteria, which forms the foundation for the estuarine food webs and dictates the habitat quality for benthic and pelagic fauna. One means of evaluating the efficiency of nutrient cycling within an estuary is to estimate its N and P budgets (Sutula *et al.* 2001). Budgets are a useful method to assess the relative importance of allochthonous inputs ("new" nutrients) versus internal recycling ("recycled" nutrients) on primary productivity (Mitsch and Gosselink 1993) – the main symptom of eutrophication.

The purpose of this section is to estimate Lagoon N and P sources, losses, and change in storage for those terms which are readily estimated. The estuarine hydrodynamic and water quality models will be used in the future to develop refined nutrient budgets for the Lagoon. However, in the interim, coarse estimates of nutrient budgets can be derived. This information, in conjunction with data estimating the change in storage, can shed light on the efficiency of nutrient cycling, identify potential sources that are unaccounted for and inform potential management actions in the Lagoon.

4.2 Methods

Budgets are estimated by determining the sum of source and loss terms from an estuary during the time period of interest (Figure 4.1). The sum of the source and loss terms, plus the change in "storage" of nutrients within specific compartments within the estuary (e.g., sediments, surface water, primary producers), should be equal to zero (equation 4.1). Table 4.1 gives a summary of all the possible nutrient source, loss, and change in storage terms for an estuary and which of these were measured in the Lagoon.

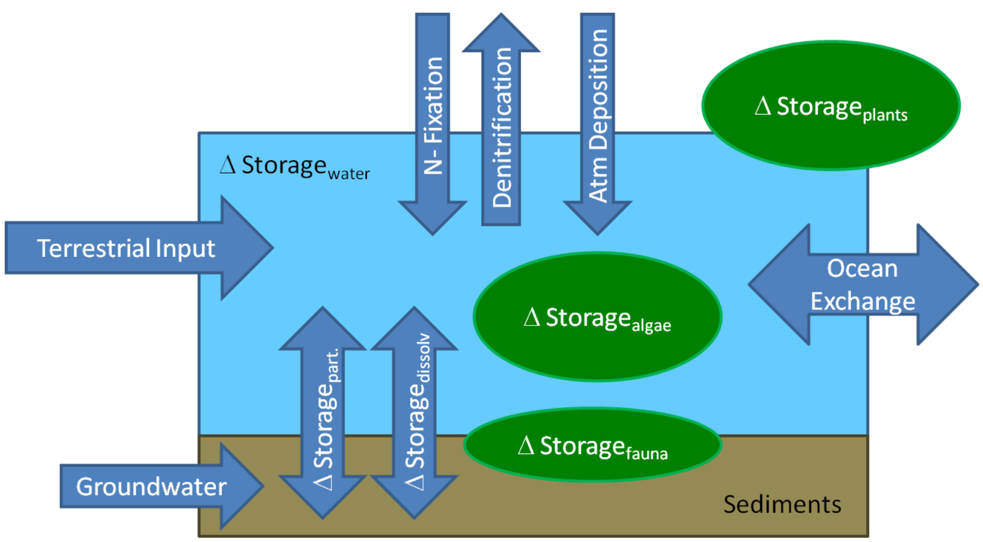


Figure 4.1. Conceptual model for development of budget estimates.

Nutrient sources to the Lagoon include: terrestrial runoff (wet and dry weather from creeks and storm drains), groundwater efflux, atmospheric deposition, tidal surface water inflow, and benthic N fixation (Table 4.1). Nutrient losses to include: groundwater recharge, tidal surface water outflow, sediment burial, and benthic denitrification. Change in storage includes benthic exchange with surface waters, aquatic primary producer biomass, sediment mass accumulation or loss, and faunal uptake and release.

$$Load_{watershed} \pm Load_{ocean} \pm Load_{groundwater} + \text{Atmospheric Deposition} - \text{Denitrification} + \text{N fixation} - \Delta Storage_{algae} - \Delta Storage_{plants} - \Delta Storage_{fauna} + \Delta Storage_{part} + \Delta Storage_{dissolv} - \Delta Storage_{water} + Residual = 0 \qquad \textbf{Eq. 4.1}$$

These terms were estimated from monitoring data or from literature values for the period of November 1, 2007- October 31, 2008, with specific detail as follows.

Terrestrial runoff was estimated from wet and dry weather runoff monitoring conducted by MACTEC, Inc. (2009). Benthic N fixation and denitrification were measured during each of the index periods at the segment site (personal communication, T. Kane, UCLA Department of Biological Sciences Doctoral Dissertation).

Atmospheric deposition rates were not estimated in this study and no local data were available. Atmospheric deposition rates are estimated from a National Atmospheric Deposition Program site in the San Bernardino Mountains during 2007. Dry deposition for NH_4 and $NO_3$for this site was 2.6 kg ha^{-1} $year^{-1}$ while wet deposition was 1.5 kg ha^{-1} $year^{-1}$. Fewer data are available for atmospheric deposition of P; data from south Florida indicate total (wet+dry) P fluxes ranging from 0.1 to 0.4 kg ha^{-1} $year^{-1}$, with an average of 0.3 kg ha^{-1} $year^{-1}$ (Redfield 2000, Ahn and James 2001). Typically ratios of dry:wet P deposition are 3:1. These numbers were used to estimate annual atmospheric loads for the Lagoon, but are acknowledged to be highly uncertain.

Sediment mass accumulation and loss was estimated from long-term annual deposition rates measured by Louisiana State University (see Chapter 2). However, while these terms are important to the overall mass balance of nutrients, they were not included in the calculation of the residual because of lack of certainty on the net sediment transport through the estuary and because particulate nutrients are less biologically active then dissolved forms. Benthic flux accounts for sediment exchange with the surface waters, and thus incorporates the short-term effects of particulate nutrient deposition.

Table 4.1. Summary of nutrient budget terms: sources, losses and change in storage.

Budget Term	Nitrogen	Phosphorus
Sources		
Terrestrial Runoff (wet and dry weather)	MACTEC	MACTEC
Groundwater efflux	Unquantified	Unquantified
Atmospheric deposition	Literature values	Literature values
Tidal surface water inflow	Unquantified	Unquantified
Benthic nitrogen fixation	UCLA Study	N/A
Losses		
Tidal surface water outflow[1]	Unquantified	Unquantified
Grounwater influx	Unquantified	Unquantified
Denitrification	UCLA Study	N/A
Sediment burial	LSU	
Change in Storage		
Benthic exchange of nutrients with surface waters	SCCWRP	SCCWRP
Plant/algal uptake/ release	Residual of Sum of Sources, Losses and Change in Storage Terms	
Sediment deposition/resuspension of particulate nutrients	LSU	LSU
Faunal uptake and release	Assumed negligible	Assumed negligible

Groundwater interactions and the change in storage associated with faunal and emergent vegetation contributions were not quantified. Tidal surface water inflow and outflow cannot be estimated through a spreadsheet exercise, but rather through the development of a hydrodynamic model for the estuary. Thus net exchange with the coastal ocean is included in the residual budget term. However, concentrations of nutrients in the ocean are very low, so as an approximation, we assumed that ocean inputs of nutrients to the estuary are negligible.

In order to construct coarse budgets, a number of assumptions were necessary. First, benthic nutrient flux, denitrification and N fixation rates were extrapolated over the quarter over which the index period represents and the area of habitat available in the estuary. As these rates are expressed in a per square meter basis, the rates were multiplied by the representative area of intertidal and subtidal habitat in each of Segment 1 and 2. For the purposes of estimating benthic flux, it was assumed that nutrient exchange with the emergent marsh habitat was negligible, that the 675,759 m^2 of mudflat habitat was inundated ½ of the time, so the representative area of mudflat used was 337,879 m^2 plus the area of subtidal habitat (109,847 m^2), for a total of 447,726 m^2. Likewise, estimates of primary producers that are expressed on an areal basis (MPB and macroalgae) were multiplied by the total area of mudflat (675,759 m^2) and subtidal habitat (109,847 m^2). Table 4.2 presents the literature and assumptions were used to convert primary producer biomass to N and P.

Table 4.2. Literature values for Chla:C and C:N:P ratios of primary producer communities and assumptions to convert biomass to areal estimates of N and P associated with biomass.

Community	Stoichiometry (C:N:P)	Reference
Phytoplankton, assumed 1.5 m water depth	Chl a: C Ratio of 30:1 C:N:P = 106:16:1	(Cloern *et al.* 1995), Redfield Ratio (Redfield 1958, Anderson and Sarmiento 1994)
Cyanobacteria mats	50% C by dry wt C:N:P = 550:30:1	Study data (Atkinson and Smith 1983)
Macroalgae	22% C by dry wt C:N:P = 80:5:1	Study data, (Eyre and McKee 2002)
Benthic microalgae	Chl a: C ratio of 30:1 C:N:P = 90:15:1	(Sundbäck and McGlathery 2005) (Eyre and McKee 2002)

4.3 Results and Discussion

Coarse seasonal N and P budgets for the Lagoon provide order of magnitude estimates of nutrients available for primary productivity and can be used interpret the importance of external loads versus internal biological recycling in supporting it.

Wet weather, as measured at the mass emission station, slightly exceeded dry weather runoff in magnitude (18,110 kg versus 13,311 kg respectively, Table 4.3). Winter dry weather runoff (Nov-Jan, 7,213 kg TN) represents 22% of the total annual export and 54% of the total dry weather runoff. Terrestrial runoff during summer and fall were low, but not negligible (4130 kg TN).

With respect to relative sources, terrestrial TN input overwhelmed all other sources[2] during the wet season, but during the summer and fall estimated terrestrial input only represented 23 - 28% of TN loads to the surface waters (Table 4.4). In contrast, benthic flux ranged acted as a sink for a term greater than terrestrial N during the winter index period, but then became a dominant source during the summer and fall, representing 72 - 77% of TN sources during the period of peak primary producer biomass. Direct atmospheric deposition and benthic N fixation are negligible sources.

[2] The net exchange of groundwater is unknown.

Table 4.3. Comparison of estimated nitrogen source, loss and change in storage terms in the Lagoon during dry weather periods (kg N). Positive and negative under "source and loss" terms indicates source and loss to the Lagoon respectively. Positive and negative numbers in change of storage terms indicate gain and loss from compartment respectively. Residual is the sum of source and loss terms, minus the change in storage. Denitrification is excluded from the calculations, but discussed in the text.

Budget Term	Wet Weather	Dry Weather Nov-Jan	Dry Weather Feb-Apr	Dry Weather May-Jul	Dry Weather Aug-Oct	Annual (Wet +Dry)
Source and Loss Terms						
Terrestrial Runoff	18,110	7,213	1,969	2,047	2,083	31,422
N - Fixation	--	8	1	1	1	12
Atmos. Deposition	189	82	82	82	82	517
Source + Loss Terms	18,300	7,139	1,888	1,966	2,002	30,916
Change in Storage						
Benthic N Flux	--	-8,655	-9,665	5,251	6,828	-6,241
1^0 Producer N	--	1	46	496	-543	1
Residual	18,300	-1,516	-7,824	6,721	9,373	24,674

Table 4.4. Comparison of loads from watershed versus benthic nutrient flux (kg).

