EUTROPHICATION AND NUTRIENT CYCLING IN BUENA VISTA 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 the SCCWRP study conducted in Buena Vista Lagoon in support of the SDRWQCB Monitoring Order (R9-2006-0076), which required stakeholders to collect data necessary to develop models to establish TMDLs for nutrients and other contaminants (e.g. bacteria). SCCWRP, LSU and UCLA, supported by a Prop 50 grant from the State Water Resources Control Board (SWRCB), conducted studies in support of model development including monitoring of primary producer biomass, measurement of sediment and particulate nitrogen and phosphorus deposition, measurement of benthic dissolved oxygen and nitrogen (N) and phosphorus (P) fluxes, and sediment bulk and porewater 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 Buena Vista Lagoon (the Lagoon).
- Synthesize study data to inform management actions to address eutrophication and improve the efficiency of nutrient cycling in Lagoon.

Following are the major findings of this study:

- The Lagoon is exhibiting symptoms of eutrophication, as documented by episodes of low dissolved oxygen in both the East and Central Basins and high biomass of phytoplankton in the East and macroalgae in the Central Basins. Symptoms of eutrophication were most severe in the Central Basin.

    a. Dissolved oxygen concentrations found to be below 5 mg L^{-1} about 0.6-16% of the wintertime and 20 and 30% of the summertime at East and Central Basins respectively during the 2008 TMDL field studies. On average, estuary benthic metabolism tends to be net heterotrophic (net uptake of oxygen by sediments) year round, with peak net rates of -227 mmol O2 m^{-2} d^{-1} occurring in the Central Basin during July 2008 relative to the East Basin (peak net rate of -35 mmol m^{-2} d^{-1}).

    b. Estimates of biomass of macroalgae in the Central Basin were extremely high with transect means of 3591 to 6384 g wet wt m^{-2} over the summer and fall 2008 index periods and 100% cover. 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%.

    c. Mean phytoplankton biomass concentrations in the East Basin peaked in the spring (360 mg chl a L^{-1}), but was generally high throughout summer and fall index periods as well (36 – 102 mg chl a L^{-1}). The California freshwater lakes Nutrient Numeric Eendpoint framework provide 2 thresholds that can be considered for brackish water lagoons dominated by phytoplankton: 20 mg chl a L^{-1} is considered to be sustaining aquatic life use, while 50 mg chl a L^{-1} is considered to indicate a clear impairment of aquatic life use (Tetra Tech 2006). While these thresholds have not been yet to coastal lagoons, measured concentrations of 102 to 360 mg chl a L^{-1} are likely to be considered eutrophic to hypereutrophic.

d. The two basins have a vast difference in the amount of carbon and nutrients stored in the sediments and aquatic primary producer communities: in the East Basin, sediments are grade from high sand content proximal to the Creek mouth toward finer grain sizes at the I-5 bridge; suspended sediment concentrations in the surface waters of the East Basin are higher. As a result, the APP community is dominated by phytoplankton with, relative to Central Basin, low APP biomass. Central Basin sediments range from 80 - 100% fines, with a > 1 m layer of unconsolidated floc at the surface. The primary producer community is dominated by macroalgae and to a lesser extent, SAV. As a result, the Central Basin supports three orders of magnitude higher primary producer biomass than East Basin and is much more prone to problems with dissolved oxygen.

- These preliminary nutrient budgets for Buena Vista Lagoon illustrate that terrestrial loads dominate nutrient cycling in the East Basin, while aquatic primary productivity and internal recycling of N and P control nutrient cycling in the Central Basin. Nitrogen assimilation is more efficient in the East Basin, as evidence by high nitrate influxes (presumably through denitrification) during the spring. Internal recycling of Central Basin nutrient stores through a cycle of benthic release, uptake and overgrowth by primary producers, then senescence and release of organic nutrients to the sediments perpetuates hypereutrophication in the Central Basin. This concept is supported by the following findings:

a. Benthic efflux of ammonium and SRP was the high in the Central Basin during summer and fall (4.8 mmol NH_4 m^{-2} d^{-1} and 1.1 mmol SRP m^{-2} d^{-1}) during peak periods of primary productivity. In contrast, East Basin ammonium and SRP fluxes were low during peak primary production (0.3 mmol NH_4 m^{-2} d^{-1} and -0.1 mmol SRP m^{-2} d^{-1}); thus internal recycling of nutrients is particularly important in the Central Basin and is likely providing a major source of nutrients to support primary productivity. These fluxes in the Central Basin meet or exceed required N and P to support the amount of observed primary producer biomass observed. 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.

b. Patterns of nitrate versus ammonium fluxes indicate that denitrification (conversion of nitrate to nitrogen gas that is permanently lost from the estuary) is a more important mechanism in the East Basin while dissimilatory nitrate reduction (reduction of nitrate to ammonium) is more dominant in the Central Basin. Mean annual influx of nitrate was high (-3.5 mmol m^{-2} d^{-1}). East Basin, the most proximate to high sources of nitrate (Buena Vista Creek), had the highest rates of nitrate influx during the winter and spring (-8.8 to -13.6 mmol m^{-2} d^{-1}), relative to the Central Basin (-4.2 to -0.4 mmol m^{-2} d^{-1}). High ammonium fluxes, coupled with very high ammonium, SRP and sulfide porewater concentrations, signal that Central Basin sediments in an anoxic state and thus would favor DNR over denitrification. Thus in the winter and spring, the Lagoon is better able to assimilate external nitrate inputs through denitrification in the East Basin, but as the estuary becomes more eutrophic during summer and fall, the efficiency of nitrogen loss may be reduced in the Central Basin, retaining N in primary producer biomass that is returned to the sediments during the fall and available again for primary production the following year.

c. The patterns of ammonium and nitrate fluxes suggest that denitrification (loss of nitrate to nitrogen 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, 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 nutrient 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 Buena Vista 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 nitrogen 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

Buena Vista Lagoon (Lagoon) is located on the border between the cities of Oceanside and Carlsbad in San Diego County, California. The Lagoon, which is bordered by the Pacific Ocean on the west, Vista Way/Freeway 78 on the north, and Jefferson Street on the east and south, covers an area over 200 acres. The Lagoon 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, California Brown Pelican, and Belding's Savannah Sparrow. The Lagoon drains the Buena Vista Creek watershed, which encompassed 52 km^2. Urban and agricultural land uses in the watershed resulted in hydrological modifications to the Lagoon. Increased watershed discharge, in tandem with sewage spills, has augmented the organic matter and nutrient loading to the Lagoon.

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 oxygen (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 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 in the 58 square kilometer Buena Vista Creek Watershed in located on the border between the cities of Oceanside and Carlsbad in San Diego County, California. The lagoon is an ephemerally tidal coastal lagoon whose ocean inlet is closed to surface water exchange with the ocean through the presence of a weir. However, exchange occurs under the sand berm and thus the western and central basins are brackish water, while the eastern basin is fresh.

Table 1.1 gives the distribution of habitat in the Lagoon by basin, according to USFWS National Wetland Inventory data (T. Dahl, January 2009). Emergent marsh habitat in the eastern and central basins are dominated by tule and cattails, which are increasingly encroaching on open water habitat over time.

Table 1.1. Distribution of open water, aquatic bed and emergent marsh habitat by basin in Buena Vista Lagoon. Areas are given in square meters.

Basin	Open Water/Subtidal	Aquatic Bed	Emergent Marsh	Total
East	160,358		186,135	346,493
Central	150,346	131,375	157,249	438,970
West	59,317		33,539	92,856
Total	370,021	131,375	376,924	878,320

The primary source of freshwater input into the estuary is surface flow from the Buena Vista Creek, though ancillary freshwater input for the estuary is likely to come from runoff and ground seepage. Analysis of land use in the watershed shows that urban areas cover approximately 75% of the watershed. Nutrient sources appear to be predominantly from the watershed and include storm water and subsurface runoff under wet weather conditions, as well as wastewater, nuisance water, and irrigation return water under dry weather conditions (Everest International, 2005).

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 Buena Vista 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 mass emission (ME) site and the ocean inlet site, as well as two segment sites within the Lagoon. In the Buena Vista 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). Table 1.2 and Figure 1.1 summarize the dates and sampling locations for each of the different types of monitoring studies in Buena Vista Lagoon.

Table 1.2. Summary of the different sampling activities in Buena Vista 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	1/16/08
Continuous Monitoring	Water Quality Monitoring	MACTEC	1/1/08- 10/23/08
Preliminary Sampling 1	Sediment Deposition	LSU	11/15/07
Preliminary Sampling 2	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	1/16/08
	Benthic Chamber Study- SEG 1	SCCWRP	1/31/08
	Benthic Chamber Study- SEG 2	SCCWRP	2/1/08
	Porewater Peeper Deployment	SCCWRP	1/7-1/22/08
	Sediment Core	SCCWRP	1/22/08
	Macroalgae Monitoring	UCLA	1/22/08
	Sediment Deposition	LSU	1/22/08
Interim Sampling 1	Sediment Deposition	LSU	2/28/08
Index Period 2	Ambient Sampling	MACTEC	3/31-4/1/08, 4/7-4/10/08
	Transect Sampling	MACTEC	3/31/08
	Benthic Chamber Study- SEG 1	SCCWRP	3/31/08
	Benthic Chamber Study- SEG 2	SCCWRP	4/1/08
	Porewater Peeper Deployment	SCCWRP	3/18-4/2/08
	Sediment Core	SCCWRP	4/2/08
	Macroalgae Monitoring	UCLA	4/11/08
	Sediment Deposition	LSU	4/2/08
Interim Sampling 2	Sediment Deposition	LSU	5/15/08

Table 1.2. Continued

Period	Event	Organization	Date
Index Period 3	Ambient Sampling	MACTEC	7/14-7/16/08, 7/21-7/23/08
	Transect Sampling	MACTEC	7/14/08
	Benthic Chamber Study- SEG 1	SCCWRP	7/16/08
	Benthic Chamber Study- SEG 2	SCCWRP	7/17/08
	Porewater Peeper Deployment	SCCWRP	7/3-7/22/08
	Sediment Core	SCCWRP	7/22/08
	Macroalgae Monitoring	UCLA	7/21/08
	Sediment Deposition	LSU	7/22/08
Interim Sampling 3	Sediment Deposition	LSU	8/20/08
Index Period 4	Ambient Sampling	MACTEC	9/15-9/17/08, 9/22-9/24/08
	Transect Sampling	MACTEC	9/15/08
	Benthic Chamber Study- SEG 1	SCCWRP	9/17/08
	Benthic Chamber Study- SEG 2	SCCWRP	9/18/08
	Porewater Peeper Deployment	SCCWRP	9/12-9/29/08
	Sediment Core	SCCWRP	9/29/08
	Macroalgae Monitoring	UCLA	9/29/08
	Sediment Deposition	LSU	9/29/08

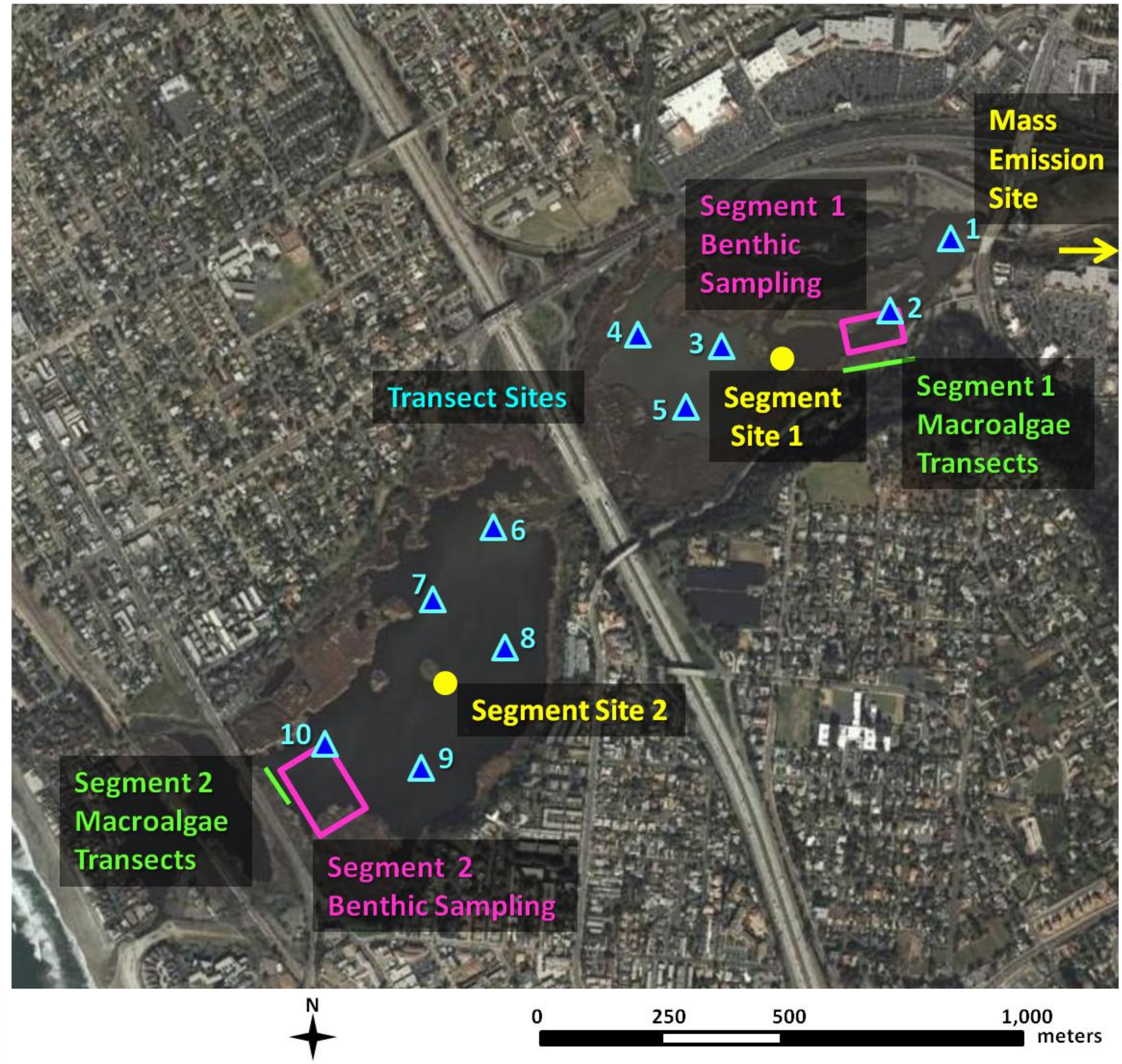


Figure 1.1. Location of sampling activities in Buena Vista Lagoon.

2 Patterns in Surface Water and Sediment Nutrients and Primary Producer Communities in the Buena Vista 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 Buena Vista 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 Buena Vista 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 10 sites along a longitudinal gradient of the Buena Vista 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 deinonized 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 %OC, %organic N and %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 organic carbon (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 %OC, percent total nitrogen (%TN) and percent total phosphorus (%TP) analysis. The remainder of the section was utilized for grain size analysis (% 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 NH_4, NO_3, 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 N (TDN), total dissolved P (TDP), TN, and TP via a 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 coulometer. Inorganic nutrients were run by the Marine Science Institute at the University of California, Santa Barbara and total dissolved and total N and P were run at the University of Georgia Analytical Chemistry Laboratory.

Dried sediment samples were subsampled and ground for analysis of %OC, %TN, and %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 63µm 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}):

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

Eq. 2.1, 2.2

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

where W_{wet} and W_{dry} are the wet and dry sediment weights, respectively. Subsequently, when enough sample was available, 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:

$$\phi = \frac{\frac{f_{wet}}{\rho_{water}}}{\frac{f_{wet}}{\rho_{water}} - \frac{f_{dry}}{\rho_{drygrain}}}$$

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, specific conductivity and DO in the Eastern and Central Basins as a function of freshwater flow into the Lagoon 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 641 - 2772 cfs) occurring in November through March. With the onset of the dry season (May-October 2009), freshwater base flow gradually reduces to 3 - 7 cfs.