Term	Wet Weather	Index Period 1		Index Period 2		Index Period 3		Index Period 4		Annual (Wet+ Dry)	
		Water-shed	Benthic Flux	Water-shed	Benthic Flux	Water-shed	Benthic Flux	Water-shed	Benthic Flux	Water-shed	Benthic Flux
TN	18,110	7,213	--	1,969		2,083		2,047		31,422	--
TDN	14,930	5,653	-8655	2,791	-8,500	2,286	5,251	2,170	6,828	27,829	-5,076
NH_4	884	217	779	354	-81	50	6,582	28	7,217	1,532	14,497
NO_3	17,251	5,787	-10,471	537	-4,311	1,589	-315	1,250	-682	26,414	-15,779
TP	2,879	181	--	113	--	70	--	91	--	3,334	--
TDP	2,068	148	-107	175	87	78	1,117	93	1,448	2,562	2,545
SRP	1,981	112	281	70	-227	58	509	62	797	2,283	1,360

A closer inspection of the balance between NO_3, NH_4 and TDN fluxes during each of the index periods is helpful in understanding the relative importance of two pathways of N cycling: denitrification and DNR (Table 4.4). Denitrification is the microbially mediated conversion of NO_3 to N gas, a process that occurs in moderately reduced (low O_2) sediments and represents an important permanent loss of N from an estuary (Seitzinger 1988). DNR is the microbially mediated conversion of NO_3 to NH_4, a process which occurs in anoxic sediments (An and Joye 2006) and by which N can be recycled to surface waters and available for biological uptake. During the winter and early spring index periods, sediments appeared to be a net sink for TDN (-17,155 kg TDN over a 6 month period), driven by large NO_3 fluxes into the sediment (-14,782 kg TN over 6 months). During the Nov-Jan index period, NH_4fluxes during these time periods are negligible. Denitrification rates measured on slurried cores were high (133 µmol m^{-2} hr^{-1} respectively, T. Kane, UCLA Doctoral Dissertation 2011). This rate would produce loss from denitrification on the order ~ 3,690 kg N (over 6 months), a term one order of magnitude less than as observed NO_3 fluxes during this period. During the 6-month summer and fall index period, TDN fluxes out of the sediment (~13,100 kg TN) are driven by NH_4fluxes (13,800 kg TN) and NO_3 fluxes into the sediments are much smaller (~1000 kg TN). The patterns illustrate that denitrification may be playing a large role during the winter and spring time when sediments are better flushed and oxygenated (Seitzinger 1988). Remineralization of organic matter to NH_4 and DNR are more like to be dominant pathways during the summer time and are likely responsible for the large fluxes of NH_4observed during these periods. Thus in the winter and spring, the Lagoon is better able to assimilate external DIN inputs through denitrification, but shifts towards less efficient pathways during summer and fall as sediments become more anoxic.

This budget shows that peak periods of macroalgal blooms, benthic flux of NH_4 is 10X the N required to grow the abundance of macroalgae observed (6582 kg NH_4 –vs- 496 kg of algal N for summer). Macroalgae is an efficient trap for DIN and has been shown to intercept benthic nutrient effluxes and can even increase the net flux by increasing the concentration gradient between sediments and surface waters (Tyler et al. 2001, Tyler et al. 2003, Sutula et al. 2006). The storage of large quantities of N as algal biomass thus diverts N loss from denitrification and providing a mechanism for N retention and recycling within the estuary (Krause-Jensen et al. 1999, Fong and Zedler 2000). Denitrification is thought to be an unimportant sink for N in eutrophic, shallow coastal lagoons because primary producers typically outcompete bacteria for available N, and partitioning of NO_3 reduction will shift to DNR to NH_4in later stages of eutrophication (Risgaard-Petersen and Ottosen 2000, An and Gardner 2002, Dalsgaard 2003, McGlathery *et al.* 2007).

Wet weather terrestrial runoff of TP constituted the majority (86%) of annual terrestrial input from the mass emission station (Table 4.5). Sixty-four percent of the total annual dry weather runoff (455 kg) occurred over the winter and spring index periods. Terrestrial TP loads during summer and fall were low (161 kg TP over a six month period). Wet weather terrestrial TP runoff was 33% particulate P, approximately equal to that found in dry weather terrestrial loads (Table 4.4).

With respect to relative sources, terrestrial TP input overwhelmed all other sources[3] during the wet season, but during the summer and fall estimated terrestrial loads only represented 6% of TP loads to the surface waters (Table 4.4). Benthic flux became a dominant source during the summer and fall (92% of TP sources), the periods of peak primary producer biomass. Direct atmospheric deposition is a negligible source.

The P budget shows that during peak periods of macroalgal blooms; benthic flux of TP is 5X the P required to grow the abundance of macroalgae observed (1117 kg TDP –vs- 249 kg of algal P for summer). As with N, macroalgae is an efficient trap for phosphate and has been shown to intercept benthic nutrient effluxes and can even increase the net flux by increasing the concentration gradient

[3] The net exchange of groundwater is unknown.

between sediments and surface waters (Tyler et al. 2001, Tyler et al. 2003, Sutula et al. 2006). Macroalgae can change redox condition directly under the mat, causing phosphate to solublize and become a source to surface waters (Roden et al. 1997).

Table 4.5. Comparison of estimated phosphorus source and loss terms in the Lagoon during dry weather periods (kg P). Positive and negative under "source and loss" terms indicates source and loss to the Lagoon respectively. Positive and negative numbers in change of storage terms indicate gain and loss from compartment respectively. Residual is the sum of source and loss terms, minus the change in storage.

P Budget Term	Wet Weather	Dry Weather Nov-Jan	Dry Weather Feb-Apr	Dry Weather May-Jul	Dry Weather Aug-Oct	Annual (Dry Weather Only)
Source and Loss Terms						
Terrestrial runoff	2,879	181	113	70	91	3334
Atmos. Deposition	9.47	7.10	7.10	7.10	7.10	37.9
Source + Loss Terms	2,889	188	120	77	98	3372
Change in Storage						
Benthic N Flux	--	-107	87	1117	1448	2545
1^0 Producer P	--	0.3	10	250	-260	0.3
Residual	2,889	80	197	945	1,806	5,917

Interestingly, both N and P appear to be seasonally limiting in the Lagoon. Surface water nutrients were phosphorus-limited during the winter, and strongly N limited during the summer and fall. Comparison of these data with ratios of DIN:DIP in budget estimates are complementary. Management of both N and P sources and the ratios available for primary productivity is critical for managing eutrophication.

Observations of mass balance made here should be regarded as preliminary. Nitrogen mass balance in the estuary during winter and spring shows that more nitrate is being fluxed into sediments (-15,792 kg N over 6 months) than what is being delivered via the mass emission site over that same period (6,324 kg N). While wet weather runoff may provide some of this nitrate, there is a great deal of uncertainty in load estimates from the watershed. Current estimates of terrestrial loads account only for loads from Escondido Creek and do not include Orilla Creek. In addition, some nonpoint sources of N may be delivered to San Elijo Lagoon via storm drains that are not included in this budget. Similarly, benthic NH_4 flux into the estuary into the estuary during the summer and fall is 10X that required to support measured biomass. We acknowledge the difficulty in trying to produce whole estuary N budget based on two sites. Estuary-wide nutrient mass balances can be much better refined with a dynamic simulation model that can account for hydraulic residence time as well as differences in fluxes as a function of grain size and invertebrate abundance.

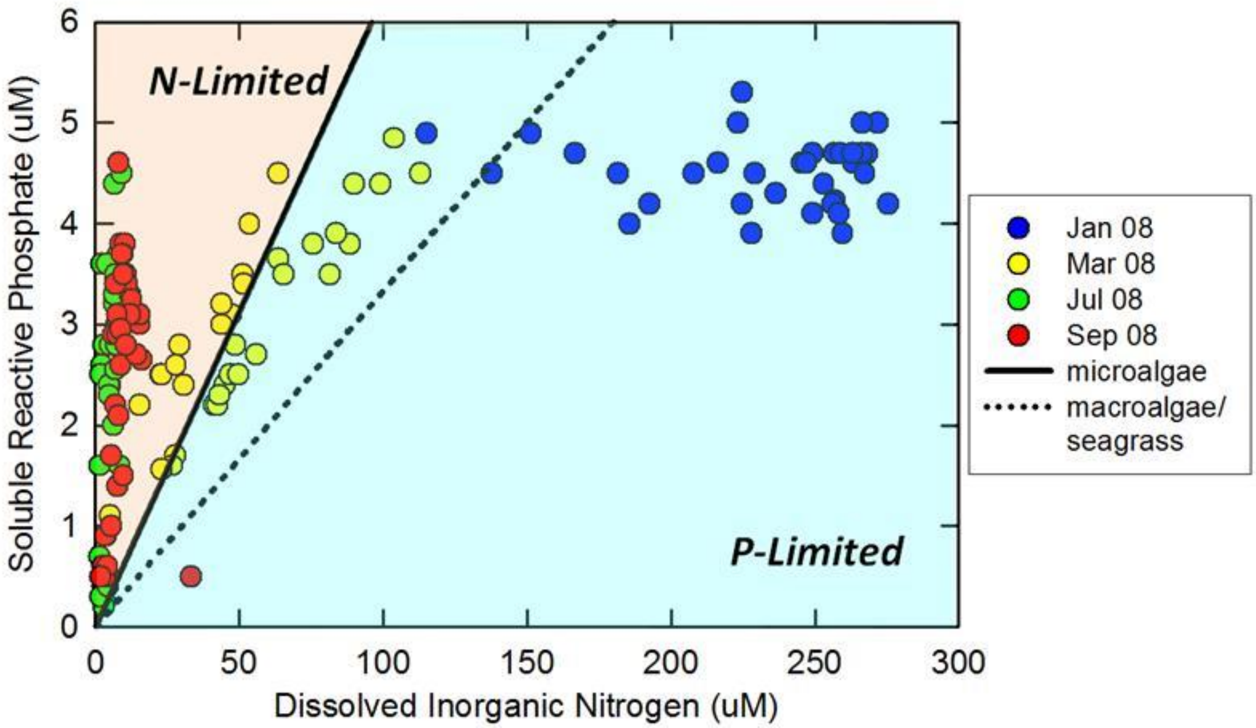


Figure 4.2. Ambient soluble reactive phosphorus versus dissolved inorganic nitrogen (nitrate, nitrite, and ammonium) from transect data taken in the northern channel (transect station # 11 - 15) and the southern basin (transect station # 1 - 10). The solid black line indicates the N and P requirements for both phytoplankton and benthic microalgae (N:P = 16:1), and the dotted black line indicates the N:P ratio for macroalgae and seagrasses (N:P = 30:1). If ambient values fall above these lines the communities are N limited. If values fall below, the communities are P limited.

4.3.1 Management Options to Reduce Eutrophication in the Lagoon

These preliminary nutrient budgets for San Elijo Lagoon illustrate that internal recycling of N and P have a more important role than terrestrial runoff during peak periods of productivity. While exchange with the ocean is not well quantified and a great deal of uncertainty in these budgets exists, the relative magnitude of these inputs is not likely to change this conclusion. Sediment data indicate that the Lagoon has accumulated a large amount of organic matter in the sediments. Because benthic flux is the major source of N to the Lagoon, recycling of this organic matter to biologically available forms of nutrients will likely continue to cause problems with algal blooms and hypoxia, even with nutrient reductions, unless restoration is undertaken to flush the Lagoon of the fine-grained sediments and improve circulation.

Given the findings of this study, the following options for management of eutrophication in the Lagoon should be considered:

- Increase flushing and circulation within the Lagoon to decrease detention of fine-grain sediments and decrease water residence time. Restoration options which favor intertidal habitats over subtidal habitats will be an advantage over subtidal habitat, which will tend to plagued by hypoxia.
- Reduce terrestrial loads from the watershed, with emphasis on detention of fine-grained particles before it reaches the Slough. Emphasis should be placed on reducing both P as well as N from the watershed.

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Appendix 1 - Quality Assurance Documentation

This section presents the results of the QA/QC procedures conducted throughout the sampling period at the Lagoon.

Sampling Equipment Maintenance:

Benthic chambers, porewater peepers and sediment cores were inspected prior to each deployment for cracks and/or deformities. Chambers were "re-plumbed" with new tubing and make-up bags during each index period and the diffuser bars were scrubbed internally and flushed with distilled water to make sure they were not clogged with sediment. Dark chambers were further inspected to make sure they were completely covered and no light was transmitted to the chamber. Peepers were cleaned and scrubbed with ethyl alcohol (to kill algae and microbial growth), rinsed in a 5% hydrochloric acid bath, then rinsed three times with distilled water prior to assembly to minimize contamination.

Data Sondes: Calibration, Drift, and Logging

Data sondes deployed in each benthic chamber and in the ambient surface water were calibrated not more than four days prior to deployment and a drift check was completed after deployment. No calibration problems or drift were apparent in any of the sonde maintenance events. During index period 1 sondes in chambers 3 and 4 failed to log data and during index period 3 the sonde in chamber 1 failed to log data. Reason for the lost data was due to a failure of the power supply.

Holding Times Violations

All water and sediment samples met the required holding times for benthic flux study in the Lagoon SCCWRP special studies. Porewater samples had holding times violations for dissolved inorganic nutrients (NH_4, NO_3, NO_2, and SRP) by UCSB for two periods: samples collected on 4/3/08 were not analyzed until 5/5/08 and exceeded the holding times by four days, and samples collected on 7/23/08 were run on 8/27/08 and exceeded the holding time by six days. These were considered minor violations and the data were used in calculations.

Laboratory Blanks

All of the laboratory blanks were reported to be below the level of detection, suggesting no bias from analytical techniques.

Field Blanks

One field blank was collected for each analyte during each benthic flux study and during each porewater peeper study. Field blank samples were collected using the same sample handling and collection equipment as field samples, except distilled- deinonized water was processed instead of sample water to assess possible contamination issues. Field blanks for total dissolved nitrogen, ammonium, total carbon dioxide and iron had a small percentage of samples fall outside the acceptable range. All other field blanks were below the minimum detection limit.

Laboratory Control Standards

All of the laboratory control standards were met acceptance criteria for percent recovery.

Laboratory Duplicates

Laboratory duplicates were processed by all analytical laboratories. A subset of samples (~5%) were randomly selected by the technician, split in the laboratory, and run separately to assess the comparability of the sample analysis process. All laboratory duplicates were within the analytical reporting limits for each analyte.

Field Duplicates

One field duplicate was collected for each analyte during each benthic flux study and during each porewater peeper study. Ammonium, nitrate + nitrite, and total dissolved phosphorus had a small percentage of samples fail to meet the acceptance criteria. Field duplicates for all other analytes fell within the acceptance criteria.

Laboratory Matrix Spikes

Matrix spike samples were processed in the laboratory by adding a known concentration of a specific analyte to a field sample. The sample was analyzed prior to addition of the spike and again after addition. The calculated analyte concentration was prepared and compared to the analytical concentration. Matrix spike results are acceptable when the percent recovery is between 80% and 120%. All of the matrix spike results were within the acceptable range for the the Lagoon special studies.

Table A1.1 QA/QC analysis for the Lagoon Data Set.

Constituent	Percentage Lab Blanks >MDL	Percentage Field Blanks >MDL	Percentage Lab Duplicates >25% RPD	Percentage Field Duplicates >25% RPD	Percentage Holding Times Violation
Water Analyses					
TN	0%	0%	0%	0%	0%
TDN	0%	12%	0%	0%	0%
NH_4	0%	12%	0%	12%	15%
NO_3 + NO_3	0%	0%	0%	12%	15%
NO_3	0%	0%	0%	0%	15%
TP	0%	0%	0%	0%	0%
TDP	0%	0%	0%	12%	0%
SRP	0%	0%	0%	0%	15%
TCO_2	0%	12%	0%	0%	0%
Fe	0%	12%	0%	0%	0%
Mn	0%	0%	0%	0%	0%
S^{-2}	0%	0%	0%	0%	0%
Suspended CHL a	0%	0%	0%		0%
Sediment Analyses					
%OC	0%	NA	0%	0%	0%
%TN	0%	NA	0%	0%	0%
%TP	0%	NA	0%	0%	0%
Grain Size	NA	NA	NA	0%	0%
Benthic CHL a	0%	NA	0%		0%

Appendix 2 – Summary of Data to Support Modeling Studies

This appendix provides SCCWRP data in tabular format to facilitate use of the data for the development and calibration of the water quality model for the Lagoon.

MASS EMISSIONS

Table A2.1. Summary of mass emission site data by analyte for all storm events. Mean and standard deviation of TN, ammonium, and Nitrate+Nitrite, TP, and soluble reactive phosphorus concentrations in wet (storm) and dry (index) weather periods at Mass Emission Station. All concentrations in µM.

Event	Date	TN	NH4	NO3+NO2	TP	SRP
Storm 1	1/5/2008	116.4±114.5	9.3±3.1	98.6±65.8	7.7±4.5	6.2±3.9
Storm 2	1/27/2008	238.5±131.7	9.3±4.7	192.8±189.3	23.9±17.2	4.2±3.2
Index 1	1/31/2008	223.3±221.0	6.7±2.9	179.9±230.0	2.5±1.3	1.6±1.4
Index 2	3/24/2008	38.4±17.4	6.9±0.8	10.5±11.4	1.0±0.6	0.6±0.2
Index 3	7/21/2008	114.5±36.2	2.7±0.5	87.3±46.8	1.7±0.4	1.4±0.6
Index 4	9/23/2008	163.4±29.7	2.2±0.5	99.8±33.2	3.3±0.7	2.2±0.2

SEDIMENT DEPOSITION

Table A2.2. Be inventory data calculation input and output are shown, including bulk density, sample interval, and total, residual, new inventories.

Date	Depth in Core (*z, cm*)	Core section Thickness (*h, cm*)	Wet Bulk Density (*ρ, g cm⁻³*)	Be-7 Activity (*A, dpm g⁻¹*)	Be-7 Inventory (*I, dpm cm⁻²*)	Total Inventory (*I_T, dpm cm⁻²*)	Time Elapsed (*days*)	Residual Inventory (*I_R, dpm/cm²*)	New Inventory (*I_N, dpm cm⁻²*)	Mass Flux (*g cm⁻²*)	Mass Flux (*g cm⁻² day⁻¹*)
San Elijo Segment Site 1											
	0-1	1	0.982	-0.190	0.00	3.04	initial				
	1-2	1	1.194	-0.207	0.00						
	2-3	1	1.140	1.153	1.31						
11/15/07	3-4	1	1.160	1.488	1.73						
	0-1	1	0.982	0.610	0.60	0.60	28	2.113	-1.514	-2.483	-0.089
12/13/07	1-2	1	1.194	-0.260	0.00						
	0-1	1	0.982	1.590	1.56	7.10	39	0.360	6.736	3.203	0.082
	1-2	1	1.194	2.895	3.46						
	2-3	1	1.140	1.824	2.08						
1/21/08	3-4	1	1.160	-1.431	0.00						
	0-1	1	0.982	1.909	1.87	1.87	38	4.329	-2.455	-1.286	-0.034
2/28/08	1-2	1	1.194	-0.557	0.00						
	0-1	1	0.982	0.186	0.18	1.64	34	1.204	0.434	2.334	0.069
	1-2	1	1.194	1.219	1.46						
4/3/08	2-3	1	1.140	-1.585	0.00						
	0-1	1	0.982	-1.103	0.00	0.78	41	0.961	-0.179	-1.020	-0.025
	1-2	1	1.194	0.351	0.42						
5/14/08	2-3	1	1.140	0.319	0.36						
	0-1	1	0.982	0.642	0.63	2.65	71	0.311	2.343	3.984	0.056
	1-2	1	1.194	1.176	1.40						
	2-3	1	1.140	0.039	0.04						
	3-4	1	1.160	0.495	0.57						
7/24/08	4-5	1	1.142	-0.755	0.00						
	0-1	1	0.982	0.141	0.14	2.83	27	1.868	0.963	0.804	0.030
	1-2	1	1.194	2.255	2.69						
8/20/08	2-3	1	1.140	-0.460	0.00						
	3-4	1	1.160	-5.224	0.00						
9/30/08	0-1	1	0.982	-1.514	0.00	3.71	41	1.661	2.045	2.568	0.063

	1-2	1	1.194	0.535	0.64						
	2-3	1	1.140	0.386	0.44						
	3-4	1	1.160	2.265	2.63						
	4-5	1	1.142	-1.673	0.00						
San Elijo Segment Site 2											
11/15/07	0-1	1	1.208	-1.091	0.00	0.00	initial				
	0-1	1	1.208	1.979	2.39	3.13	28	0.000	3.127	2.304	0.0823
	1-2	1	1.001	0.735	0.74						
12/13/07	2-3	1	1.023	-0.983	0.00						
	0-1	1	1.208	1.339	1.62	1.67	39	1.883	-0.209	-0.299	-0.0077
	1-2	1	1.001	0.056	0.06						
1/21/08	2-3	1	1.023	-0.369	0.00						
	0-1	1	1.208	2.414	2.92	4.26	38	1.021	3.243	2.606	0.0686
	1-2	1	1.001	-0.177	0.00						
2/28/08	2-3	1	1.023	1.319	1.35						
	0-1	1	1.001	0.468	0.47	0.47	34	2.740	-2.271	4.848	0.1426
4/3/08	1-2	1	1.023	-0.960	0.00						
	0-1	1	1.208	-0.004	0.00	0.55	41	0.275	0.273	1.529	0.0373
	1-2	1	1.001	-0.050	0.00						
5/14/08	2-3	1	1.023	0.536	0.55						
	0-1	1	1.208	0.306	0.37	2.46	41	0.322	2.138	5.755	0.1404
	1-2	1	1.001	-1.401	0.00						
	2-3	1	1.023	-0.432	0.00						
	3-4	1	1.146	0.454	0.52						
	4-5	1	1.051	0.870	0.91						
7/24/08	5-6	1	1.095	0.598	0.66						
	0-1	1	1.208	0.941	1.14	3.70	27	1.731	1.965	2.338	0.0866
	1-2	1	1.001	0.718	0.72						
	2-3	1	1.023	0.901	0.92						
8/20/08	3-4	1	1.146	0.803	0.92						
	0-1	1	1.208	-0.008	0.00	0.67	41	2.169	-1.495	9.276	0.2262
	1-2	1	1.001	-0.628	0.00						
	2-3	1	1.023	0.531	0.54						
	3-4	1	1.146	0.114	0.13						
9/30/08	4-5	1	1.051	-1.007	0.00						

SEDIMENT BULK CHARACTERISTICS BY INDEX PERIOD: C, N, P

Table A2.3. Sediment bulk characteristics for each index period.