East and west basin salinities were in the fresh to brackish range, with specific conductivities ranging from 0.03 to 3.7 mS cm^{-1} (0 - 2 ppt) and 0.3 to 6.5 mS cm^{-1} (0 - 3.5 ppt) respectively.

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

Period	2007-2008 Dicharge (cf)
Annual	7.996E+08
Wet Season	7.513+08
Dry Season	8.24E+07

Dissolved oxygen concentrations in the East and Central Basins averaged 8.6 and 7.0 mg L^{-1} respectively. Instantaneous concentrations fell below 5 mg L^{-1} approximately 12 and 24% of the time during the period of record (January 2008-October 2008) for East and Central Basins respectively for the TMDL study (Figure 2.2).

The percentage of time below 5 mg L^{-1} was higher during the summer (20 and 30% for East and Central Basins respectively) versus winter (0.6% and 16% respectively), coincident with higher water temperatures, decreased freshwater flow, and peak primary productivity (Figure 2.1).

Concentrations of < 5 mg L^{-1} typically occurred in nighttime through early morning hours at both basins (Figure 2.4). Spatially, periods of low O_2 (< 5 mg L^{-1}) more prevalent in the Eastern Basin during the summer, while low DO occurred in the Central Basin year round.

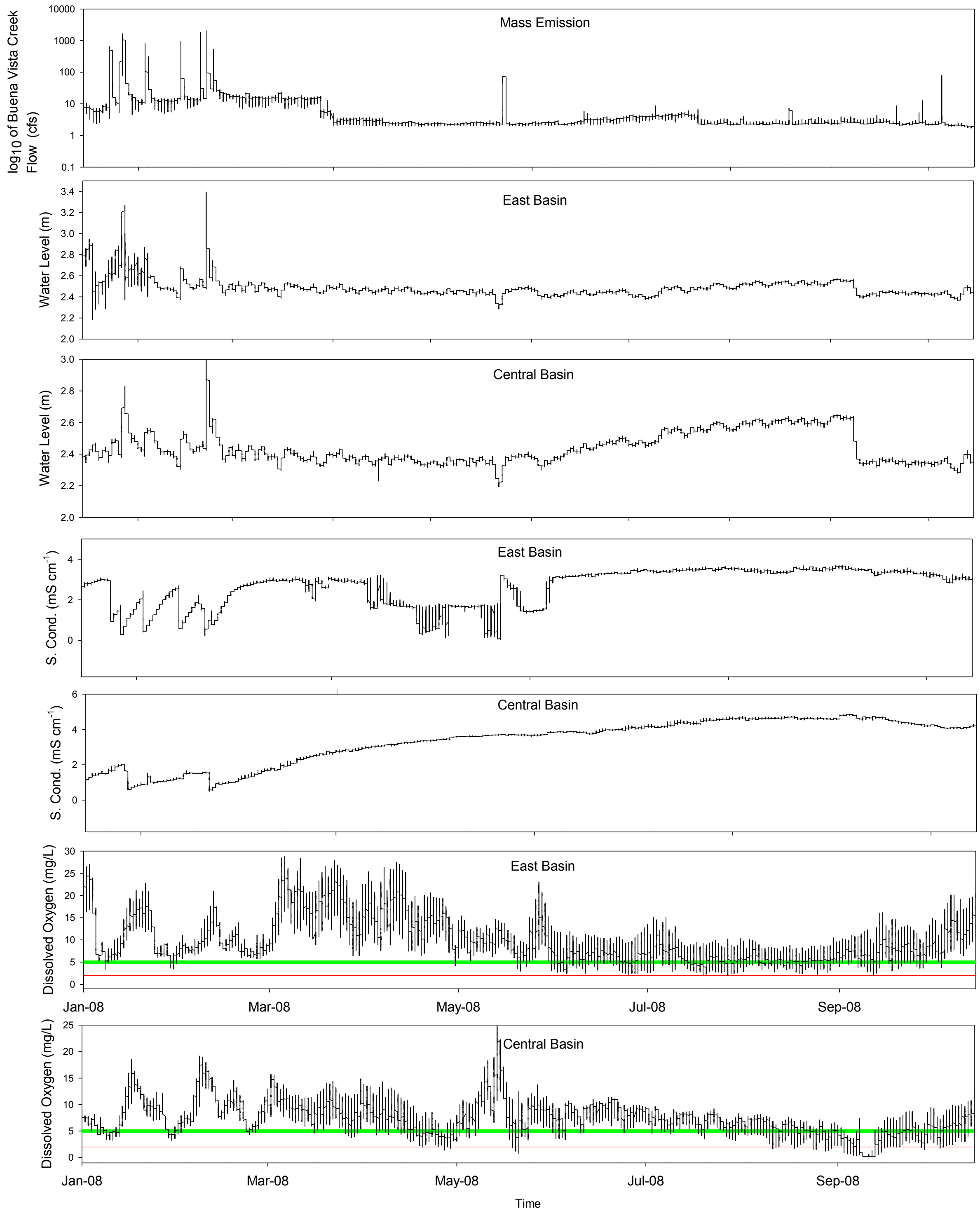


Figure 2.2. Continuous freshwater flow (cfs, $\log_{10}$ scale at Buena Vista Creek Mass Emission Station) and East and Central Basin water level (m), specific conductivity (mS cm^{-1}), and dissolved oxygen (mg L^{-1}) during 2008 TMDL field studies (MACTEC 2009). Green and red lines in dissolved oxygen graph show the SDRWQCB 5 mg L^{-1} basin plan objective and the 2 mg L^{-1} definition of hypoxia (Diaz 2001), respectively.

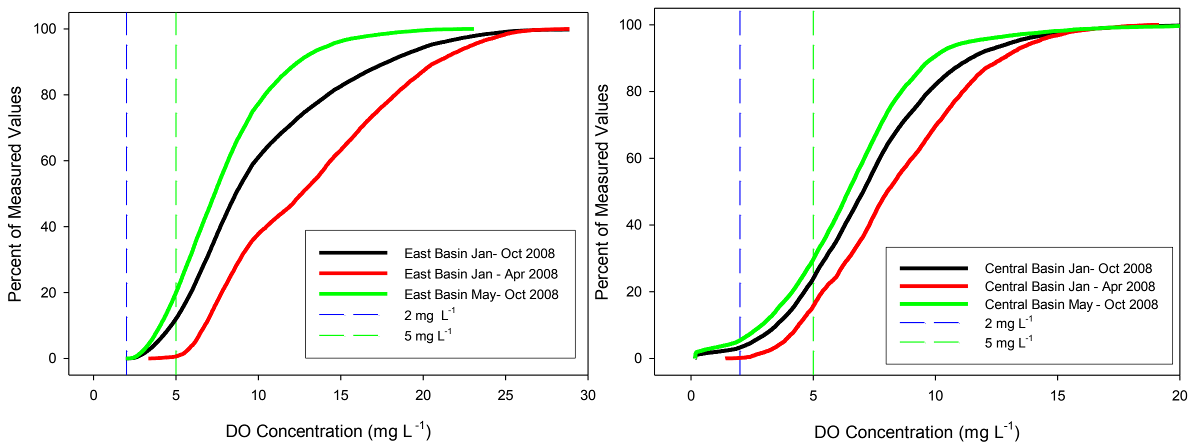


Figure 2.3. Cumulative frequency distribution of dissolved oxygen concentration annually (black line), during wet season (Jan-Apr) and during dry season (May-Oct) at East and Central Basins during the TMDL study (MACTEC 2009).

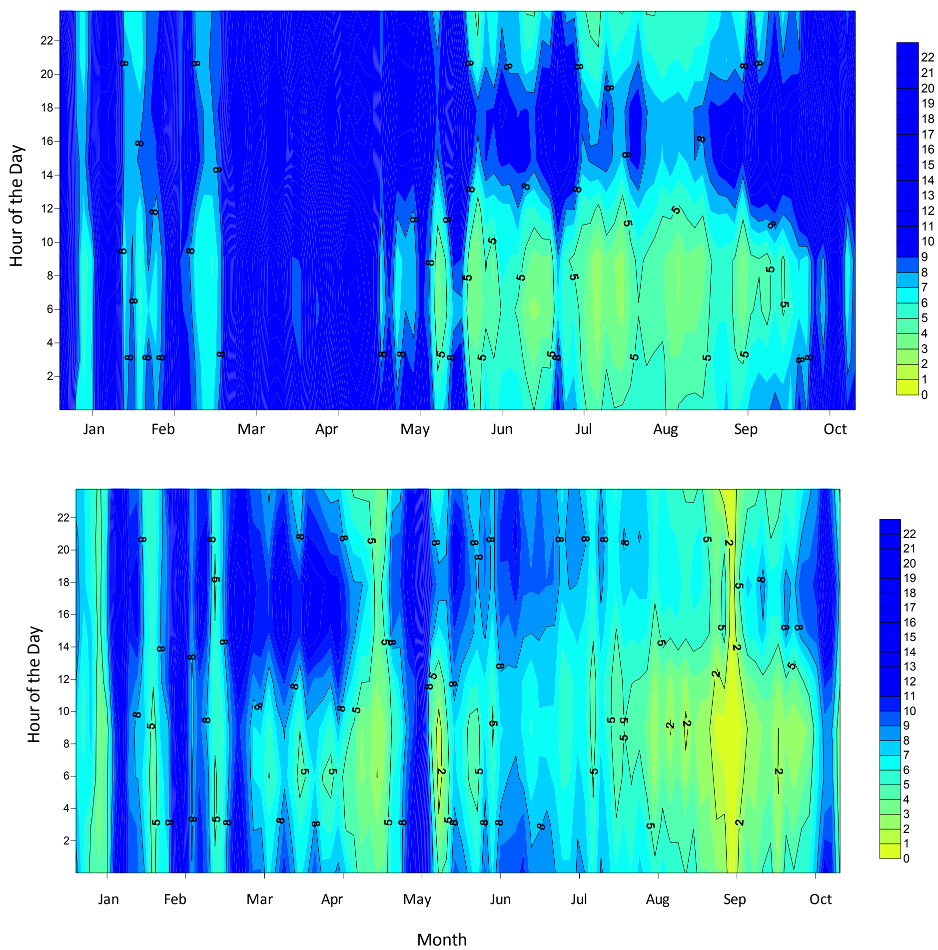


Figure 2.4. Contour plot (top panel) of East Basin (top panel) and West Basin (bottom panel) DO by month (x axis) and time of day (y-axis) during the 2008 TMDL field study. Legend on right shows color key for DO concentration.

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). During the winter and spring index periods, mean ME TN was generally equivalent to East Basin mean TN (136 - 180 µM TN), while Central Basin TN was approximately half that of East Basin (98 - 114 µM TN). TN declined further during the summer index periods, with the ME, East and Central Basin sites generally equivalent in concentration (41 - 68 µM). In the fall, ME TN (106 µM) was twice that of Lagoon TN concentrations (44 - 68 µM). In January, the percentage of TN as NO_2+NO_3 decreased from 97% of the TN at the ME station, to 65% in the East Basin and 26% in the Central Basin. In the spring, summer and fall index periods, however, NO_2+NO_3 only made up a high percentage at the ME station (40 - 73%); at the East and Central Basin this percentage was 2 and 5% in the Central and East Basin respectively. High values of TDN indicate that most of the TN at these sites was dissolved organic N (DON). Ammonium concentrations were low and generally equivalent across sites and seasons.

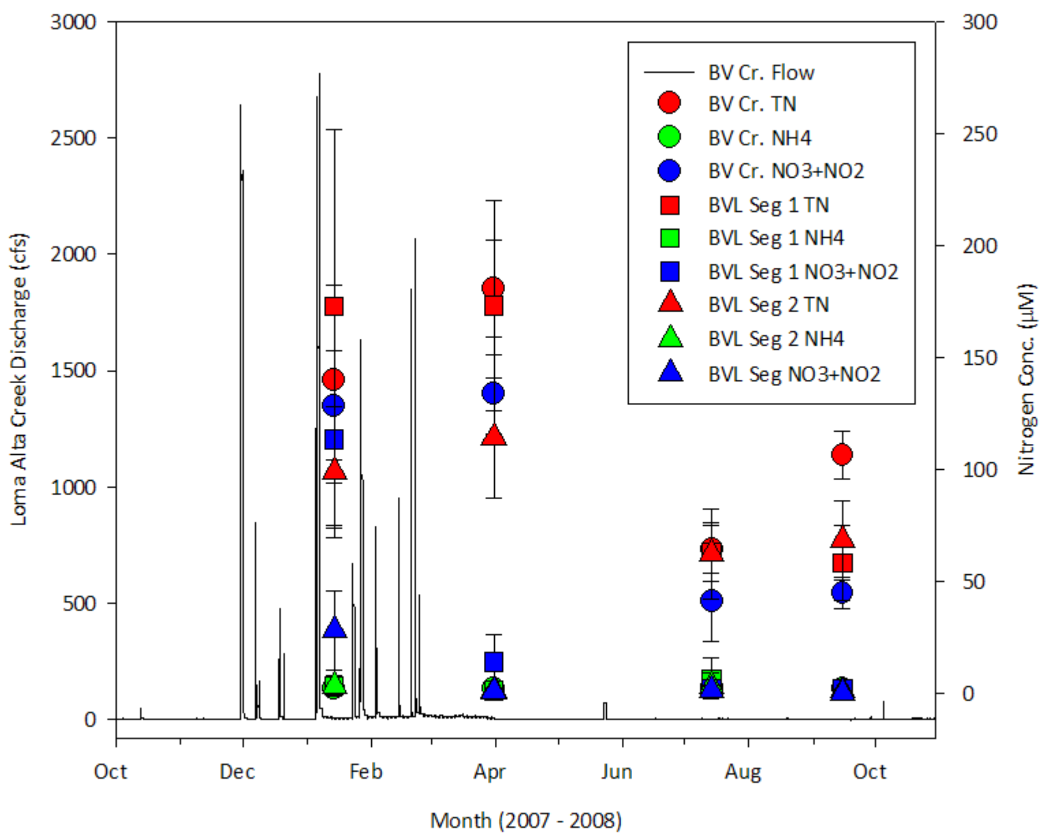


Figure 2.5. Dry weather concentrations of TN, ammonium and nitrate concentrations in Buena Vista Cr., Buena Vista Lagoon East and Central Basins as a function of freshwater flow into Buena Vista Lagoon. Data from MacTech Inc. (2009).

In contrast to TN, TP and SRP during the winter and spring index periods were highest in the Central Basin (7.5 to 9.4 µM), decreasing to the lowest value in the ME station (2.7 to 6.5 µM). TP and SRP values were lower during the summer and fall (1.3 - 3.3 µM) and generally equivalent across all sites.

SRP represented the highest fraction of TP during the winter and summer index periods (47 - 85 and 60 - 98%) respectively, while this percentage was much lower during the spring and fall (6 - 25% and 8 - 62% respectively). TSS was highest at the East Basin and decreased markedly at the Central Basin, with values highest during the winter and spring (75 and 45 mg L^{-1} respectively).

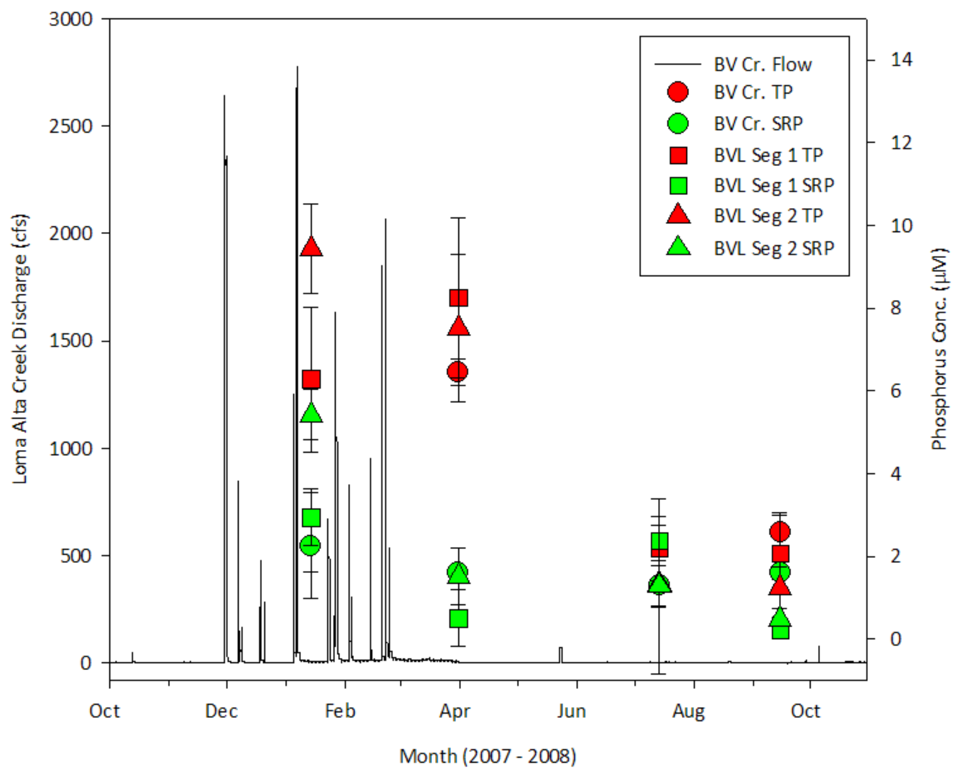


Figure 2.6 Dry weather concentrations of TP and SRP concentrations in Buena Vista Cr., Buena Vista Lagoon East and Central Basins as a function of freshwater flow into Buena Vista Lagoon. Data from MacTech Inc. (2009).

Nutrient transect data of are helpful in interpreting areas within the Lagoon that are sources (e.g. storm drains, groundwater, benthic flux, biological release) or sinks (benthic flux, denitrification, biological uptake) are visible (Figure 2.7). During the winter index period, the East Basin was a sink for NO_2+NO_3 (95 µM). This pattern was repeated during the spring index period, though not as dramatic; NO_2+NO_3 concentrations dropped 50 µM from transect sites 1 to 2, proximal to Buena Vista Creek mouth, then stayed low through the rest of the lagoon. TN did not drop so quickly, indicating production of DON through a part of the East Basin (transects sites 1 - 3), and then at transect sites 7 - 9 in the Central Basin. During the summer and fall, transect sites 3 - 5 appeared to be a source of DON.

With respect to phosphorus, the Central Basin tended to be a source of P. This was most evident during the winter (increase of 5 µM SRP and 8 µM TP) from the East to the Central Basin. The increase was more modest during the spring, summer and fall, with portions of the East Basin occasionally acting as a source of SRP and TP coincident with increased in TN (see above) .

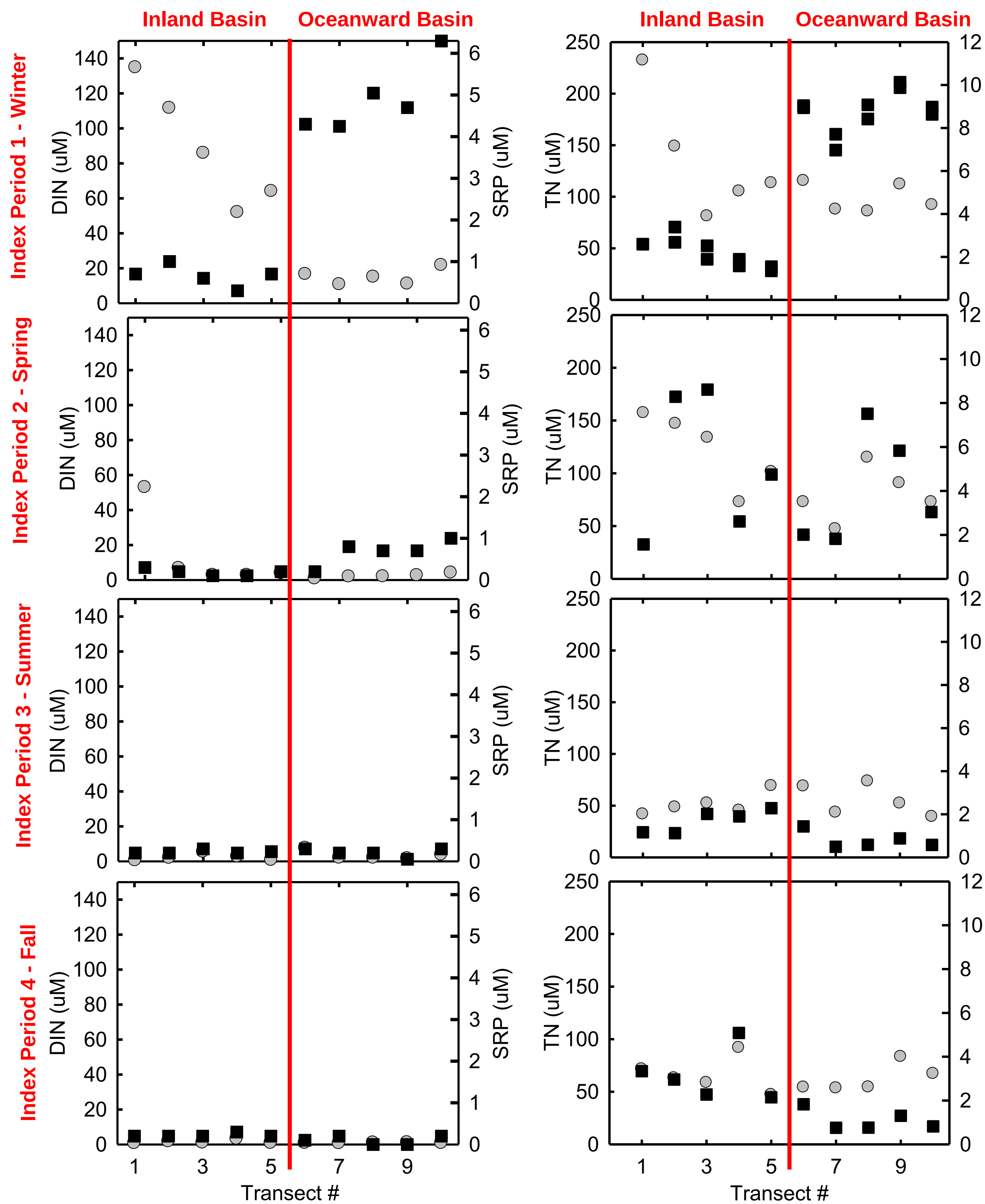


Figure 2.7. Transect data for each index period in the I-5 (Inland) and PCH (Oceanward) basins of Buena Vista Lagoon. N is represented by grey circles, while P is represented by black squares.

2.3.2 Seasonal Trends in Primary Producers

This study assessed seasonal trends in biomass and or percent cover of four aquatic primary producer (APP) communities:

- phytoplankton (measured as suspended chlorophyll a)
- macroalgae and cyanobacterial mats (biomass and percent cover)
- microphytobenthos (measured as benthic chlorophyll a)
- submerged aquatic vegetation (SAV; measured as biomass and cover)

Figure 2.7 shows the comparative biomass of phytoplankton, macroalgae and microphytobenthos, and SAV, standardized to mass of carbon (C) per unit area by 2008 sampling period for East and Central Basins. In East Basin, phytoplankton were the dominant primary producer, with only modest proportions attributable to MPB (100 mg m^{-2} Chl a) during the spring. Neither SAV nor macroalgae were observed during any index periods. Concentrations of phytoplankton were highest in the spring (360 mg L^{-1} Chl a) and fall (102 mg L^{-1} Chl a), and lowest in the winter and summer (21 and 36 mg L^{-1} Chl a).

Primary producer communities in the Central Basin were dominated by a combination of macroalgae and SAV (Figures 2.87 and 2.10). During the winter index period, primary producer carbon was high and dominated by the macroalgae *Chara sp.* (257 g dry wt m^{-2}). By the spring index period, the macroalgae had disappeared and the primary producer biomass was low and dominated by MPB (80 mg Chl a m^{-2}). During summer, *Chara* again dominated APP biomass (218 g dry wt m^{-2}), while the SAV species *Ruppia Cirhhosa* appeared in the deeper areas of the Central Basin (> 5 m; 256 g dry wt m^{-2}). By the fall index periods, a combination of *Rhizoclonium spp*. and *Chara sp.* were the dominant APP present in the shallower portions of the Central Basin (397 g dry wt m^{-2}), while Ruppia exhibited biomass twice that in the deeper areas (820 g dry wt m^{-2}).

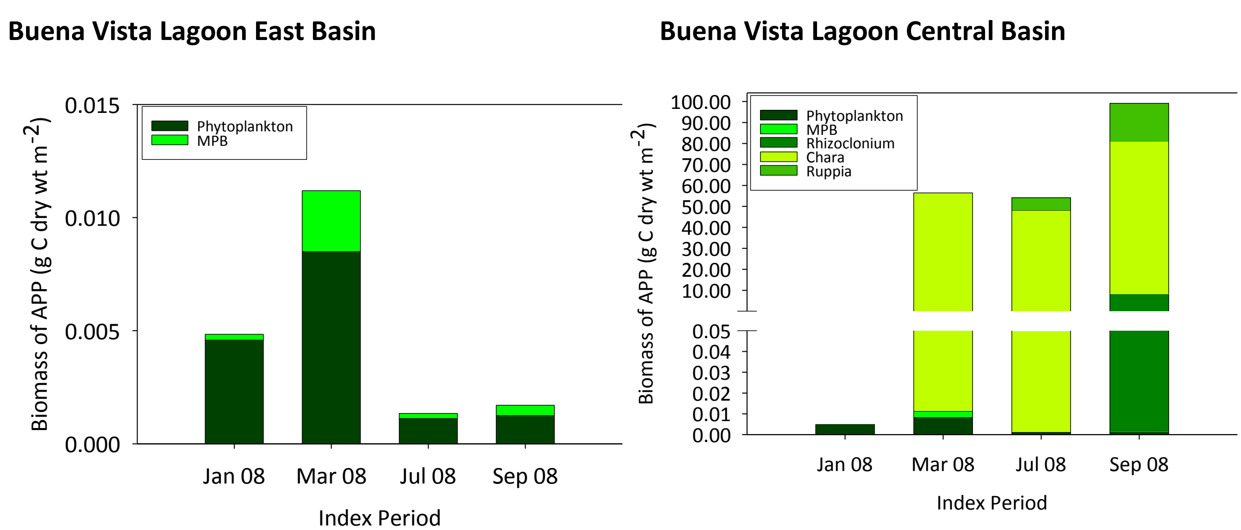


Figure 2.8. Mass of carbon associated with the five types of primary producers observed in Buena Vista Lagoon. *Chara* and *Rhizoclonium* are macroalgae, while *Ruppia* is SAV.

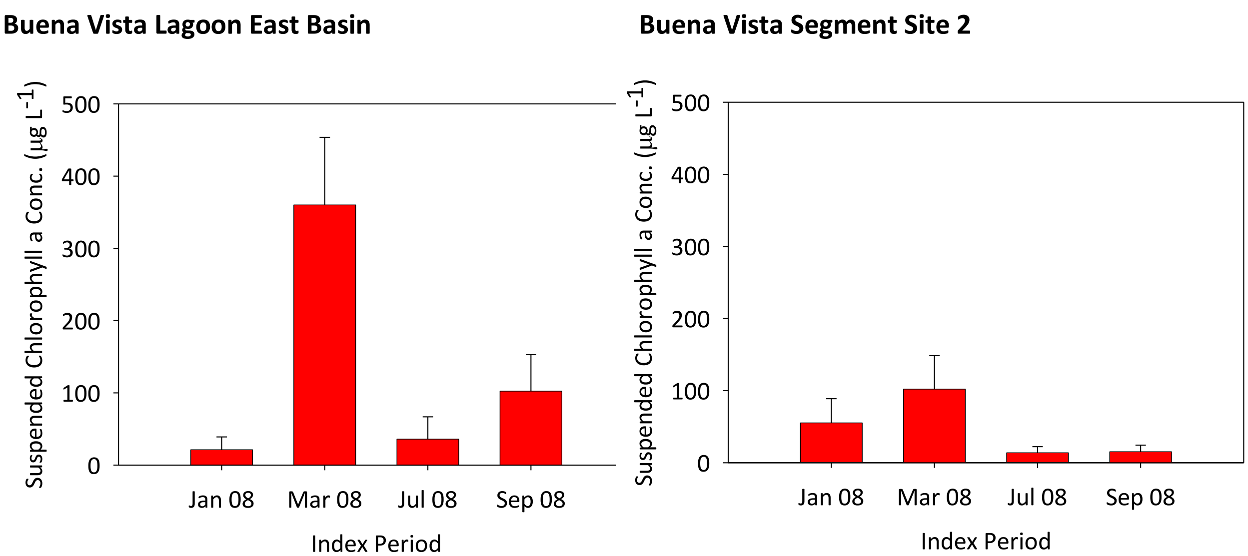


Figure 2.9. Suspended Chlorophyll a concentrations for each index period.

Table 2.2. Wet weight biomass and % cover of macroalgae in the Buena Vista Lagoon Central Basin.

Measure	Index 1	Index 2	Index 3	Index 4
Biomass	2448±4613	0±0	3591±720	6384±1973
Cover	100±0	0±0	100±0	100±0

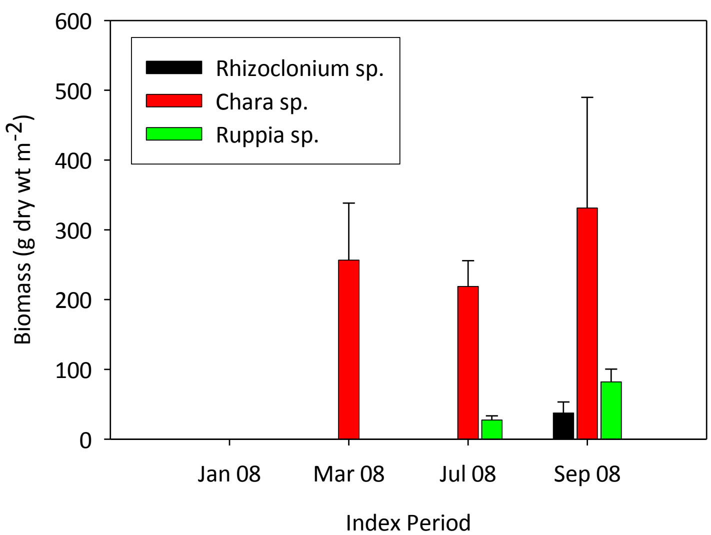


Figure 2.10. Macroalgae and SAV biomass by genus in the Central Basin (dry wt m^{-2}).

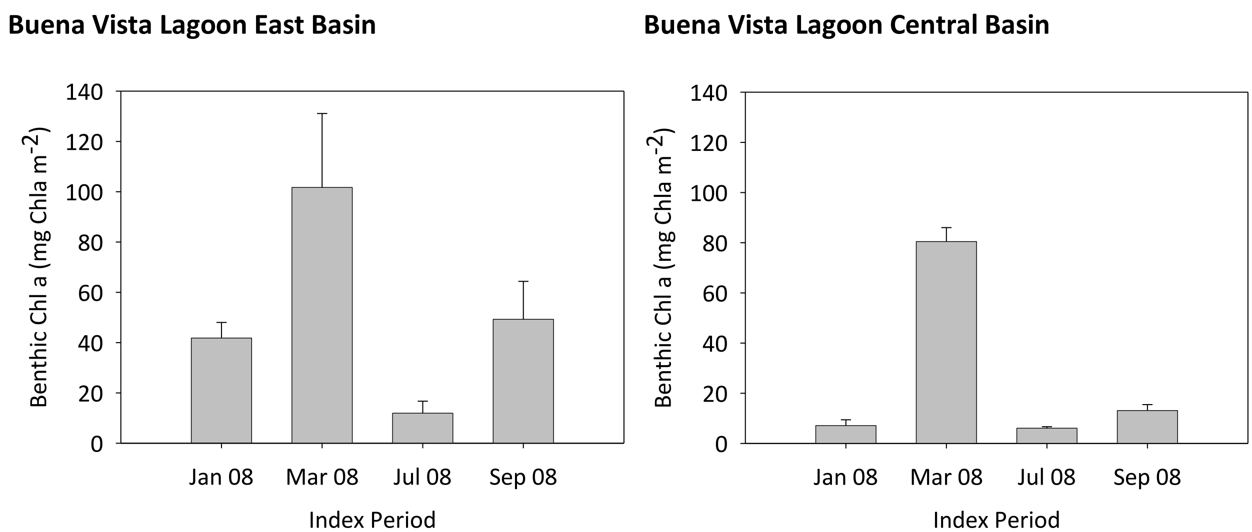


Figure 2.11. Benthic Chlorophyll a concentrations for each index period.