Index Period	Site	Sample Depth	% Organic C	% Total N	% Total P	OC:N (molar)	OC:P (molar)	N:P (molar)	% Fines
Pre-liminary Sampling	Segment Site 1	0 – 1 cm	2.0	0.24	0.073	9.7	70.8	7.3	70.159
		1 – 2 cm	1.8	0.21	0.0614	10.0	75.7	7.6	68.052
		2 – 3 cm	1.7	0.16	0.058	12.4	75.7	6.1	66.59
		3 – 4 cm	1.8	0.19	0.054	11.1	86.1	7.8	69.557
		4 – 6 cm	2.5	0.25	0.082	11.7	78.8	6.8	44.918
		6 – 8 cm	3.1	0.32	0.107	11.3	74.8	6.6	40.919
		8 – 10 cm	2.8	0.28	0.099	11.7	73.1	6.3	35.673
Index Period 1 - Winter		0 – 1 cm	--	0.35	0.05875	--	--	13.2	--
		1 – 2 cm	2.2	0.27	0.037	9.5	153.6	16.2	48
		2 – 3 cm	2.7	0.33	0.019	9.5	367.1	38.5	53.7
		3 – 4 cm	2.6	0.27	0.032	11.2	209.9	18.7	49.1
		4 – 5 cm	5.05	0.24	0.026	24.5	501.8	20.4	36.4
		5 – 6 cm	2.2	0.16	0.0819	16.0	69.4	4.3	35.9
		6 – 8 cm	2.6	0.18	0.0173	16.9	388.2	23.0	33.9
		8 – 10 cm	3.0	0.28	0.0223	12.5	347.5	27.8	38.4
		10 – 12 cm	2.6	0.29	0.0601	10.5	111.8	10.7	53.4
Index Period 2 - Spring		0 – 1 cm	1.3	0.14	0.0007	10.8	5063.7	467.4	28.9
		1 – 2 cm	2.2	0.23	0.0801	11.2	70.9	6.4	34.2
		2 – 3 cm	2.0	0.21	0.0798	10.9	63.8	5.8	44.8
		3 – 4 cm	2.9	0.28	0.0997	12.1	75.1	6.2	26.2
		4 – 5 cm	3.1	0.30	0.1082	12.1	74.0	6.1	52.1
		5 – 6 cm	2.6	0.26	0.0992	11.7	67.7	5.8	61.6
		6 – 8 cm	3.6	0.38	0.1138	11.1	81.7	7.4	58.5
		8 – 10 cm	2.4	0.26	0.0851	10.8	72.8	6.8	59.4
		10 – 12 cm	1.5	0.16	0.0558	10.9	69.5	6.4	75.2
Index Period 3 - Summer		0 – 1 cm	0.53	0.08	0.0469	7.7	29.2	3.8	15.8
		1 – 2 cm	1.5	0.20	0.0646	8.5	58.3	6.9	41.2
		2 – 3 cm	2.0	0.23	0.0740	10.1	69.8	6.9	71.2
		3 – 4 cm	2.4	0.28	0.0813	10.0	76.6	7.6	82.8
		4 – 5 cm	2.3	0.28	0.0933	9.5	63.1	6.6	89.6
		5 – 6 cm	2.0	0.25	0.1301	9.4	39.9	4.3	94.9
		6 – 8 cm	2.4	0.29	0.0837	9.5	73.1	7.7	93.7
		8 – 10 cm	2.3	0.20	0.0545	13.3	108.2	8.1	93.9
		10 – 12 cm	2.6	0.21	0.0468	14.2	141.4	9.9	92.6
Index Period 4 - Fall		0 – 1 cm	0.80	0.09	0.0332	10.4	62.2	6.0	28
		1 – 2 cm	1.3	0.12	0.0387	12.5	86.1	6.9	57.3
		2 – 3 cm	1.4	0.15	0.0421	10.7	84.7	7.9	67
		3 – 4 cm	1.6	0.15	0.0425	12.2	95.3	7.8	65.1
		4 – 5 cm	1.4	0.11	0.0410	14.5	86.2	5.9	70
		5 – 6 cm	1.5	0.13	0.0400	13.1	94.2	7.2	77.8
		6 – 8 cm	1.4	0.13	0.0423	12.1	82.5	6.8	81.5
		8 – 10 cm	1.2	0.10	0.4330	13.9	7.1	0.5	86.6
		10 – 12 cm	1.4	0.12	0.0413	13.9	89.5	6.4	23.6
Pre-liminary Sampling	Segment Site 2	0 – 1 cm	2.0	0.22	0.0476	10.6	108.5	10.2	27.1
		1 – 2 cm	1.6	0.16	0.0829	11.7	49.9	4.3	39.0
		2 – 3 cm	1.9	0.19	0.0360	11.7	136.3	11.7	21.7
		3 – 4 cm	1.9	0.20	0.0370	11.1	132.7	12.0	22.4
		4 – 6 cm	2.1	0.19	0.0630	12.9	86.1	6.7	32.0

		6 – 8 cm	2.2	0.19	0.0420	13.5	135.3	10.0	22.3
		8 – 10 cm	1.8	0.14	0.0399	15.0	116.5	7.8	26.4
Index Period 1 - Winter		0 – 1 cm	2.5	0.22	0.0350	13.3	184.5	13.9	45.2
		1 – 2 cm	2.3	0.16	0.0220	16.8	270.1	16.1	47.1
		2 – 3 cm	1.6	0.12	0.0450	15.6	91.9	5.9	18.7
		3 – 4 cm	1.3	0.17	0.0320	8.9	104.9	11.8	27.3
		4 – 5 cm	1.6	0.13	0.0790	14.4	52.3	3.6	39.8
		5 – 6 cm	1.8	0.28	0.0098	7.5	474.5	63.3	28.0
		6 – 8 cm	0.85	0.24	0.0178	4.1	123.4	29.9	28.5
		8 – 10 cm	1.2	0.20	0.0582	7.0	53.3	7.6	32.5
		10 – 12 cm	1.8	0.13	0.0736	16.2	63.2	3.9	50.4
Index Period 2 - Spring		0 – 1 cm	0.88	0.10	0.0388	10.3	58.6	5.7	17.7
		1 – 2 cm	0.94	0.10	0.0396	11.0	61.3	5.6	25.8
		2 – 3 cm	1.6	0.15	0.0333	12.4	124.0	10.0	18.5
		3 – 4 cm	2.2	0.25	0.0399	10.3	142.5	13.9	25.5
		4 – 5 cm	0.86	0.10	0.0430	10.0	51.6	5.1	23.2
		5 – 6 cm	1.2	0.11	0.0418	12.7	74.2	5.8	27.2
		6 – 8 cm	2.9	0.23	0.0417	14.7	179.9	12.2	44.8
		8 – 10 cm	3.1	0.31	0.0522	11.7	153.6	13.2	49.5
		10 – 12 cm	2.5	0.26	0.0557	11.2	115.9	10.3	64.3
Index Period 3 - Summer		0 – 1 cm	0.20	0.06	0.0381	3.9	13.5	3.5	5.4
		1 – 2 cm	0.35	0	0.0190	--	47.6	0.0	8.3
		2 – 3 cm	0.41	0.06	0.0211	8.0	50.1	6.3	9.1
		3 – 4 cm	0.58	0	0.0327	--	45.8	0.0	6.8
		4 – 5 cm	0.22	0	0.0193	--	29.5	0.0	6.0
		5 – 6 cm	0.32	0	0.0153	--	54.0	0.0	4.5
		6 – 8 cm	0.31	0	0.0140	--	57.2	0.0	5.8
		8 – 10 cm	0.25	0	0.0168	--	38.5	0.0	7.9
		10 – 12 cm	0.36	0.06	0.0241	7.0	38.6	5.5	9.8
Index Period 4 - Fall		0 – 1 cm	0.28	0.00	0.0249	--	29.0	0.0	12.0
		1 – 2 cm	0.41	0.00	0.0317	--	33.4	0.0	9.9
		2 – 3 cm	0.51	0.00	0.0296	--	44.4	0.0	14.1
		3 – 4 cm	0.43	0.00	0.0296	--	37.5	0.0	9.3
		4 – 5 cm	0.56	0.07	0.0336	9.3	43.1	4.6	13.4
		5 – 6 cm	0.46	0.06	0.0262	8.9	45.4	5.1	14.8
		6 – 8 cm	0.52	0.06	0.0290	10.1	46.4	4.6	14.3
		8 – 10 cm	0.34	0.00	0.0226	--	38.9	0.0	10.9
		10 – 12 cm	0.72	0.07	0.0329	12.0	56.5	4.7	28.1

SEDIMENT POREWATER CONCENTRATIONS

Table A2.4. Porewater constituent analysis for each index period.