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 East and Central Basins sites (Figure 2.11). East Basin sites generally had lower fractions of fine-grained sediments (<40% fines, with exception of January 2008 sampling period), while Central Basin sediments were much more fine-grained, with cored surface sediments typically in the range of 60 - 100% fines. Sediments in Central Basin were generally 1 m of unconsolidated floc that was not sampled well by cores. As a result, sediment C:N ratios were higher in the East Basin (10 - 15:1) and generally below 10:1 in the Central Basin.

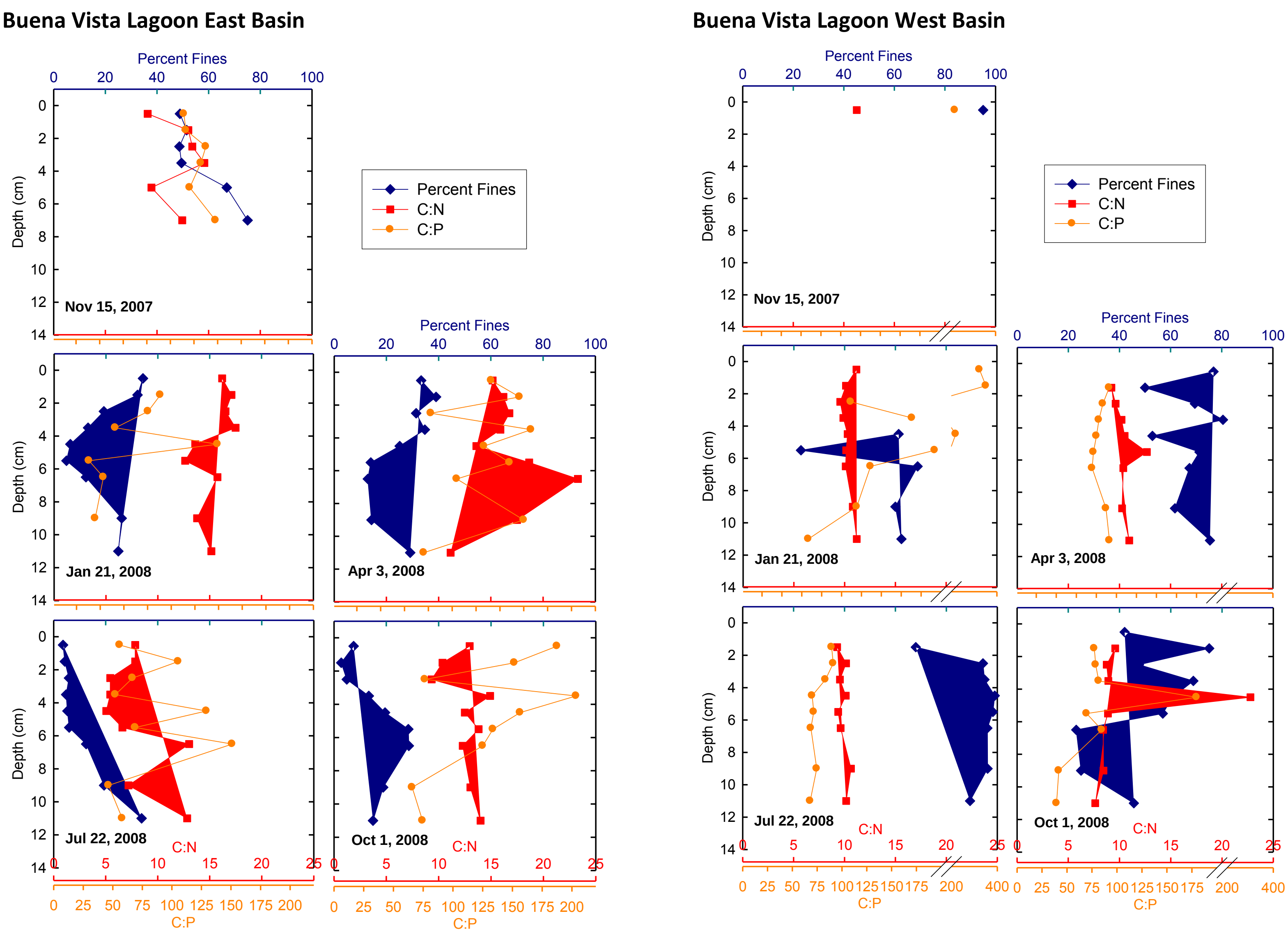


Figure 2.12. Sediment grain size (as percent fines, ♦), carbon: nitrogen (C:N, ■), and carbon: phosphorus (C:P, ●) ratios of cores taken in East and Central Basins of the Lagoon during each index period.

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}; Figure 2.13) and indicate the Buena Vista Lagoon East basin site was is primarily an erosional site, while the Central Basin is primarily depositional. Sediments at the East Basin site appeared to be net depositional in late spring, then net erosional through the summer, while net deposition appeared to occur throughout the year in the Central Basin, with the exception of some erosional even in late April/early May.

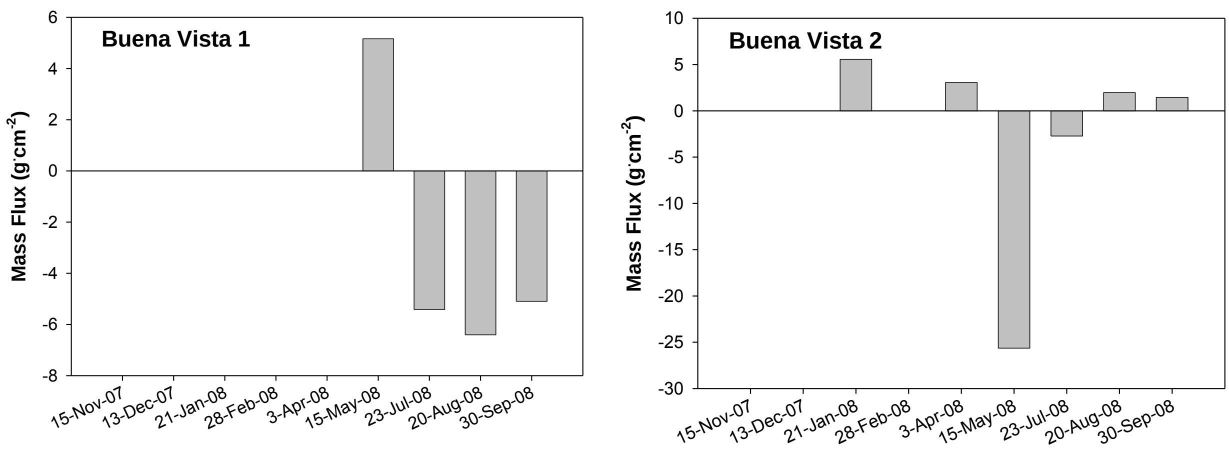


Figure 2.13. Mass flux is given as an inventory of material deposited (+) or removed (-) through time (red bars) and accumulated monthly rainfall (blue bars).

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 high coverages of macroalgae.
   a. Estimates of biomass of macroalgae were extremely high with transect means of 3591 to 6384 g wet wt m^{-2} over the fall 2008 field studies and 100% cover. 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%.
   b. Dissolved oxygen concentrations found to be below 5 mg L^{-1} about 0.6 - 16% of the wintertime and 20 and 30% of the summertime at East and Central Basins respectively during the 2008 TMDL field studies.
2. Winter dry weather concentrations of nitrate+nitrite indicate anthropogenically-enriched nutrient sources from Buena Vista Creek.
3. Sediments in the Central Basin of the Lagoon in general were extremely fine-grained, with unconsolidated floc of > 1 m in depth.

2.4.2 Significance of Macroalgae in Lagoon

Opportunistic macroalgae are highly successful in nutrient–rich freshwater and estuarine systems. These algae typically can have filamentous or sheet-like growth forms (e.g., Cladophora or *Ulva* spp.) or or whorls of filaments that occur along a main body of cells (*Chara 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).

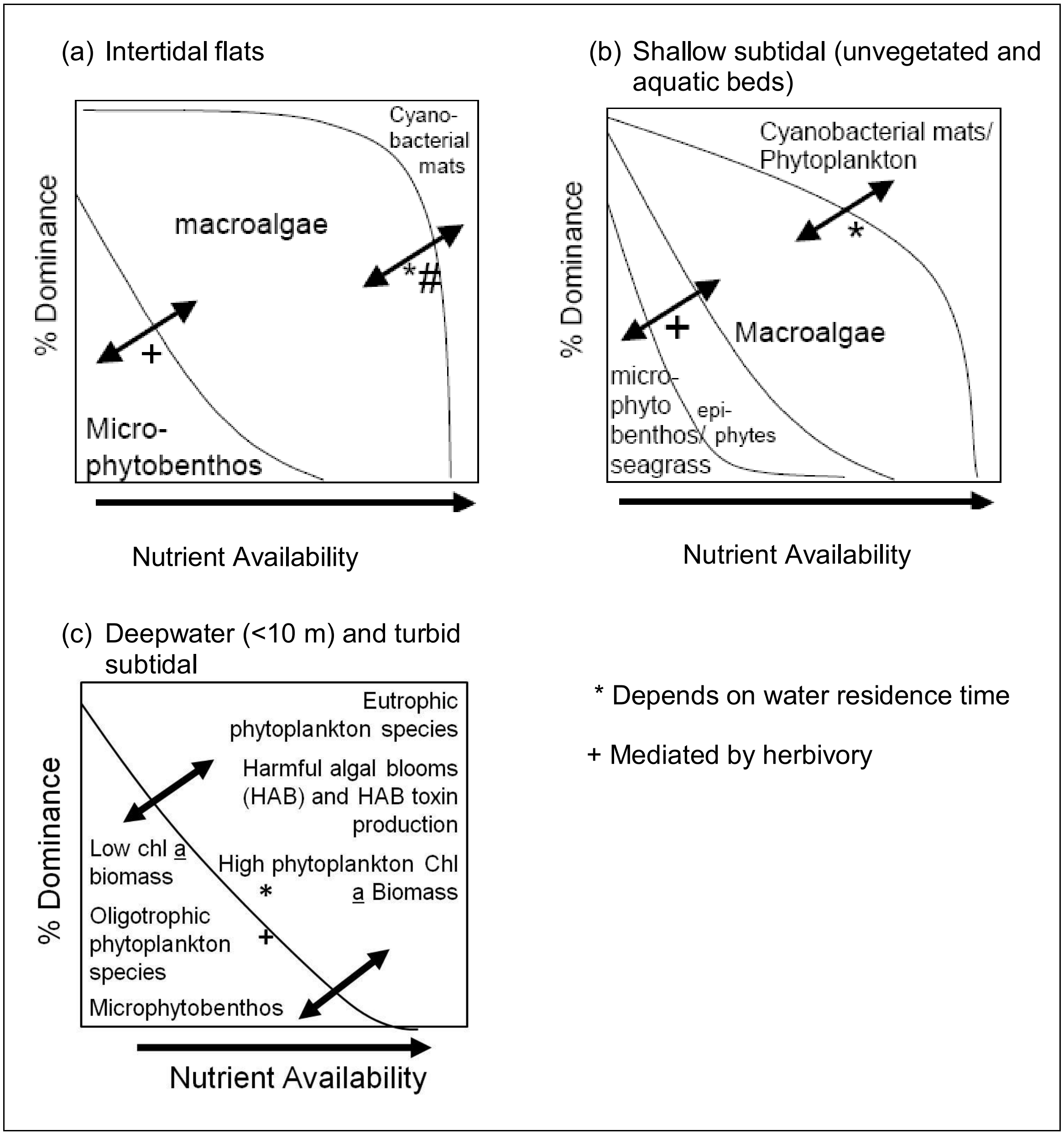


Figure 2.14 Conceptual model of relationship between nutrient availability and relative dominance of primary producers in California estuaries by major habitat type: (a) intertidal flats, (b) shallow subtidal and (c) deepwater or turbid subtidal. From Sutula et al. (2010).

In Buena Vista Lagoon, a brackish water estuary, the East and Central Basins behaved as two completely different ecosystems, but followed a generally patterns generally indicative of eutrophic estuaries around the world (Fong *et al.* 1993, Fong *et al.* 1998, Kamer *et al.* 2001). The East Basin was a more light-limited environment with higher total suspended solids (TSS) throughout the year; therefore phytoplankton was the dominant primary producer, with MPB only seasonally dominant in the spring. In turbid estuaries, phytoplankton are in competition with MPB and will dominate them under conditions of high nutrient availability (Figure 2.14a).

Mean phytoplankton biomass concentrations in the East Basin peaked in the spring (360 mg Chl a L^{-1}), but was generally high throughout summer and fall index periods as well (36 – 102 mg chl a L^{-1}). The California freshwater lakes Nutrient Numeric Endpoint framework provide 2 thresholds that can be considered for brackish water lagoons dominated by phytoplankton: 20 mg Chl a L^{-1} is considered to be sustaining aquatic life use, while 50 mg Chl a L^{-1} is considered to indicate a clear impairment of aquatic life use (Tetra Tech 2006). While these thresholds have not been yet to coastal lagoons, measured concentrations of 102 to 360 mg Chl a L^{-1} is likely to be considered eutrophic to hypereutrophic.

In the Central Basin, the primary producers in the Central Lagoon were dominated by *Chara sp.,* a macroalgae. Species in this phyla typically occur in lakes, ponds and streams attached to the bottom by rhizoids and thus resemble SAV. In the Central Basin, *Chara* grew to large areas of dense underwater monocultures in areas less than 4 m deep. *Chara* sp. dominated MPB during all times of the year, with the exception of the springtime. As nutrient availability increases, it has been well-documented in many parts of the world that blooms of macroalgae become dominant in shallow subtidal and intertidal estuaries and lagoons, replacing SAV or MPB (Figure 2.12b, 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).

Biomass and percent cover of macroalgae were extremely high, with means of 3591 and 6384 g wet wt m^{-2} during the summer and fall in the shallow areas of the lagoon (< 4m). 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). *Ruppia cirhhosa* dominated biomass and cover in the deep areas (>4 m), with peak biomass in the fall (8491 g wet wt m^{-2}). The combination of increased nutrients and low or no flushing in these systems creates a situation whereby drift and floating macroalgal mats can have maximum impact in the Central Lagoon as they are relegated to movement within the system and are limited in their ability to be flushed out (Whitfield 1988).

While primary producer biomass and percent cover are useful for understanding the extent of eutrophication in estuaries, there is currently no established assessment framework in California 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). However, the conceptual model of effects of intertidal macroalgal mats on benthic infauna do not likely apply here, floating mats of *Rhizoclonium* and attached *Chara* do not have a direct impact on benthic infauna.