Sample Period	Site	Depth	TDN (µM)	NH_4 (µM)	NO_3 + NO_2 (µM)	NO_2 (µM)	TDP (µM)	SRP (µM)	TCO_2 (µM)	S^{-2} (µM)	DOC (µM)	Fe (µM)	Mn (µM)
Index Period 1 – Winter 1/21/2008	**Segment Site 1**	Bottom water	30.6	4.6	0.2	0.0	1.3	1.3	69.1	0.02	198	0.27	0.37
		0–1 cm	151	42.2	80.0	2.6	14.8	12.0	800	0.22	640	2.33	2.18
		1–2 cm	411	438	3.4	6.4	175.1	193.5	1640	34.2	863	8.77	7.64
		2–3 cm	1260	1440	39.8	9.6	355	413.3	4850	175	1040	2.33	10.7
		3–4 cm	1130	1320	2.6	10.4	307	306.7	5120	79.4	943	4.66	12.4
		4–5 cm	1050	1280	0.0	8.0	271	262.6	4910	232	895	1.72	14.6
		5–6 cm	933	1040	0.0	9.8	185	200.3	3960	76.8	845	4.30	10.6
		7–8 cm	802	992	0.0	7.0	168	191.2	3810	32.9	748	3.94	11.5
		10–11 cm	573	716	0.0	9.8	98.6	141.2	2550	118	790.	8.24	6.37
		14–15 cm	640	706	0.0	0.0	109	121.0	1670	25.7	548	11.1	2.73
Index Period 2 – Spring 4/3/2008		Bottom water	79.9	2.2	0.4	1.4	1.0	0.9	1610	0.00	790	1.02	1.78
		0–1 cm	646	504	3.2	1.2	185	176	2220	4.23	896	55.5	27.3
		1–2 cm	747	656	3.2	0.0	218	155	2430	10.8	978	26.9	18.2
		2–3 cm	869	730	5.0	0.0	236.	159	2810	15.9	984	32.2	20.0
		3–4 cm	992	876	2.6	0.0	239	169	2840	23.0	1320	28.7	20.0
		4–5 cm	1060	974	2.6	0.0	239	171	2980	23.1	1270	21.5	16.4
		5–6 cm	1130	1040	2.6	0.0	233	148	2980	30.0	966	32.2	12.6
		7–8 cm	1330	1090	3.0	0.0	230	124	3290	40.1	980	34.0	12.4
		10–11 cm	1500	1270	3.0	0.0	210	125	3340	36.3	886	16.8	8.37
		13–14 cm	1600	1390	0.0	0.0	179	155	3130	29.5	770	25.1	7.10
Index Period 3 – Summer 7/22/2008		Bottom water	45.3	5.6	6.8	1.2	4.8	3.3	1230	0.00	659	0.73	0.81
		0–1 cm	2610	2430	29.6	0.0	23.6	236	8350	198	1060	12.0	23.7
		1–2 cm	2070	1740	32.2	0.0	191	218	4050	105	743	14.5	29.1
		2–3 cm	1500	1220	40.8	0.0	183	174	4530	67.9	705	15.0	30.9
		3–4 cm	1340	834	26.8	0.0	176	158	3360	78.9	703	13.8	32.8
		4–5 cm	764	848	36.2	0.0	160	139	2940	57.8	758	8.51	27.3
		5–6 cm	652	752	34.8	0.0	138	132	2560	45.0	728	15.0	16.8
		7–8 cm	626	678	26.2	0.0	164	143	2450	15.2	840	14.9	7.83
		10–11 cm	744	720	34.6	0.0	175	137	2540	7.19	925	14.5	4.00
		13–14 cm	845	938	52.2	0.0	166	156	2730	7.95	923	25.1	3.46
Index Period 4 – Fall 9/29/2008		Bottom water	9.5	2.5	0.0	0.0	0.4	0.6	504	0.00	69.6	23.3	10.9
		0–1 cm	35.1	9.6	5.2	0.0	2.7	4.6	899	0.01	155	17.9	54.6
		1–2 cm	78.9	56.0	4.8	1.0	23.9	21.2	1210	0.05	193	19.7	52.8
		2–3 cm	109	62.4	2.8	0.0	45.7	43.2	1240	0.43	308	16.8	120
		3–4 cm	185	142	2.4	0.0	228	262	2860	13.8	1950	25.1	218
		4–5 cm	840	1020	2.0	0.0	261	322	5950	60.4	778	93.1	237
		5–6 cm	1240	1300	0.0	0.0	321	240	5860	55.2	485	85.9	116
		7–8 cm	1270	1500	0.0	0.0	219	236	5270	56.5	431	19.7	52.8
		10–11 cm	1440	1750	0.0	0.0	184	246	5120	62.7	368	21.5	21.8

		13–14 cm	990	1190	0.0	0.0	102	112	2180	40.6	133	1.03	0.22
Index Period 1 – Winter 1/21/2008	**Segment Site 2**	Bottom water	15.1	3.1	1	0	2.07	0.6	159	0.024	130	0.19	0.00
		0–1 cm	670	766	2.8	2.6	58.2	76.4	2290	314	810	4.83	1.04
		1–2 cm	927	1140	2.4	4.8	75.5	101	2890	1450	990	4.66	1.64
		2–3 cm	1090	1340	0	4.6	89.0	122	3230	1700	1097	2.86	0.96
		3–4 cm	1210	1460	0	5.6	100	125	3600	8650	1267	4.66	0.97
		4–5 cm	1380	1460	2.4	13.2	93.0	104		11,000	1212	42.9	0.66
		5–6 cm	1370	1760	3.2	2.8	98.2	123	3720	13,580	1140	9.85	0.29
		7–8 cm	1480	1820	7	2.4	98.9	126	3670	10,270	1240	17.7	0.42
		10–11 cm	1510	1940	3.2	4	102	130	3830	10,510	1130	6.24	0.25
		13–14 cm	12.9	4.6	2.2	0	1.28	1.2	0	--	127	1.50	0.00
Index Period 2 – Spring 4/3/2008		Bottom water	56.7	0	1.1	0	0.980	0	1560	0	861	0.62	1.37
		0–1 cm	71.7	4.6	5.2	0	3.05	1.8	1230	0.186	875	41.1	0.56
		1–2 cm	77.8	27.2	3.8	0	26.6	23.8	1550	2.31	725	78.7	7.28
		2–3 cm	378	408	155	50.3	37.2	133	2280	761	712	5.55	2.73
		3–4 cm	498	416	0	0	47.7	45.6	2440	2070	840	6.98	2.55
		4–5 cm	808	614	0	0	66.3	58.6	2710	1790	751	5.73	2.55
		5–6 cm	820	776	0	0	63.1	56.2	3130	1470	775	19.3	0.61
		7–8 cm	1150	960	0	0	82.9	73.6	3460	2580	710	37.6	0.55
		11–12 cm	1730	1540	2.2	1	115	110	4600	2360	763	35.8	0.47
		13–14 cm	2530	2074	0	2	151	114	5600	3910	809	75.2	1.20
Index Period 3 – Summer 7/22/2008		Bottom water	8.73	2.7	2.1	0	0.533	0.6	447	0.003	136	0.63	0.05
		0–1 cm	422	344	37.6	1.4	231	220	1402	9.83	1080	84.1	19.8
		1–2 cm	399.	340	64.4	2	209	216	1210	8.44	715	87.7	35.4
		2–3 cm	383	324	135	0	215	188	1040	53.7	660	15.8	18.2
		3–4 cm	353	338	159	0	101	93.2	1040	66.3	477	17.9	6.92
		4–5 cm	408	443	85.3	0	78.6	74	1830	85.8	450	23.2	3.95
		5–6 cm	381	392	98.4	0	66.7	63.4	1750	199	432	19.7	6.19
		6–7 cm	269	396	90.6	0	44.6	58	1640	40.0	493	12.0	5.28
		9–10 cm	342	352	87.8	0	63.3	60	1550	30.0	375	15.7	5.82
		13–14 cm	536	621	59.2	0	91.9	84.9	2210	62.5	435	21.4	7.10
Index Period 4 – Fall 9/29/2008		Bottom water	8.56	1.2	0	0	0.516	0	507	0	60.8	0.56	0.00
		0–1 cm	63.2	29.2	0	0	82.2	74.8	879	0.310	377	87.7	41.8
		1–2 cm	457	386	0	0	94.8	84	1060	1210	222	3.94	8.92
		2–3 cm	225	400	0	0	26.7	57	1230	2830	200	8.06	7.83
		3–4 cm	419	340	0	0	45.6	57.4	1370	3250	127.5	25.0	7.10
		4–5 cm	228	368	0	0	23.2	49.2	1440	4430	170	21.4	6.19
		5–6 cm	423	420	0	0	39.4	43.6	1540	4390	242	32.2	5.28
		7–8 cm	435	486	0	0	36.4	40.2	1820	5880	212	26.8	4.73
		10–11 cm	723	616	3	0	57.7	50.4	2770	8370	377	30.4	3.82
		13–14 cm	460	560	0	0	36.2	37.4	1800	4970	120	37.6	5.28

WATER COLUMN TRANSECT DATA

Table A2.5. Transect data for each index period during ebb tide (constituents are in mmol L^{-1}, except for chlorophyll a, which is in µg/l)).

Index Period	site #	TN	TDN	NH_4	$NO_3 + NO_2$	NO_2	TP	TDP	SRP	TSS	Chl *a*
Index Period 1 Winter	1	384.9	504.1	4.50	255.1	2.50	7.36	9.02	3.90	19.7	11.7
	2	400.3	427.6	6.27	250.6	2.60	9.81	9.19	4.23	36.5	12.25
	3	304.7	304.6	17.5	168.1	3.10	8.48	6.17	3.99	34.0	10.0
	4	463.9	315.3	4.00	264.1	2.20	9.56	6.45	4.69	8.7	8.0
	5	251.0	291.9	3.70	204.0	1.90	6.32	6.53	4.49	7.7	7.3
	6	495.9	443.6	3.70	268.1	2.30	10.7	9.17	4.99	12.0	8.5
	7	557.7	665.8	4.20	245.1	2.10	9.90	8.96	4.09	12.0	9.2
	8	359.2	331.6	4.10	262.1	2.40	7.92	6.56	4.99	16.3	9.8
	9	233.5	331.7	4.10	259.1	2.50	7.63	6.63	4.69	17.7	10.7
	10	364.4	193.6	4.50	188.1	2.00	9.95	4.92	4.19	21.7	10.7
	11	304.3	283.6	6.00	250.1	2.60	7.46	6.21	4.19	26.0	9.8
	12	493.0	474.9	6.30	427.2	2.70	8.68	8.89	4.29	23.0	7.5
	13	151.7	417.1	5.20	211.1	2.40	6.54	8.52	4.59	16.3	9.3
	14	89.39	206.6	4.60	177.0	2.00	3.67	5.85	4.49	19.7	8.4
	15	350.9	318.8	7.00	222.1	2.55	8.21	6.29	4.49	15.85	7.0
	16	203.6	265.1	7.30	216.1	2.50	5.59	6.52	4.99	14.3	7.3
	17	489.8	335.2	7.00	108.1	2.40	14.0	11.0	4.89	14.3	7.2
	18	181.5	152.9	7.30	144.1	1.80	5.92	3.14	4.89	14.3	4.6
Index Period 2 Spring	1	82.1	123.6	5.20	22.5		3.49	4.60	1.70	34.7	17.1
	2	62.4	51.6	6.10	40.9		3.87	2.51	3.10	29.3	18.6
	3	43.3	64.3	5.30	25.5		3.16	2.82	2.40	34.7	19.5
	4	159.6	98.9	6.60	34.6		8.22	4.85	2.20	21.3	6.7
	5	129.3	112.1	7.80	43.4		7.75	4.16	3.50	16.0	8.0
	6	124.9	127.3	6.70	41.9		4.22	5.10	2.80	22.3	7.1
	7	154.6	88.1	6.30	38.7		6.72	4.08	2.40	25.7	9.7
	8	196.2	170.7	8.60	81.3		9.10	7.66	4.40	36.0	17.4
	9	192.9	167.8	7.35	68.3		8.41	6.51	3.80	41.0	34.7
	10	201.3	189.1	8.50	73.1		9.22	7.59	3.50	39.6	20.8
	11	122.6	100.4	6.80	44.8		6.95	3.53	3.40	34.8	13.5
	12	101.0	68.4	5.10	18.0		4.38	3.39	2.50	29.0	11.9
	13	132.7	80.3	6.40	37.4		4.96	4.46	3.00	28.3	8.9
	14	91.4	88.9	6.40	37.4		5.13	4.24	3.20	24.5	6.8
	15	75.7	128.9	7.20	42.4		3.51	3.57	2.50	23.7	8.9
	16	114.2	82.6	7.70	48.32		4.95	3.43	2.70	23.7	11.3
	17	99.9	68.5	6.80	36.4		3.93	2.61	2.30	19.3	8.0
	18	57.2	57.4	4.87	18.3		2.67	2.62	1.57	19.5	8.65
Index Period 3 Summer	1	28.2	29.1	4.70	3.40		3.59	3.11	4.60	49.7	15.3
	2	19.0	18.9	4.90	1.60		3.16	3.32	4.40	20.3	13.4
	3	37.8	36.1	7.20	1.20		2.68	2.50	1.60	10.0	3.7
	4	15.8	17.9	5.30	1.40		2.37	3.11	3.20	9.0	19.8
	5	24.3	27.1	5.40	1.80		3.82	4.62	3.00	7.0	22.7
	6	28.5	32.6	6.60	2.50		5.58	3.81	4.50	10.3	20.8
	7	27.7	28.5	1.20	1.10		6.06	5.65	2.60	55.0	31.9
	8	21.5	19.8	1.30	0.60		2.50	4.02	2.50	104.6	29.7
	9	12.9	16.6	2.60	1.35		4.26	4.33	3.60	17.3	16.1
	10	24.7	16.8	2.30	0.70		3.65	3.28	2.80	22.7	14.8
	11	16.2	13.0	5.00	1.90		3.51	2.86	3.50	18.0	13.4