Conceptually, the biomass and percent cover of floating or drifting macroalgae in closed ICOLLs could have a multitude of adverse effects, including: 1) shading effects on MPB and brackish water SAV, 2) overproduction of organic matter, leading to water column hypoxia, production of S^{-2} in sediments, and poor water quality conditions due to an overabundance of heterotrophic bacteria, and 3) changes in richness and relative abundance of primary producers, with adverse effects on higher trophic levels (invertebrates, fish and birds). With the exception of a handful of studies, little work has been done to investigate the effects of macroalgal biomass or drift algae, although several authors studying emphemerally tidal lagoon have suggested their impact could be extremely important (Kaldy and Sutula 2011, Knoppers et al. 1991, Herrera-Sileira and Morales-Ojeda 2010, Mutchler et al. 2010). When investigating the effects of mouth closure in Swartvlei Estuary in South Africa, an estuary that is closed seven months out of the year, Whitfield (1988) found that in winter, when the mouth was normally closed, *Zostera capensis* beds were covered in *Enteromorpha* sp. (now *Ulva*). The algae then detached, forming mats that moved throughout the estuary when the mouth was open. Cummins et al. (2004) experimentally manipulated drift algal biomass on seagrass beds and found huge declines in macrophyte biomass as well as infaunal communities in enclosures with algae in the Tuggerah Lakes estuary, New South Wales, Australia, where tidal exchange is <1%. Elevated biomass of floating macroalgal mats of *Ulva* spp., *Cladophora* spp., and *Rhizoclonium riparium* were found in the estuarine habitat of Patos Lagoon in southern Brazil (Odebrecht et al. 2010), but the effect of the mats on the estuarine community was not measured.

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 to 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)). Production of organic detritus from the high APP biomass can 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 0.6 - 16% of the wintertime and 20 - 30% of the summer and fall, indicating that a combination of primary producer biomass and sediment O_2 are driving factors in depressed DO concentrations. Oxygen minima in surface waters were most apparent during nighttime and early morning hours, indicating that the balance of primary producer respiration and heterotrophic oxygen demand are controlling DO. Factors affecting dissolved oxygen flux are explored further in Chapter 3.

2.4.3 Patterns in the Lagoon Surface Water 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. Plots of dissolved inorganic N to dissolved inorganic P indicate that the East Basin is primarily P-limited, while the Central Basin is N-limited (Figure 2.15).

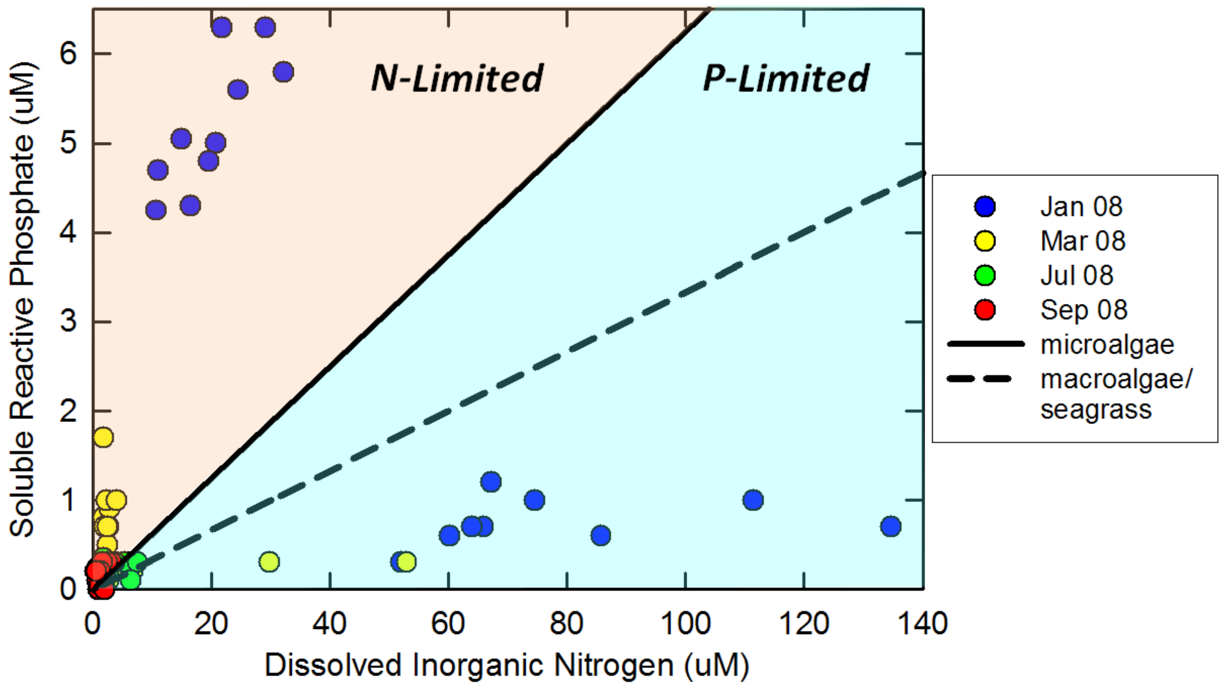


Figure 2.15. Ambient soluble reactive phosphorus versus dissolved inorganic nitrogen (nitrate, nitrite, and ammonium) from transect data in the East and Central basins. The solid black line indicates the N and P requirements for both phytoplankton and benthic microalgae (N:P = 16:1), and the dotted black 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. January values in the N-limited region are Central Basin sites, while those in the P-limited region are in the East Basin.

During winter index and wet weather periods, NO_2+NO_3 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, and SRP dominated estuarine TN and TP respectively.

Longitudinal plots of surface water transect data were particularly instructive as to whether 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). These figures show that East Basin is a strong sink for NO_2+NO_3, with very high concentrations near the creek mouth and decreasing approximately 50 µM before the first station in the Central Basin. This same trend was observed in the spring to a lesser degree and thus appears to be a function of available N loaded from the watershed. Nitrate+nitrite was consistently lower throughout the summer and fall index periods then in the winter and spring, These very low concentrations of NO_2+NO_3 indicate that either denitrification (the process of converting NO_3 to N gas, Seitzinger 1988) or plant uptake may be responsible for drawing down concentrations to near detectable values.

In contrast, the Central Lagoon appeared to be a source of phosphate and TP, 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 groundwater, or storm drains (Valiela et al. 2006).

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 the East Basin site to be net erosional. This is likely to be true close to the mouth as creek velocity entering the basin drops, depositing the coarse grained materials. This conceptually fits the sediment core data, which showed % fines to be lower than 40% at this site. As the flows move out into the rest of the East basin, the sediments are likely to be net depositional, though not additional ^{7}Be data are available to document this.

Because of the large stand of cattails that obstructs flows between the East and Central Basins, it appears that only fine suspended sediment enter the Central Basin. TSS was generally an order of magnitude lower in this basin and ^{7}Be data show the site to be net depositional. This corroborates the sediment core data, which shows sediments to be >60% fines with anecdotal observations of unconsolidated floc of greater than 1 m depth.

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 TCO_2 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 Fe and 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:

1. Measurement of porewater N, P, TCO_2, S^{-2}, Fe, and Mn concentrations to provide information about the sediment biogeochemistry and redox status of Buena Vista Lagoon sediments.

2. 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 in 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 ft of the peeper location.

Immediately following retrieval, the peepers are placed inside large format ziplock 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, SRP, TDN, 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.

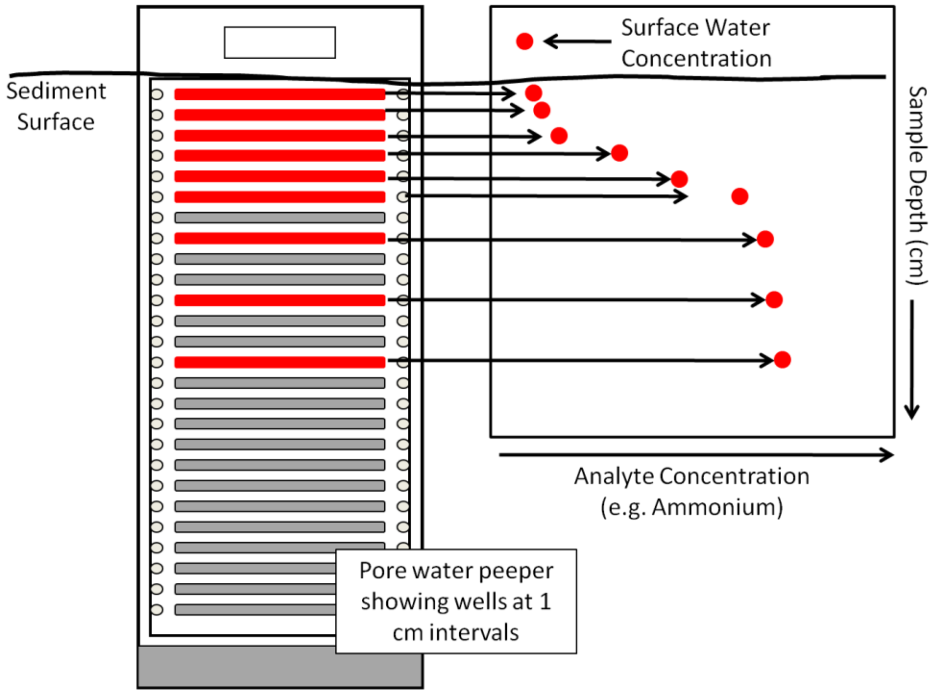


Figure 3.1. Graphic depicting how porewater profiles are generated from porewater peepers.

3.2.1.2 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).

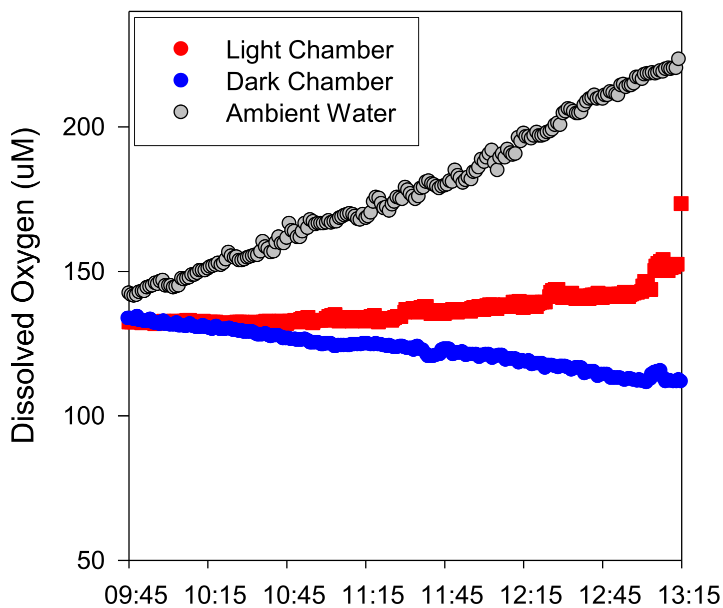


Figure 3.2. Typical chamber time series of dissolved oxygen concentration within the light and dark chambers relative to ambient surface water (I-5 Basin, January 2008). Oxygen concentrations in both the light and dark chambers steadily decreased over the incubation. Flux calculations were made during the most linear part of the curve.

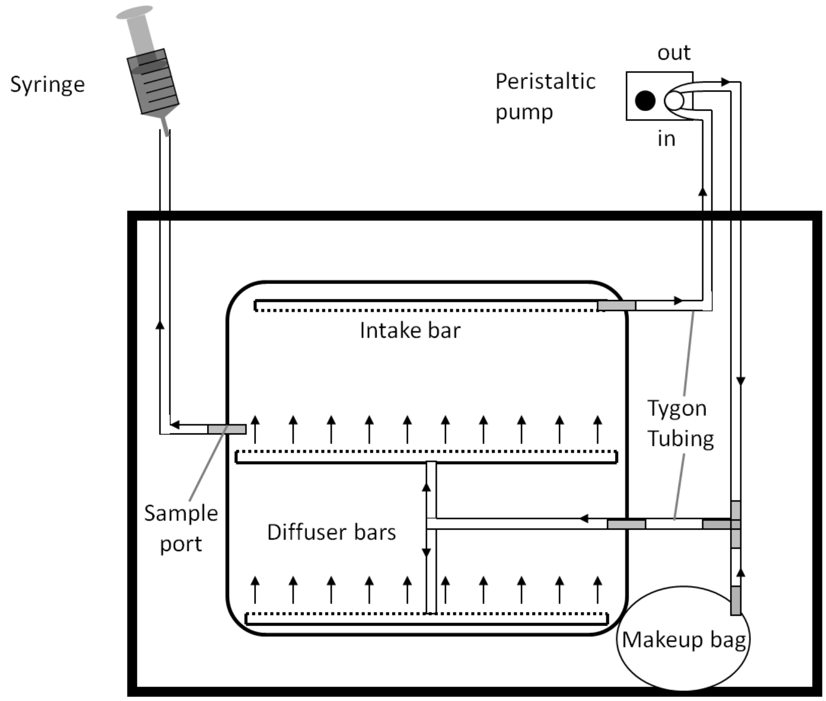


Figure 3.3. Schematic of benthic chamber design as viewed from above.

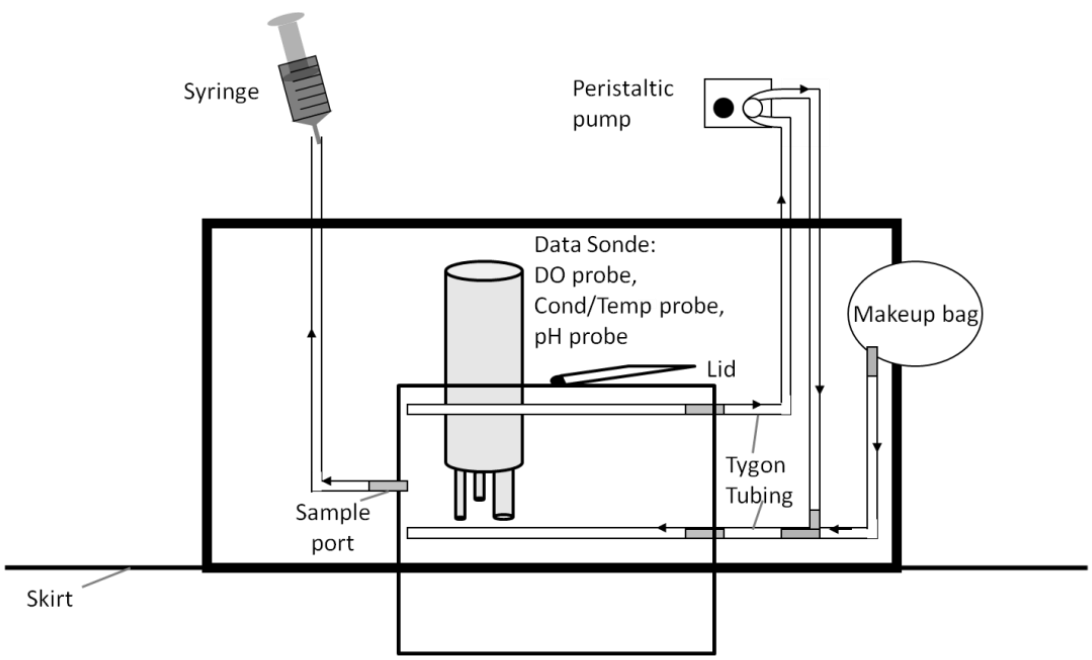


Figure 3.4. Schematic of benthic chamber design as viewed from side.

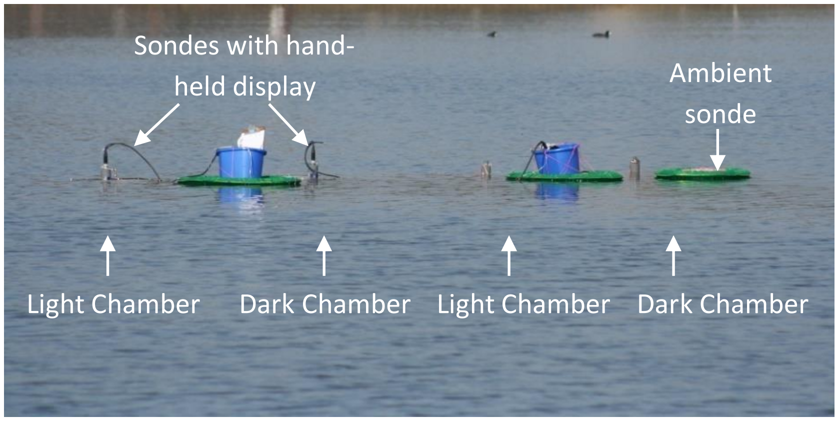


Figure 3.5. Flux chambers during deployment.