	12	24.6	9.54	3.80	1.00		3.84	2.19	2.40	10.7	7.5
	13	27.3	12.0	4.00	1.20		4.31	3.53	2.80	10.0	10.1
	14	25.9	14.8	3.80	1.00		3.25	3.45	2.30	8.3	6.4
	15	12.1	21.1	5.50	1.20		3.53	3.24	3.30	8.3	6.9
	16	29.7	33.7	4.90	2.40		3.62	3.50	2.80	6.3	3.7
	17	15.0	13.4	5.70	2.10		2.83	2.62	3.00	6.35	4.8
	18	29.5	21.4	5.35	1.65		3.63	3.13	2.55	7.35	4.3
Index Period 4 Fall	1	54.0	44.0	5.30	3.40		6.07	4.68	3.80	54.3	9.1
	2	56.8	51.6	7.10	3.30		5.88	5.40	3.80	107.5	16.1
	3	47.8	42.0	14.4	0.90		4.40	3.47	3.00	49.0	10.7
	4	59.4	48.3	9.30	6.95		5.46	4.14	2.65	10.0	13.7
	5	54.0	53.4	5.40	4.10		6.13	5.85	3.70	21.3	15.1
	6	32.4	61.8	7.40	4.70		5.90	5.47	3.30	56.3	22.7
	7	62.7	51.6	5.70	5.50		5.97	4.75	3.40	48.3	13.9
	8	59.1	55.3	4.40	2.50		5.57	5.11	3.40	39.8	20.0
	9	52.2	30.7	4.00	2.30		5.00	4.41	2.90	320.0	56.1
	10	51.2	37.2	5.80	3.20		5.94	4.17	3.70	50.7	10.7
	11	41.2	39.3	6.90	2.80		4.36	4.26	3.50	47.0	8.5
	12	61.3	38.8	5.60	1.90		4.95	3.97	3.10	35.7	6.4
	13	45.0	40.0	5.90	1.60		4.56	3.93	2.90	29.0	4.5
	14	39.5	37.6	7.30	1.50		4.09	3.83	2.95	18.5	2.7
	15	38.3	35.9	9.10	1.60		3.82	3.53	2.80	13.3	2.7
	16	35.0	30.0	7.00	1.10		3.23	2.76	2.10	6.0	2.7
	17	26.6	22.1	8.00	1.70		2.20	1.89	1.50	6.5	2.2
	18	18.9	16.3	4.60	1.00		1.60	1.34	1.00	5.2	2.7

Table A2.6. Transect data for each index period during flood tide.

Index Period	site #	TN	TDN	NH_4	NO_3 + NO_2	NO_2	TP	TDP	SRP	TSS	Chl *a*
Index Period 1 Winter	1	489.4	459.5	3.90	249.1	2.10	11.0	8.65	4.40	10.2	6.5
	2	562.7	573.7	4.60	260.1	2.30	9.43	9.54	4.60	12.3	9.8
	3	303.8	305.1	7.20	229.1	2.60	6.74	6.41	4.30	11.7	5.9
	4	372.6	430.9	5.10	251.6	2.00	8.51	9.02	4.70	30.5	22.1
	5	440.6	280.5	4.20	259.1	3.20	10.1	7.26	4.60	6.0	8.7
	6	229.4	469.8	4.00	224.1	1.80	6.53	8.46	3.90	13.3	12.8
	7	362.5	247.2	4.30	271.1	2.10	7.27	6.37	4.20	12.7	10.7
	8	626.5	497.7	4.20	262.1	2.20	11.1	9.76	4.70	9.7	9.6
	9	463.2	431.9	3.80	255.1	2.20	8.75	8.13	4.70	11.3	8.7
	10	494.2	515.1	4.50	220.1	1.90	10.1	10.4	4.20	10.0	9.3
	11	495.9	433.2	4.20	263.1	2.30	11.5	8.28	4.50	11.0	7.6
	12	519.4	377.0	3.70	134.0	1.30	12.0	10.2	4.50	13.7	5.3
	13	332.6	326.9	4.40	254.1	2.50	7.00	6.67	4.10	14.7	8.8
	14	323.6	320.1	5.00	244.1	2.50	6.59	6.65	4.70	15.0	9.8
	15	292.4	390.0	6.40	239.1	2.50	7.06	8.65	4.60	11.0	6.0
	16	369.3	354.5	6.80	240.1	2.60	8.50	6.75	4.60	11.0	8.0
	17	406.6	516.4	6.70	160.1	1.90	11.4	11.2	4.70	14.3	6.2
	18	278.0	287.3	8.50	216.1	2.80	6.22	6.35	5.30	13.7	5.8
Index Period 2 Spring	1	186.9	157.6	6.40	82.0		8.96	5.94	3.80	42.0	26.6
	2	161.3	122.1	6.50	75.0		8.91	6.48	3.50	32.0	39.7
	3	136.0	59.5	4.00	1.00		7.34	2.69	1.10	25.3	78.2
	4	160.9	125.2	10.9	102.0		9.55	6.36	4.50	17.2	13.4
	5	137.4	153.8	10.5	88.4		6.06	6.05	4.40	14.8	1.8
	6	115.9	153.8	9.65	94.0		6.64	5.66	4.85	22.0	10.7

	7	161.1	183.7	6.45	57.1		7.63	7.46	3.65	36.3	22.8
	8	166.4	154.2	7.10	56.5		6.39	7.25	4.50	32.3	17.9
	9	88.8	85.8	6.00	47.5		5.34	3.48	4.00	99.2	44.1
	10	110.6	176.9	5.90	77.8		7.06	7.15	3.90	42.0	42.8
	11	167.4	92.3	2.30	63.2		4.87	5.95	3.50	24.0	177.6
	12	77.3	46.1	0.90	21.6		5.73	1.40	2.50	36.0	200.7
	13	146.9	92.4	1.65	40.7		7.44	4.46	2.20	35.4	456.6
	14	85.9	28.3	1.60	45.3		7.47	2.09	2.50	31.3	122.3
	15	83.7	55.8	1.20	26.8		4.61	3.03	2.60	28.0	99.4
	16	89.5	55.0	1.20	27.9		3.55	2.73	2.80	21.7	36.1
	17	54.9	41.1	1.40	14.0		4.20	3.15	2.20	22.3	31.9
	18	85.3	55.5	2.40	24.4		4.07	2.66	1.60	18.3	24.0
Index Period 3 Summer	1	11.3	8.62	0.60	0.80		0.97	0.67	0.70	12.7	5.6
	2	6.57	23.1	1.70	0.70		0.44	0.53	0.50	8.7	6.7
	3	6.81	6.89	2.05	1.45		0.29	0.23	0.25	6.85	4.2
	4	37.4	26.4	1.10	1.00		4.74	3.40	3.60	22.7	41.5
	5	16.9	13.3	5.90	2.00		2.71	1.86	3.70	10.3	4.6
	6	29.3	21.8	0.70	0.80		4.41	3.18	1.60	15.7	3.9
	7	22.0	30.0	3.90	1.20		3.21	3.00	2.40	10.3	2.0
	8	29.1	8.98	4.70	1.40		3.11	1.71	2.00	14.0	3.1
	9	11.7	0.00	2.60	1.10		0.99	0.61	0.90	11.0	2.2
	10	2.82	7.32	2.80	1.10		0.77	0.56	0.50	14.7	2.6
	11	12.7	5.98	2.10	1.00		0.79	0.57	0.40	32.0	13.8
	12	1.63	8.58	2.00	0.60		1.33	0.58	0.40	10.7	0.0
	13	0.20	2.50	1.70	0.65		0.37	0.30	0.30	18.2	4.45
	14	0.00	3.08	2.60	0.70		0.39	0.28	0.40	11.3	2.2
	15	10.0	15.9	1.30	0.90		0.42	0.35	0.30	6.7	0.0
	16	1.47	9.11	1.10	2.00		0.36	0.20	0.20	6.0	2.2
	17	6.39	20.7	1.20	0.50		0.55	0.55	0.30	5.0	0.0
	18	9.00	7.39	3.00	1.40		0.97	0.37	0.40	4.0	2.2
Index Period 4 Fall	1	45.8	35.1	7.40	1.30		4.57	3.60	2.60	4.3	1.9
	2	28.8	20.9	4.75	0.80		2.93	3.32	1.70	8.8	2.2
	3	25.1	22.6	6.70	1.00		2.44	1.91	1.40	7.3	2.1
	4	67.6	54.1	10.3	5.00		5.22	4.21	3.10	7.7	7.3
	5	48.6	50.7	9.10	5.10		3.91	3.89	2.70	6.7	6.0
	6	52.5	44.2	5.90	2.30		5.33	4.75	4.60	12.0	4.0
	7	41.4	28.2	8.50	2.20		4.48	3.26	3.50	13.0	4.0
	8	42.6	31.8	11.0	1.60		4.31	3.37	3.25	7.0	2.7
	9	43.1	38.0	10.4	1.60		4.00	3.69	3.10	8.7	2.0
	10	36.4	27.0	5.90	1.00		3.77	2.65	2.20	4.8	2.0
	11	16.5	16.0	2.80	0.50		1.57	1.43	0.90	5.7	1.6
	12	12.5	11.4	2.10	0.50		0.99	0.76	0.60	5.7	2.2
	13	11.9	12.6	2.60	0.70		0.91	0.75	0.50	8.0	2.1
	14	9.78	16.0	3.65	0.85		0.70	0.70	0.50	4.3	2.4
	15	11.9	11.5	3.00	0.50		0.95	0.79	0.50	6.0	1.8
	16	16.9	13.4	3.50	0.70		0.96	0.84	0.60	5.0	1.8
	17	9.99	12.6	2.40	0.00		0.65	0.55	0.50	4.5	1.3
	18	11.1	12.6	4.20	29.1		0.69	0.70	0.50	2.0	2.2

PRIMARY PRODUCER BIOMASS AND/OR PERCENT COVER

Table A2.7. Means and standard deviations of suspended chlorophyll *a* concentrations in San Elijo Lagoon.