Each chamber is equipped with a YSI 6920 data sonde containing a temperature/conductivity probe, optical DO 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 their 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_3, NO_2, 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 TDN/TDP. The second syringe was fitted with a PES filter, which was rinsed with 10 ml 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, organic carbon, organic nitrogen, 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).

3.2.1.3 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 nitrogen from all N compartments into NO_3 and the phosphorus 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 668 nm. 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 N and P 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):

$$F = h * \left(\frac{dC}{dt}\right) \qquad \textbf{Eq. 3.1.}$$

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 (carbon dioxide) converted to autotrophic biomass and is calculated from the difference between light (with photosynthesis) and dark (without photosynthesis) TCO_2 fluxes:

$$\text{Carbon Fixation} = \text{Flux TCO2}_{light} - \text{Flux TCO2}_{dark} \qquad \textbf{Eq. 3.2}$$

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:

$$\text{GPP} = \text{Flux O2}_{light} - \text{Flux O2}_{dark} \qquad \textbf{Eq. 3.3}$$

3.3 Results

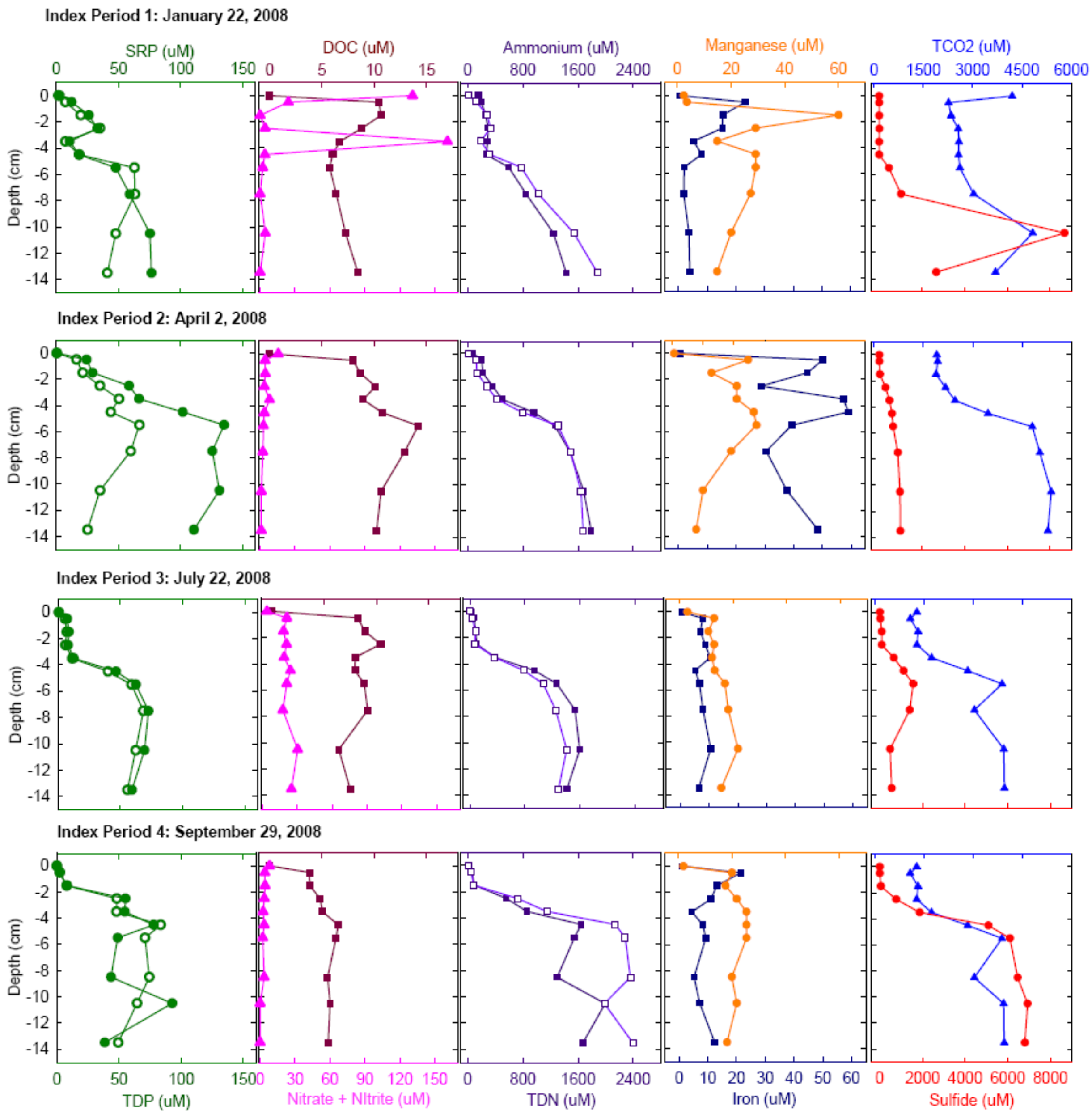
3.3.1 Sediment Porewater Concentrations

Porewater N and P concentrations showed distinct seasonal differences among the East and West Basins (Figure 3.6). Ammonium and SRP comprised the majority of TDN and TDP in porewaters at all sites. Central Basin TDN, NH_4, TDP and SRP concentration were roughly a factor of two or greater than that of the East Basin, while peak DOC concentrations were four orders of magnitude higher. In the Central Basin, peak concentrations of TDN, NH_4, TDP and SRP were shallower in the Central Basin (0 - 2 cm in depth) and coincident with extremely high S^{-2} concentrations (7,155 to 51,109 µM). Central Basin $NH_4$and SRP concentration peaked in January, September and, to a lesser extent, July index periods, while NO_3 values were near non-detect in surface sediments.

In the East Basin, porewater TDN, NH_4, TDP and SRP vertical profiles had very similar peak concentrations with depth among seasons. Vertical profiles of these constituents were depleted at the surface and peaked around 6 - 8 cm in depth. Nitrate values were high to moderate high in surface sediments during the winter and summer index period, with peaks of 161 and 30 µM respectively, but were at near non-detectable levels during the other index periods.

At both segment sites, vertical profiles of SRP, NH_4, and S^{-2} concentrations tended to covary, showing peaks at mid-depths of the core and declines further down core. Dissolved OC and to a lesser extent nitrate+nitrite tend to covary with reduced Mn and Fe.

A. Buena Vista Lagoon East Basin



B. Buena Vista Segment Site 2

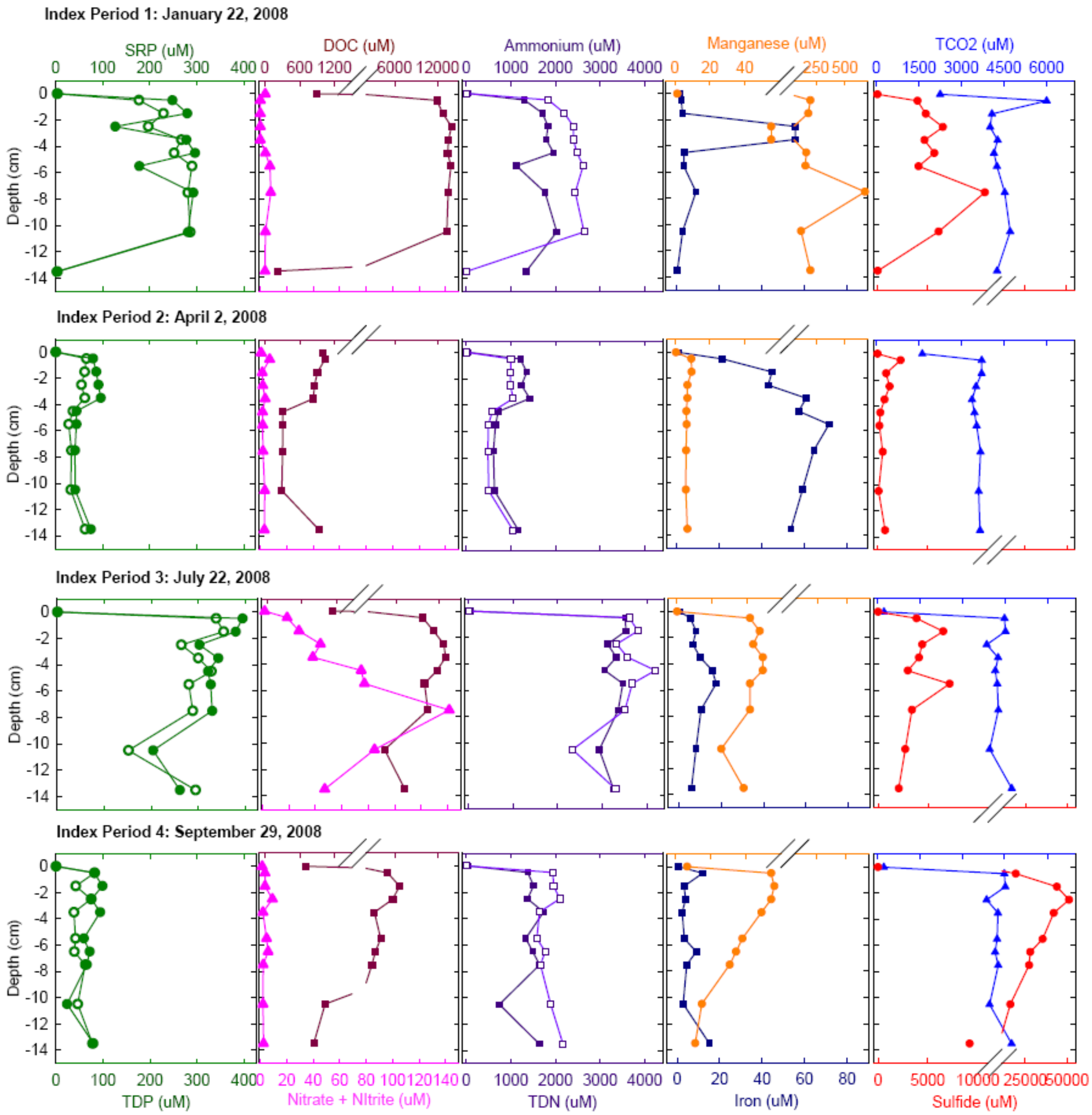


Figure 3.6 Results of sediment porewater sampling in Buena Vista Lagoon East Basin (A) and 2 (B) during each index period; each row represents an index period, first column is total dissolved phosphorus (●) and soluble reactive phosphate (○), second column is nitrate + nitrite (▲) and dissolved organic carbon (■), third column is total dissolved nitrogen (■) and ammonium (□), fourth column is iron (■) and manganese (●), fifth column is 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 East and Central Basins showed distinct differences by season (Table 3.1, Figures 3.7 and 3.8). East Basin sediments showed an uptake of O_2 (-3.5 to 39.5 mmol O_2 m^{-2} d^{-1}) and release of TCO_2 (15.1 to 31.1 mmol m^{-2} d^{-1}) during the winter through summer, indicating that sediments were net heterotrophic during this period (respiration exceeds primary production). Sediment oxygen demand was highest during the spring, during peak periods of phytoplankton biomass. During the fall, when phytoplankton was low and MPB was at its peak, the sediments were net autotrophic (primary production exceeds respiration), with a release of O_2 (39.6 mmol m^{-2} d^{-1}) and an uptake of TCO_2 (-9.9 mmol m^{-2} d^{-1}; Figure 3.7).

In contrast, sediments from the Central Basin were net heterotrophic year round, with oxygen uptake rates ranging from -101.6 mmol m^{-2} d^{-1} in the winter index period to -227.2 mmol m^{-2} d^{-1} in the summer. TCO_2 fluxes were consistent with DO fluxes, showing a net release of 24.5 mmol m^{-2} d^{-1} in the spring, and 91.1 mmol m^{-2} d^{-1} in the fall. There was good correspondence between the DO and TCO_2 data, showing similar trends between both data types.

Among cofactors measured in all chamber incubations at East and Central Basins, DO flux was positively correlated with sediment C:N ratio and benthic Chl a, and negatively correlated with total infaunal abundance, sediment % fines, macroalgal biomass, TCO_2,TDP and SRP fluxes (Table 3.2). TCO_2 flux positively correlated with sediment percent fines (Table 3.2).

Table 3.1. Means and standard deviation of East and Central Basins DO fluxes by index period.

Index Period	East Basin		Central Basin	
	Net	Std. Dev	Net	Std. Dev
Jan 2008	-3.5	2.2	-101.6	83.1
Mar 2008	-39.5	34.0	-119.8	128.1
July 2008	-13.6	5.7	-227.2	41.6
Sept 2008	39.6	22.7	-131.4	46.1
Annnualized	-4.3	41.4	-145.0	164.8

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	Sediment C:N Ratio	Sediment % Fines	Benthic Chl a	Macroalgal biomass	DO flux	TCO_2 flux	TDN flux	TDP flux	NH4 flux	NO3 flux	SRP flux	Fe flux	Mn flux
Tot. Infauna abundance	Corr.	-0.11	0.14	-0.13	0.33	**-0.40**	0.26	0.01	-0.07	0.27	-0.18	0.26	-0.04	0.24
	p-value	0.60	0.49	0.49	0.08	**0.05**	0.17	0.97	0.71	0.15	0.34	0.17	0.82	0.19
Sediment C:N Ratio	Corr.	1	**-0.42**	**0.64**	**-0.44**	**0.52**	-0.04	-0.31	-0.27	-0.30	**-0.61**	**-0.37**	-0.09	**-0.35**
	p-value		**0.03**	**0.00**	**0.02**	**0.01**	0.82	0.10	0.16	0.11	**0.00**	**0.05**	0.63	**0.07**
Sediment % Fines	Corr.		1	-0.28	**0.62**	**-0.81**	**0.39**	0.02	**0.46**	0.27	**0.46**	**0.49**	-0.01	0.05
	p-value			0.15	**0.00**	**<.0001**	**0.04**	0.91	**0.01**	0.16	**0.02**	**0.01**	0.95	0.80
Benthic Chl a	Corr.			1	**-0.73**	**0.39**	-0.12	-0.27	**-0.43**	**-0.42**	-0.20	-0.22	-0.27	**-0.59**
	p-value				**<.0001**	**0.04**	0.51	0.14	**0.01**	**0.02**	0.27	0.22	0.13	**0.00**
Macroalgal biomass	Corr.				1	**-0.65**	0.23	0.10	**0.41**	**0.40**	0.03	**0.37**	0.17	**0.47**
	p-value					**0.00**	0.21	0.61	**0.02**	**0.02**	0.85	**0.04**	0.35	**0.01**
DO flux	Corr.					1	**-0.61**	0.06	**-0.43**	-0.28	-0.24	**-0.59**	0.19	-0.23
	p-value						**0.00**	0.78	**0.02**	0.15	0.23	**0.00**	0.35	0.25
TCO_2 flux	Corr.						1	-0.09	0.01	-0.11	0.02	0.29	0.02	0.19
	p-value							0.63	0.95	0.56	0.93	0.11	0.91	0.29
TDN flux	Corr.							1	-0.03	0.15	0.22	0.07	0.11	0.19
	p-value								0.86	0.40	0.22	0.72	0.57	0.30
TDP flux	Corr.								1	0.12	0.12	**0.47**	-0.02	**0.37**
	p-value									0.52	0.50	**0.01**	0.92	**0.04**
NH4 flux	Corr.									1	0.11	0.07	-0.03	**0.40**
	p-value										0.53	0.71	0.86	**0.02**
NO3 flux	Corr.										1	0.15	-0.04	-0.16
	p-value											0.42	0.83	0.38
SRP flux	Corr.											1	**-0.12**	**0.36**
	p-value												**0.04**	**0.04**
Fe flux	Corr.												1	-0.04
	p-value													0.84