Index Period	Site	Mean Suspended Chlorophyll a (mg/m^3)
Index Period 1 Winter	Segment Site 1	3.52 ± 0.30
Index Period 2 Spring		2.09 ± 0.26
Index Period 3 Summer		2.44 ± 0.13
Index Period 4 Fall		0.77 ± 0.72
Index Period 1 Winter	Segment Site 2	3.46 ± 1.21
Index Period 2 Spring		2.53 ± 1.30
Index Period 3 Summer		1.01 ± 0.75
Index Period 4 Fall		0.18 ± 0.12

Table A2.8. Macroalgae total percent cover and biomass by species (average and standard error) during each index period.

Site	Date	Dry Biomass (g/m2)										Total % Cover	
		Ulva intestinalis		Ulva expansa		unknown red		Cyanobacteria		total biomass			
		avg	SE	avg	SE	avg	SE	avg	SE	avg	SE	avg	SE
1	1/22/08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0
	4/11/08	0.565	0.314	0.00	0.00	0.00	0.00	0.00	0.00	0.565	0.314	5.8	3.3
	7/21/08	29.8	24.32	19.59	10.11	0.816	0.816	0.00	0.00	50.2	27.28	66.7	15.5
	9/29/08	0.408	0.408	11.84	5.139	0.00	0.00	0.00	0.00	12.24	5.082	8.9	1.0
2	1/22/08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	70.3	6.8
	4/11/08	3.467	2.502	0.00	0.00	0.00	0.00	0.00	0.00	3.467	2.502	73.6	13.2
	7/21/08	9.231	3.891	30.61	7.717	3.265	3.265	0.00	0.00	43.11	10.18	73.3	8.1
	9/29/08	5.714	2.692	1.633	1.19	0.00	0.00	0.816	0.816	8.163	2.813	85.6	7.0

RATES OF EXCHANGE BETWEEN SURFACE WATERS AND SEDIMENTS – BENTHIC FLUX

Table A2.9. Benthic Fluxes for all index periods in the Lagoon.

Index Period	Site	Light/ Dark	Benthic Flux (mmol m^{-2} d^{-1})										
			DO	TCO_2	TDN	TDP	DOC	NH_4	NO_3	DIN	SRP	Fe	Mn
Index Period 1 Winter	Segment Site 1	Chamber 1 light	13.3	-210	-325	-6.68	-835	-6.82	-82.4	-89.2	-6.13	-1.45	-0.35
		Chamber 3 light	23.2	-197	-518	-7.01	139	-1.28	8.62	7.34	0.83	-0.04	0.09
		light avg	18.2	-204	-421	-6.85	-348	-4.05	-36.9	-40.9	-2.65	-0.75	-0.13
		light stdev	7.04	8.61	136	0.23	689	3.92	64.3	68.3	4.93	1.00	0.31
		Chamber 2 dark	-14.0	12.7	-507	-9.54	171	1.92	61.1	63.1	1.91	-0.58	-0.28
		Chamber 4 dark	-1.54	118	-30.6	-0.55	-267	-3.86	15.1	11.2	2.31	-0.97	-0.28
		dark avg	-7.77	65.6	-269	-5.04	-47.6	-0.97	38.1	37.1	2.11	-0.77	-0.28
		dark stdev	8.81	74.7	337	6.36	310	4.09	32.6	36.7	0.29	0.27	0.00
Index Period 2 Spring		Chamber 1 light	10.4	99.8	-292	0.22	-369	0.49	8.41	8.90	0.78		
		Chamber 3 light		84.3	-22.2	0.73	-90.0	-1.84	16.7	14.9	-1.59		
		light avg	10.4	92.1	-157	0.47	-230	-0.67	12.6	11.9	-0.40		
		light stdev		11.0	191	0.36	198	1.64	5.87	7.51	1.68		
		Chamber 2 dark	-13.9	113	-3.72	0.44	-353	-3.16	-48.8	-51.9	2.33		
		Chamber 4 dark	-18.9	170	131	1.17	-963	-1.44	-99	-101	1.41		
		dark avg	-16.4	142	63.8	0.80	-658	-2.30	-74.2	-76.5	1.87		
		dark stdev	3.55	40.4	95.6	0.52	431	1.22	36.0	37.2	0.65		
Index Period 3 Summer		Chamber 1 light	-132	79.4	-9.96	-0.84	256	0.34	0.00	0.34	-0.64	-2.95	-0.31
		Chamber 3 light		100	-3.54	0.10	311	1.04	-0.37	0.67	0.38	-0.50	-0.06
		light avg	-132	89.7	-6.75	-0.37	284	0.69	-0.18	0.51	-0.13	-1.73	-0.19
		light stdev		14.5	4.54	0.67	39.0	0.49	0.26	0.75	0.72	1.74	0.17
		Chamber 2 dark	-85.4	64.67	2.73	-0.91	408	0.34	-1.03	-0.69	0.39	5.41	-0.45
		Chamber 4 dark	-132	37.73	4.89	2.16	-496	1.40	-0.69	0.71	0.32	1.51	-0.20
		dark avg	-109	51.2	3.81	0.62	-44.0	0.87	-0.86	0.01	0.35	3.46	-0.32
		dark stdev	32.8	19.1	1.53	2.17	639	0.74	0.24	0.99	0.05	2.75	0.18
Index Period 4 Fall		Chamber 1 light	17.9	-79.8	29.3	3.02	77.7	1.60	-0.15	1.45	-0.15	-0.03	0.00
		Chamber 3 light	24.3	47.3	2.58	0.90	203.5	1.14	0.46	1.60	-7.07	-1.27	-0.18
		light avg	21.1	-16.3	15.9	1.96	1401	1.37	0.16	1.53	-3.61	-0.65	-0.09
		light stdev	4.53	89.8	18.9	1.50	88.9	0.32	0.43	0.75	4.89	0.87	0.13
		Chamber 2 dark	-47.4	66.7	-20.8	-1.84	193	-0.59	0.47	-0.12	-0.08	-0.62	-0.65
		Chamber 4 dark	-43.8	29.1	6.89	0.04	186	1.60	-2.29	-0.70	0.23	-0.37	-0.11
		dark avg	-45.6	47.9	-6.94	-0.90	189	0.50	-0.91	-0.41	0.07	-0.49	-0.38
		dark stdev	2.53	26.6	19.5	1.32	5.56	1.55	1.95	3.50	0.22	0.18	0.38
Index Period	Seg	Chamber 1 light	-41.5	100	-788	-10.1	2950	-0.64	43.8	43.1	0.54	-0.03	0.26

1 Winter		Chamber 3 light	-48.5	60.1	-404	-7.28	683	1.84	-3.91	-2.06	-0.91	0.43	-0.02
		light avg	-45.0	80.0	-596	-8.68	1820	0.60	19.9	20.5	-0.18	0.20	0.12
		light stdev	4.95	28.2	271	1.99	1600	1.75	33.7	35.5	1.03	0.33	0.20
		Chamber 2 dark	-33.4	434	209	3.46	346	0.22	33.5	33.7	-0.54	0.60	-0.14
		Chamber 4 dark	-38.0	58.9	-70.8	-2.22	226	1.07	160	161	0.08	-0.33	0.31
		dark avg	-35.7	246	69.1	0.62	286	0.65	96.9	97.5	-0.23	0.14	0.09
		dark stdev	3.19	265	198	4.01	84.6	0.60	89.6	90.2	0.43	0.66	0.32
Index Period 2 Spring		Chamber 1 light		-93.2	-71.9	-1.12	31.1	-1.11	1.11	-0.01	-1.11		
		Chamber 3 light	43.07	-211	-49.9	-3.23	-194	-0.74	1.13	0.39	-0.37		
		light avg	43.07	-152	-60.9	-2.17	-81.6	-0.93	1.12	0.19	-0.74		
		light stdev		83.6	15.6	1.50	159	0.27	0.02	0.28	0.53		
		Chamber 2 dark	-11.8	-123	56.9	1.54	-243	-0.74	1.89	1.16	-1.12		
		Chamber 4 dark	-19.2	-196	-85.7	-11.3	-143	-1.47	0.21	-1.27	-0.75		
		dark avg	-15.5	-159	-14.4	-4.85	-193	-1.11	1.05	-0.06	-0.93		
		dark stdev	5.26	51.5	101	9.05	70.7	0.52	1.19	1.71	0.27		
Index Period 3 Summer		Chamber 1 light	-41.3	80.1	31.2	2.80	79.76	18.48	-0.57	17.91	2.33	-4.40	-2.40
		Chamber 3 light	-107	176	25.2	29.9	-163	16.71	0.00	16.71	-0.59	0.56	-1.05
		light avg	-74.3	128	28.2	16.3	-41.5	17.60	-0.29	17.31	0.87	-1.92	-1.72
		light stdev	46.7	67.6	4.22	19.2	171	1.25	0.41	1.66	2.07	3.51	0.96
		Chamber 2 dark	-61.6	78.1	48.4	1.49	-1000	31.6	-0.67	30.9	1.09	-0.33	-3.14
		Chamber 4 dark		39.1	28.7	1.67	-1250	22.2	-0.48	21.7	0.61	-1.44	-1.15
		dark avg	-61.6	58.6	38. 6	1.58	-1130	26.9	-0.57	26.3	0.85	-0.88	-2.15
		dark stdev		27.6	13.9	0.13	173.9	6.65	0.14	6.78	0.34	0.79	1.40
Index Period 4 Fall		Chamber 1 light	-65.8	57.9	29.0	3.56	41.0	23.6	0.73	24.3	2.91	0.60	0.66
		Chamber 3 light	-34.9	66.3	65.9	6.93	40.2	29.4	1.46	30.9	2.55	2.35	0.86
		light avg	-50.4	62.1	47.4	5.24	40.6	26.5	1.09	27.6	2.73	1.47	0.76
		light stdev	21.8	5.96	26.1	2.38	0.52	4.10	0.52	4.62	0.25	1.24	0.14
		Chamber 2 dark	-162	102	39.5	3.18	-958	30.5	1.09	31.6	2.91	-0.14	1.69
		Chamber 4 dark	-117	43.1	12.1	0.27	671	12.5	0.74	13.3	0.35	-2.36	0.72
		dark avg	-140	72.6	25.8	1.72	-143	21.5	0.91	22.4	1.63	-1.25	1.21
		dark stdev	32.4	41.8	19.4	2.06	1150	12.7	0.25	13.0	1.81	1.57	0.69

DATA ON ADDITIONAL FACTORS CONTROLLING BENTHIC FLUX

Table A2.10. Number of benthic infauna in each chamber and Slough average.

Index Period	Segment Site	Chamber	Polychaetes (individuals/ m²)	Capitellids (individuals/ m²)	Oligochaetes (individuals/ m²)	Mollusks (individuals/ m²)	Crustaceans (individuals/ m²)	Other (individuals/ m²)	Total Polychaetes (individuals/ m²)	Total Infauna (individuals/ m²)
Index Period 1 Winter	Segment Site 1	Chamber 1 (light)	--	--	--	--	--	--	--	--
		Chamber 2 (dark)	0	0	0	0	509	0	0	509
		Chamber 3 (light)	0	0	0	0	0	0	0	0
		Chamber 4 (dark)	0	0	0	0	0	0	0	0
		Average	0	0	0	0	170	0	0	170
		Standard Deviation	0	0	0	0	294	0	0	294
Index Period 2 Spring		Chamber 1 (light)	0	0	0	0	0	0	0	0
		Chamber 2 (dark)	0	0	0	0	0	0	0	0
		Chamber 3 (light)	0	0	0	0	0	0	0	0
		Chamber 4 (dark)	--	--	--	--	--	--	--	--
		Average	0	0	0	0	0	0	0	0
		Standard Deviation	0	0	0	0	0	0	0	0
Index Period 3 Summer		Chamber 1 (light)	0	0	509	0	6620	1530	0	8660
		Chamber 2 (dark)	0	0	0	0	4580	0	0	4580
		Chamber 3 (light)	1020	0	0	0	6620	1530	1020	10200
		Chamber 4 (dark)	0	0	0	0	2040	1530	0	3570
		Average	255	0	127	0	4970	1150	255	6750
		Standard Deviation	509	0	255	0	2180	764	509	2750
Index Period 4 Fall		Chamber 1 (light)	0	0	0	0	1530	509	0	2040
		Chamber 2 (dark)	0	0	0	0	0	0	0	0
		Chamber 3 (light)	0	0	3570	0	7130	0	0	10700
		Chamber 4 (dark)	0	0	509	0	5090	0	0	5600
		Average	0	0	1020	0	3440	127	0	4580
		Standard Deviation	0	0	1720	0	3260	255	0	4060

Index Period 1 Winter	Segment Site 2	Chamber 1 (light)	2040	0	2040	0	1020	509	2040	7640
		Chamber 2 (dark)	3060	0	1530	0	0	2550	3060	10200
		Chamber 3 (light)	509	509	3060	0	1020	1020	1020	7131
		Chamber 4 (dark)	2040	1020	1020	0	0	509	3056	7640
		Average	1910	382	1910	0	509	1160	2290	8150
		Standard Deviation	1050	488	870	0	588	964	975	1190
Index Period 2 Spring		Chamber 1 (light)	0	0	0	0	509	0	0	509
		Chamber 2 (dark)	0	0	0	0	0	1020	0	1020
		Chamber 3 (light)	3060	3060	509	509	0	0	6110	13200
		Chamber 4 (dark)	8150	2550	0	509	0	509	10700	22400
		Average	2800	1400	127	255	127	382	4200	9290
		Standard Deviation	3850	1630	255	294	255	488	5200	9130
Index Period 3 Summer		Chamber 1 (light)	8660	0	509	0	2550	0	8660	20400
		Chamber 2 (dark)	2550	0	509	0	509	0	2550	6110
		Chamber 3 (light)	8660	1530	0	1020	6110	0	10200	27500
		Chamber 4 (dark)	2550	0	0	509	6110	0	2550	11700
		Average	5602	382	255	382	3820	0	5980	16400
		Standard Deviation	3530	764	294	488	2770	0	4020	8170
Index Period 4 Fall		Chamber 1 (light)	4580	0	2040	509	1020	0	4580	12700
		Chamber 2 (dark)	0	0	0	0	9680	509	0	10200
		Chamber 3 (light)	0	0	0	1020	2040	0	0	3060
		Chamber 4 (dark)	0	0	0	2550	0	0	0	2550
		Average	1150	0	509	1020	3180	127	1150	7130
		Standard Deviation	2290	0	1020	1100	4410	255	2290	4430

Appendix 3 - Graphs of Segment 1 and Segment 2 2007-2008 Continuous Data (From MACTEC Inc. 2009)

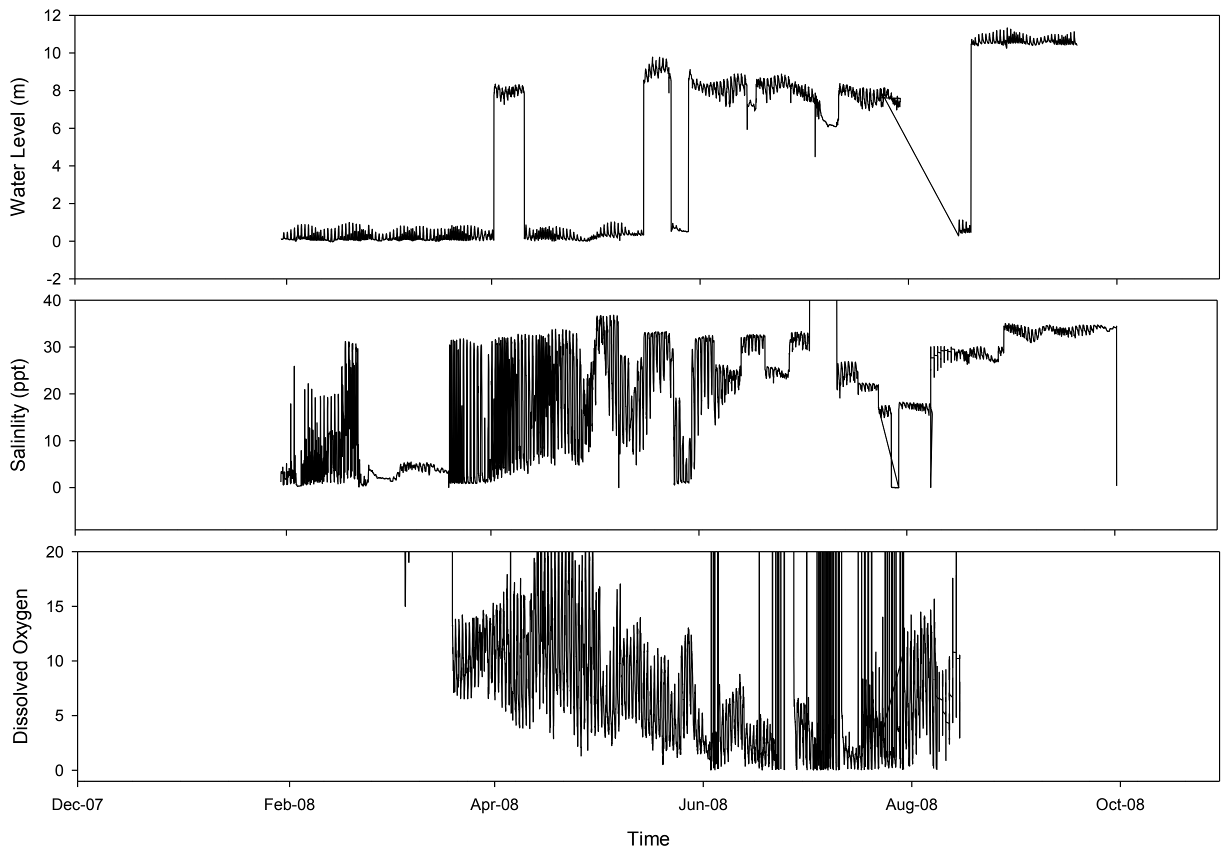

Figure A3.1. Continuous water level, salinity, and dissolved oxygen data over December 2007-October 2008 for Segment One (upstream; MACTEC 2009).

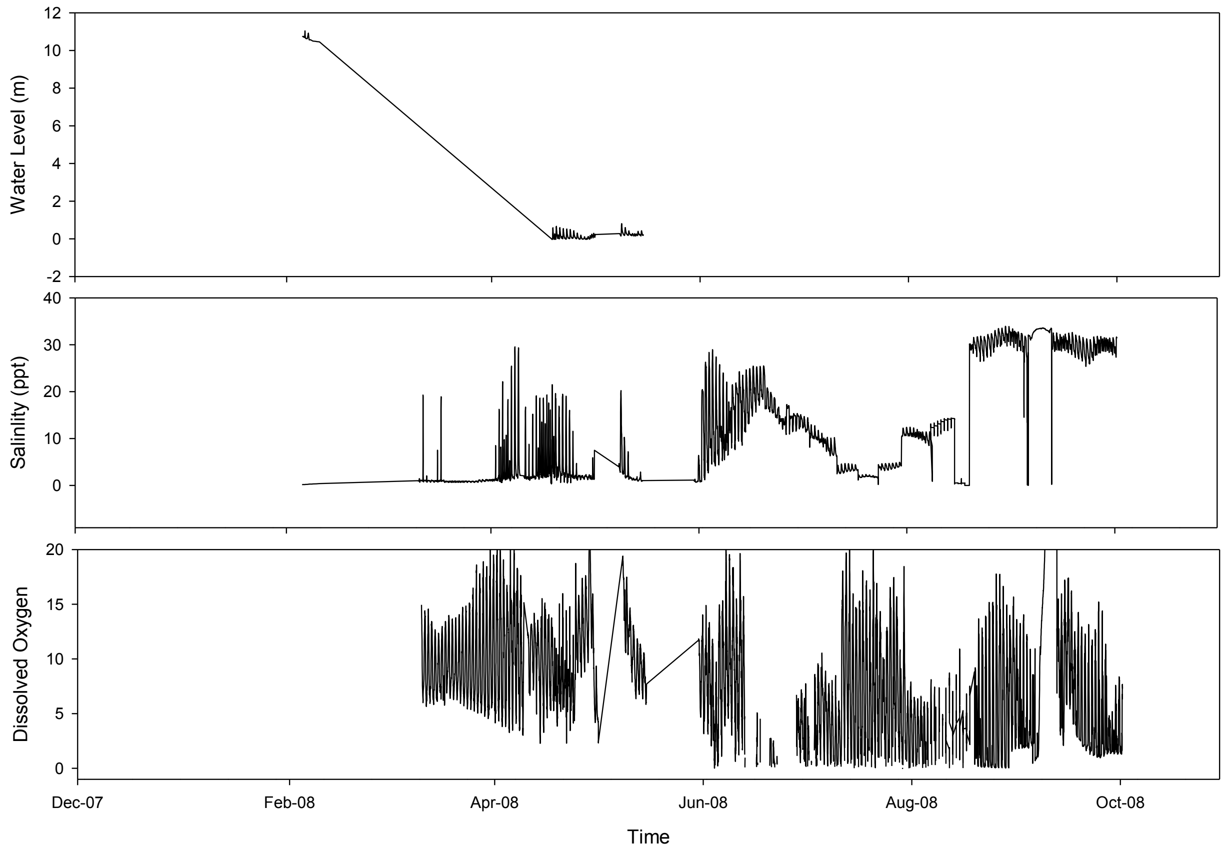

Figure A3.2. Continuous water level, salinity, and dissolved oxygen data over December 2007-October 2008 for Segment Two (downstream; MACTEC 2009).