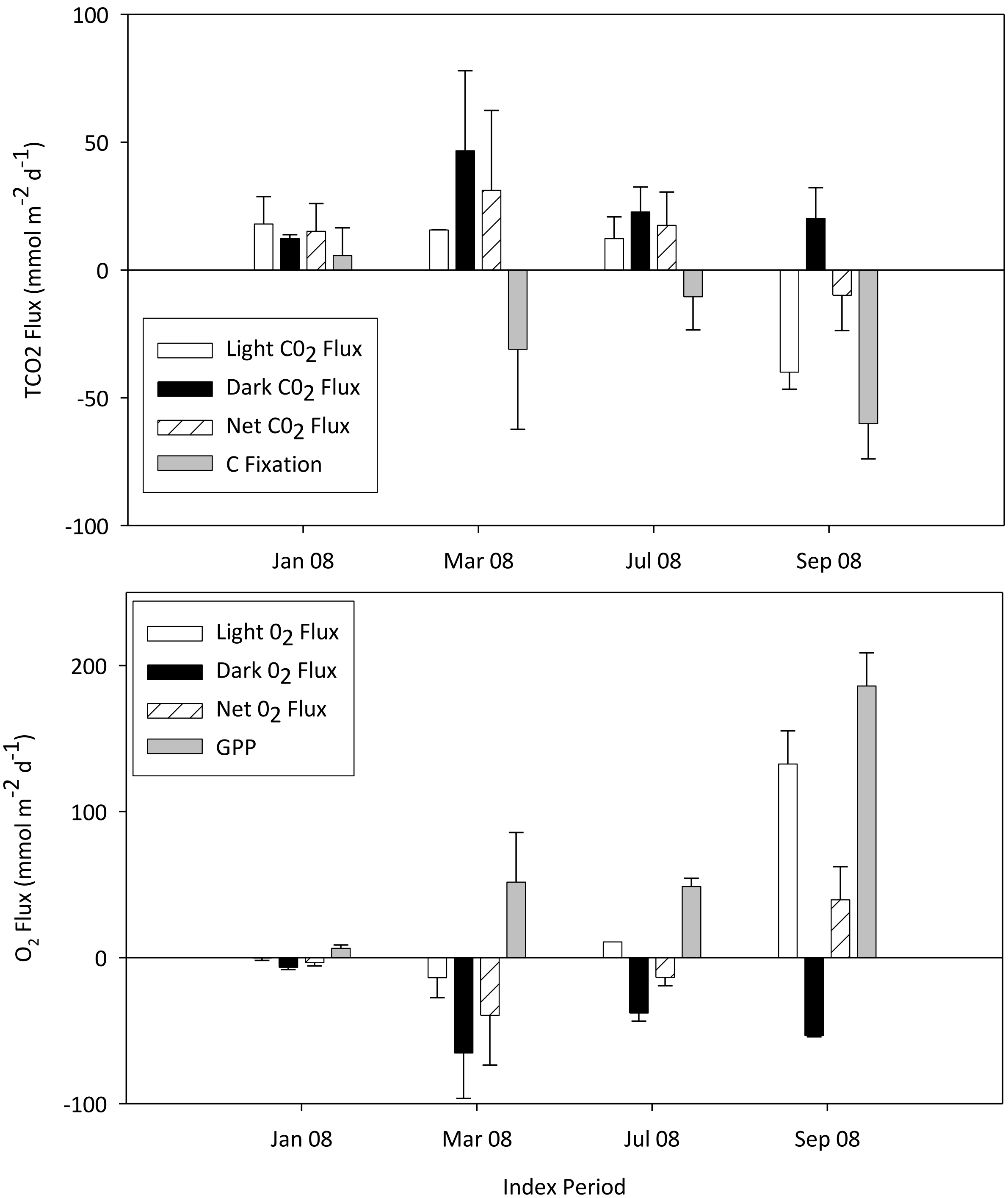


Figure 3.7. Light, dark, net (24-hour average of light and dark) TCO_2 fluxes and estimated C fixation (calculated as $TC02_{light}$ – $TCO2_{dark}$) for Buena Vista Lagoon I-5 Basin. Error bars represent the standard deviation between replicates.

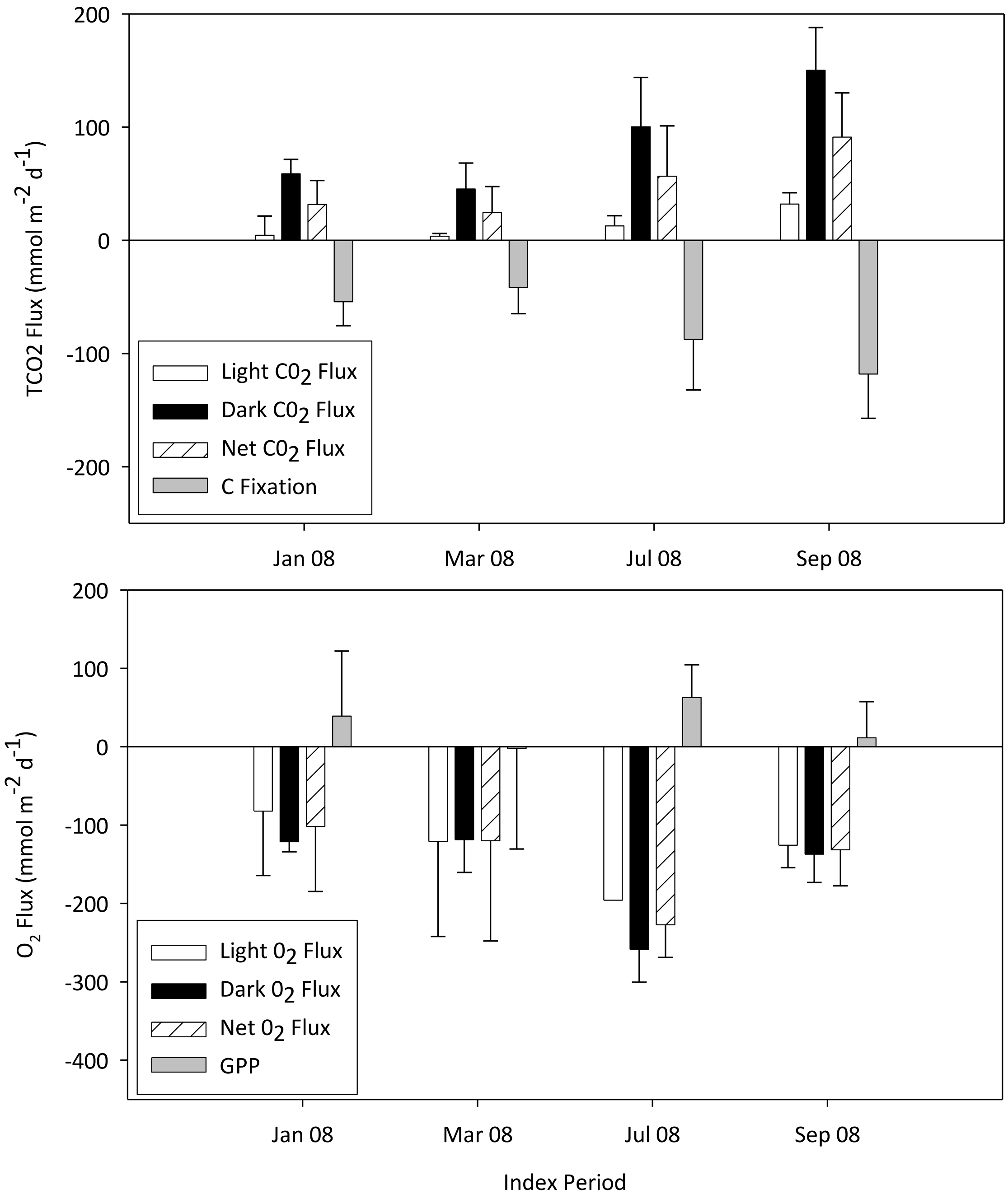


Figure 3.8. Light , dark , net (24-hour average of light and dark) TCO_2 fluxes, and estimated C fixation (calculated as $TC02_{light} – TCO2_{dark}$) for Buena Vista Lagoon West Basin. Error bars represent the standard deviation between replicates.

3.3.2.1 Nitrogen Fluxes

Net fluxes (mean of light and dark incubations) of NH_4, NO_3 and TDN) exhibited some clear seasonal patterns with respect to Basin (Table 3.3; Figure 3.9). Net fluxes across light and dark chambers show East and West Basin were a consistent sink of TDN in the winter and spring. TDN was generally a source in both basins during the summer and fall index periods, with the exception of the east basin in the fall. TDN fluxes were extremely variable, particularly in the Central Basin as sediments were very floccy, making benthic chamber deployment difficult.

Both basins also appeared to be a sink for NO_3 during all seasons, with the highest fluxes in the winter and spring, consistent with elevated watershed sources of NO_3. During the summer and fall, the NO_3 fluxes were near non-detect. High NO_3 influxes drove negative TDN fluxes in the winter and spring, while summer and fall TDN fluxes driven by NH_4fluxes and, to a lesser extent DON. Net fluxes showed that NH_4fluxes provided a minor source to the East Basin during all year, while in the Central Basin NH_4fluxes were of significance only during the spring and summer.

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	NH_4	NO_3
Jan-08	East Basin	-4.8±2.6	0.1±0.3	-8.8±4.0
Mar-08		-9.8±11.3	0.6±0.5	-13.6±12.4
Jul-08		0.3±5.3	0.4±2.1	-1.1±0.4
Sep-08		-2.7±4.2	0.2±0.5	0.0±0.0
Jan-08	West Basin	-2.3±8.0	0.1±10.8	-4.2±4.2
Mar-08		-3.2.0±13.5	-1.9±14.3	-0.2±1.0
Jul-08		6.5±6.3	4.8±2.8	-0.3±0.4
Sep-08		4.3±84.6	4.9±4.1	0.0±0.0

Of the co-factors measured in benthic chamber incubations at East and Central Basins, NH_4 flux had significant positive correlations with macroalgal biomass, SRP and Mn fluxes. Nitrate fluxes had significant positive correlations with sediment % fines and negative correlations with sediment C:N ratio. No variables were significantly correlated to TDN flux.

3.3.1.3 Phosphorus Fluxes

Net fluxes (mean of light and dark incubations) of TDP and SRP exhibited some clear seasonal patterns with respect to Basin (Table 3.4, Figure 3.9). Net fluxes across light and dark chambers show East basin a small sink for SRP during all seasons and for TDP during the winter and spring index periods (-0.7 to -0.1 mmol SRP m^{-2} d^{-1}). In contrast, TDP and SRP were a source in the Central Basin during the all index periods (0.5 to 1.4 mmol SRP m^{-2} d^{-1}), with the exception of winter when net TDP flux was negative.

Of the cofactors measured in benthic chamber incubations at East and Central Basins, TDP flux had significant positive correlations with %fines, macroalgal biomass, SRP and Mn fluxes, and a negative correlation with benthic Chl a and DO flux. Simillarly, SRP flux had significant positive correlations with %fines, macroalgal biomass, TDPand Mn fluxes, and a negative correlation with sediment C:N ratio, DO and Fe fluxes (Table 3.2).

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	East Basin	-0.2±0.6	-0.7±0.5
Mar-08		-1.0±0.3	-0.3±0.1
Jul-08		0.0±0.3	-0.1±0.2
Sep-08		0.5±0.3	-0.1±0.1
Jan-08	West Basin	-0.2±1.3	0.9±0.7
Mar-08		0.3±1.2	0.5±1.3
Jul-08		1.3±1.3	1.4±1.3
Sep-08		0.9±0.7	0.8±1.4

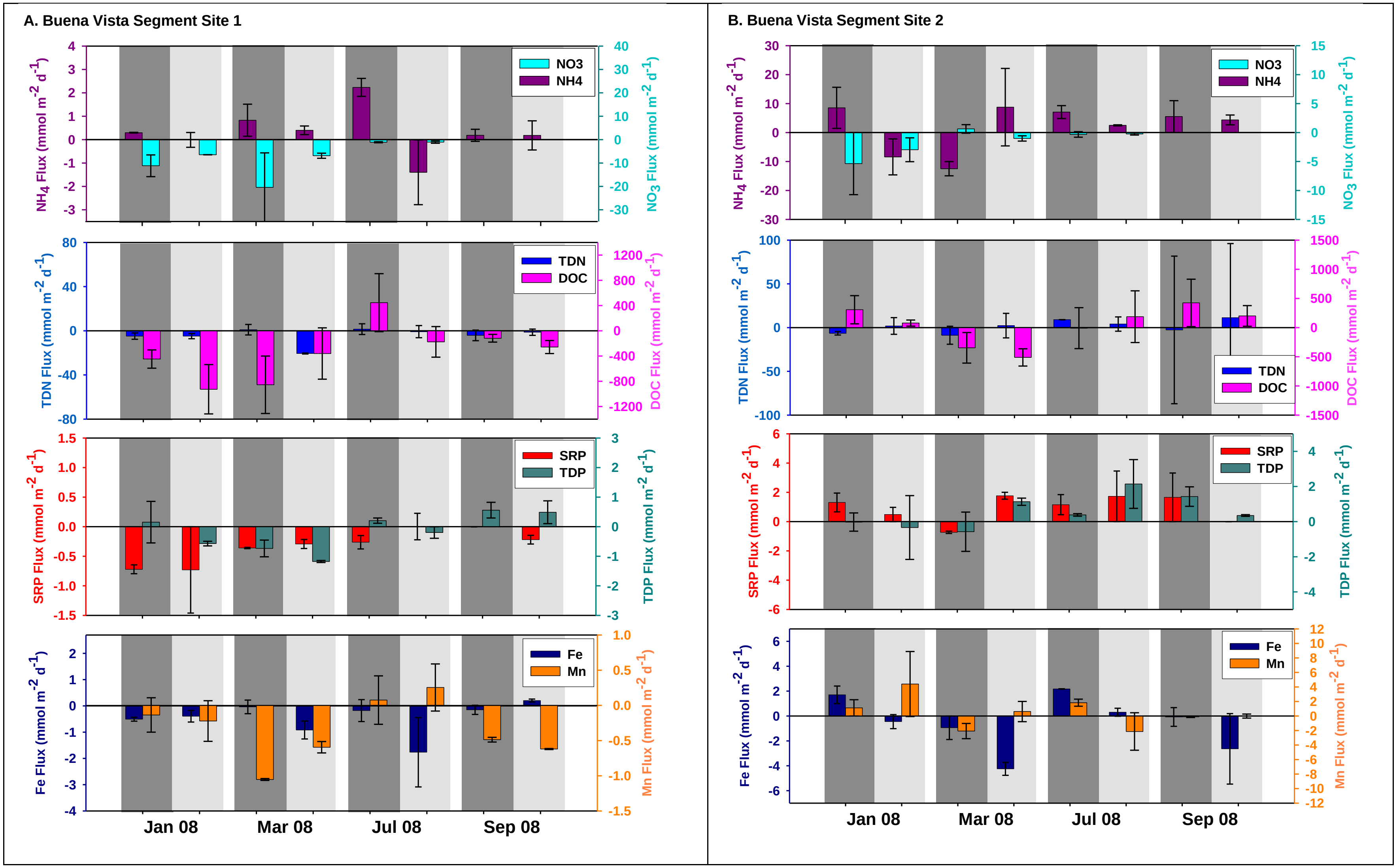


Figure 3.9 Benthic fluxes for dark (dark grey bands) and light (light grey bands) for each of the index periods for (A). Buena Vista Lagoon East Basin (left graph) and (B). Buena Vista Lagoon Segment Site 2 (right graph). Error bars represent the standard deviation between replicate chambers.

3.4 Discussion

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 three principal findings:

- Annually estuary benthic metabolism was net heterotrophic (net uptake of O_2 by sediments). The fluxes, measured with benthic chambers, are supported by continuous DO data, which showed the estuary to be below 5 mg L^{-1} 20 - 30% of the time during the summer and fall at East and West Basin respectively. These rates of O_2 uptake were comparable to other depositional environments in eutrophic/hypereutrophic estuaries. Lagoonal environments (Buena Vista, San Elijo Lagoons and Famosa Slough) are more likely to be susceptible to hypoxia than river mouth estuaries (Loma Alta Slough and Santa Margarita Estuary) because they have a tendency to deposit fine-grain, organic matter rich sediments that consume O_2. The East Basin is more regularly flushed with freshwater from Buena Vista Creek, while Central Basin receives minimal flushing. As a result, sediment percent fines were greater in the Central Basin, primary producer biomass was three orders of magnitude higher, and the Central Basin had very high sediment O_2 demand (peak net rate of -227 mmol O_2 m^{-2} d^{-1}) relative to the East Basin (peak net rate of -35 mmol m^{-2} d^{-1}).
- Averaging over season and Basin, benthic flux appears to provides net source of NH_4 (1.2 mmol NH_4 m^{-2} d^{-1}) and SRP (0.3 mmol SRP m^{-2} d^{-1}) to surface waters. Benthic efflux of $NH_4$and SRP was the high in the Central Basin during summer and fall (4.8 mmol NH_4 m^{-2} d^{-1} and 1.1 mmol SRP m^{-2} d^{-1}) during peak periods of primary productivity. In contrast, East Basin $NH_4$and SRP fluxes were low during peak primary production (0.3 mmol NH_4 m^{-2} d^{-1} and -0.1 mmol SRP m^{-2} d^{-1}); thus internal recycling of nutrients is particulary important in the Central Basin and is likely providing a major source of nutrients to support primary productivity.
- Patterns of NO_3 versus NH_4 fluxes indicate that denitrification (conversion of NO_3 to N gas that is permanently lost from the estuary) is a more important mechanism in the East Basin while dissimilatory nitrate reduction (DNR; reduction of NO_3 to NH_4) is more dominant in the Central Basin. Mean annual influx of NO_3 was high (-3.5 mmol m^{-2} d^{-1}). East Basin, the most proximate to high sources of NO_3 (Buena Vista Creek), had the highest rates of NO_3influx during the winter and spring (-8.8 to -13.6 mmol m^{-2} d^{-1}), relative to the Central Basin (-4.2 to -0.4 mmol m^{-2} d^{-1}). High NH_4 fluxes, coupled with very high NH_4, SRP and S^{-2} porewater concentrations, signal that Central Basin sediments in an anoxic state and thus would favor DNR over denitrification. Thus in the winter and spring, the Lagoon is better able to assimilate external NO_3 inputs through denitrification in the East Basin, but as the estuary becomes more eutrophic during summer and fall, the efficiency of N loss may be reduced in the Central Basin, retaining N in primary producer

biomass that is returned to the sediments during the fall and available again for primary production the following year.

3.4.1 Significance of Rates of Benthic O_2 and TCO_2 Fluxes in Buena Vista 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 Buena Vista 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 Central Basin of Buena Vista Lagoon is of equal or greater magnitude to all well-documented eutrophic estuaries (Table 3.6). The net O_2 and TCO_2 fluxes show that Central Basin sediment were net heterotrophic year round and East Basin sediment were net heterotrophic in the winter through the summer, 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). Dissolved Oxygen fluxes are supported by continuous DO data, which found DO concentrations below 5 mg L^{-1} approximately 20 - 30% of the time during the summer and fall with brief periods of hypoxia (<2 mg L^{-1}), coinciding with periods of peak primary productivity and decline, particularly in the Central Basin.

Shallow estuaries such as Buena Vista Lagoon can develop hypoxia typically through either of two main processes: 1) as episodic events driven by primary producer blooms and their subsequent decomposition (McGlathery *et al.* 2007), and 2) chemical O_2 demand driven by sediment heterotrophic bacteria or redox reactions. In East Basin, the basin was frequently flushed by storm events, sediment % sand and C:N ratio were higher than in the Central Basin and primary producer community dominated by phytoplankton. As a result, DO and TCO_2 fluxes were moderate (peak if -39 mmol). In contrast, Central Basin was largely a settling basin (see Chapter 2), with fine-grained, unconsolidated sediments, and measurements of macroalgal biomass that are among the highest recorded recently in Southern California estuaries (3591 to 6384 g wet wt m^{-2}). 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. As evidence that these sediments were net heterotrophic year round, peak DO fluxes ranged from -101 to 27 mmol O_2 m^{-2} d^{-1}, and porewater S^{-2} peak concentrations were 51,000 µM.

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). This study found that O_2 were positively correlated with sediment

C:N ratio and benthic Chl a and negatively correlated with infaunal abundance, sediment % fines and macroalgal biomass. This indicates that sediment O_2 demand is typically higher in sediments with greater organic matter and nutrient content, greater % fines. 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 MPB tend to oxygenate sediments (Sundeback and McGlathery 2005), resulting in a lower sediment O_2 demand. Thus lagoonal estuaries such as Buena Vista, Famosa Slough and Buena Vista Lagoon have higher sediment O_2 demand than river mouth estuaries such as Santa Margarita River and Loma Alta Slough (Table 3.5*)*.

Table 3.5. Comparison of fluxes from the Buena Vista Lagoon to other estuarine environments. Reported fluxes from this study represent annual means and standard deviations from the four index periods.

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)					
East Basin	-4.6±28.5	13.4±14.8	-0.3±0.6	0.3±2.2	-5.9±13.0
Central Basin	-145.02±48.0	50.9±26.0	0.9±2.4	2.0±18.0	-1.2±4.3
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

Table 3.5. Continued

Site	O_2	TCO_2	SRP	NH_4	NO_3
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 Buena Vista Lagoon

In shallow coastal lagoons such as the Buena Vista 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, DNR, decomposition and uptake by organisms (Figure 3.10). Exchange with the surface waters can be driven by diffusion, 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.

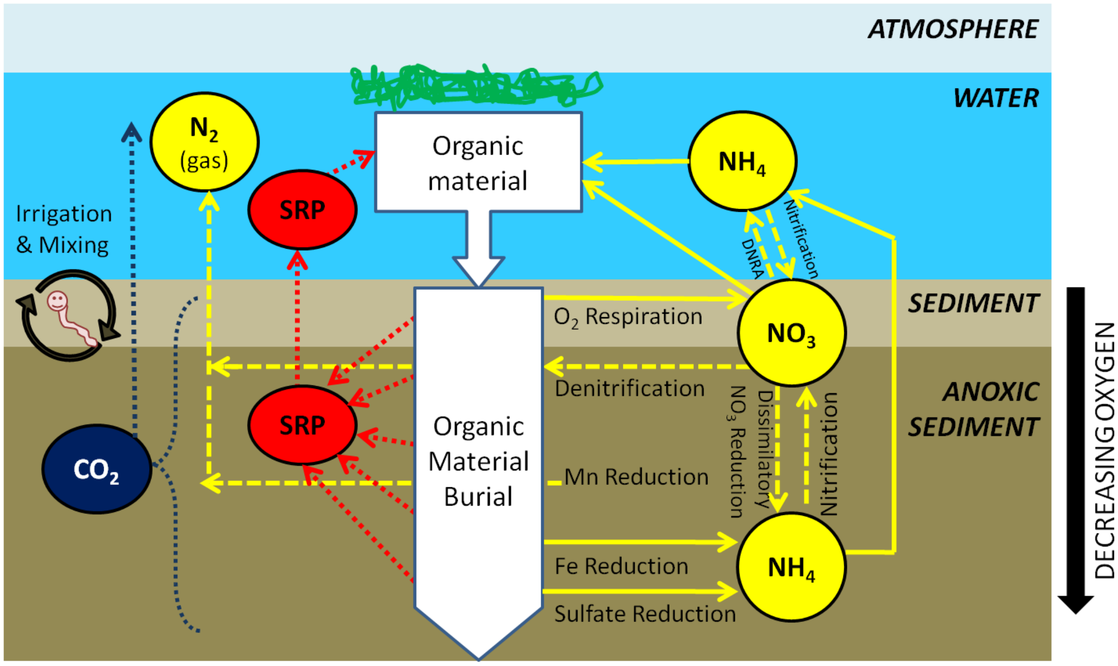


Figure 3.10. Pathways for nutrient cycling and decomposition of organic matter in the sediments.

For estuaries with high inputs of NO_3, the balance between denitrification and dissimilatory NO_3 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 oxygen) sediments and represents an important permanent loss of N from an estuary (Seitzinger 1988). Dissimilatory N reduction 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 provides minor net source of NH_4 (0.3 mmol NH_4 m^{-2} d^{-1}) to surface waters and a sink for NO_3 (-3 mmol NO_3 m^{-2} d^{-1}), particularly in the spring time when watershed NO_3 is a dominant source. These patterns suggest that denitrification is the dominant pathway over DNR in the east basin, while DNR is likely to be more important in the Central Basin, as evidence by high NH_4fluxes. Very high NH_4, SRP and S^{-2} porewater concentrations, signal that sediments in an anoxic state and thus would favor DNR over denitrification. Thus in the winter and spring, the Lagoon is better able to assimilate external dissolved inorganic nitrogen (DIN) inputs through denitrification, but as the estuary becomes more eutrophic during summer and fall, the efficiency of N loss may be reduced in the Central Basin.

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

Segment	January 2008	March 2008	July 2008	August 2008
East Basin	59.8±19.8	0±0	0±0	0.2±0.1
Central Basin	0.5±0.1	0.6±0.2	33.0±10.4	0.1±0.1

Averaging over index periods, sediments of the Lagoon appear to be source of SRP in the Central Basin (0.9 mmol SRP m^{-2} hr^{-1}) and a sink for SRP in the East Basin (-0.3 mmol SRP m^{-2} hr^{-1}) . Throughout the year, sediment O_2 demand in the East basin is lower, porewater profiles suggest the sediments are less anoxic and thus would be in the position of trapping phosphorus associated with iron and aluminum oxides (Figure 3.11, Roden and Edwards 1997). In contrast, Central Basin sediments appear to act as a source to surface waters. These fluxes are corroborated by observations of a source of SRP and TDP in the longitudinal transect data during the winter and spring. The consequences of sulfate reduction for P cycling and fluxes, as indicated by peak S^{-2} concentrations in the Central Basin ranging from 7,000 to 51,000 µM. is important. As sulfate is reduced, Fe(II) is converted to iron-sulfides (Roden and Edmonds 1997). Because iron-sulfides cannot bind SRP, SRP adsorbed to Fe(II) are released, producing high porewater concentrations and net effluxes to surface waters.

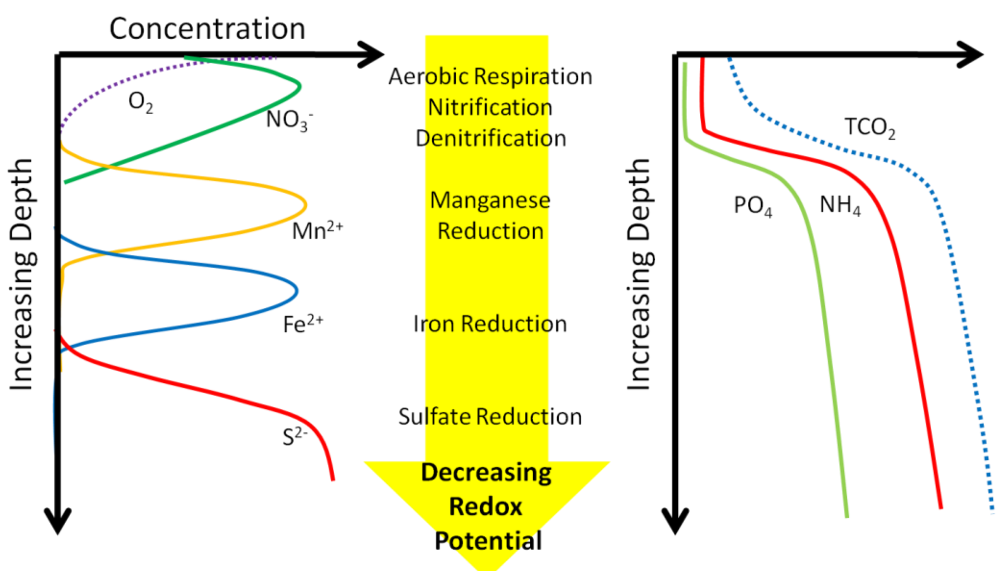


Figure 3.11. Sediment porewater profiles reflect redox status of the sediment.

4 Buena Vista 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 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 chapter 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.

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.

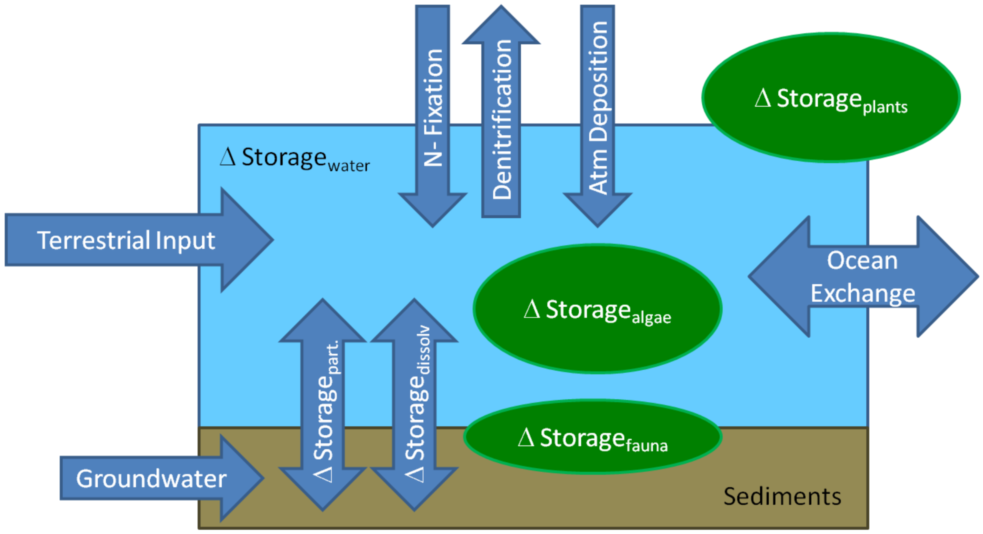


Figure 4.1. Conceptual model for development of budget estimates.

For the purposes of this exercise, the East and Central Basins are treated as separate systems in which flow from the East Basin passes in a unidirectional fashion to the Central Basin. Therefore, it was assumed that no water was lost or gained within the East Basin and that flow into the East Basin, as estimated from the ME station was equal to flow out. Wet and dry weather runoff into the East Basin was estimated from wet and dry weather runoff monitoring conducted by MACTEC, Inc. *(2009)*. Nutrient loads into the Central Basin were therefore calculated from the mean concentrations of Transect Station 4 during dry weather multiplied by dry weather flows at the ME station. No estimates were available for wet weather flows to the Central Basin.

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 Bernadino 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 phosphorus; 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 subtidal habitat in each of East and Central Basins (Table 4.2). For atmospheric deposition, rates were applied across the total of both open water and emergent marsh. For the purposes of estimating benthic flux, it was assumed that nutrient exchange with the emergent marsh habitat was negligible, so that the total area of subtidal habitat was multiplied by the benthic flux rate to yield the net yield over the entire basin. Likewise, estimates of primary producers that are expressed on an areal basis (MPB and macroalgae) were multiplied by the total area of subtidal habitat. *Ruppia* was limited to deep areas, which represent approximately 10% of the Central Basin. Therefore, primary producers found in the shallow areas (*Chara* sp. and *Rhizoclonium*) were allotted 90% of the available habitat, while *Ruppia* biomass was allotted 10%. Table 4.3 presents the literature and assumptions were used to convert primary producer biomass to N and P.

Table 4.2. Distribution of open water, aquatic bed and emergent marsh habitat by basin in Buena Vista Lagoon. Areas are given in square meters.

Basin	Open Water	Emergent Marsh	Total
East	160,358	186,135	346,493
Central	281,721	157,249	438,970

Table 4.3. 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

4.3.1 Summary of Findings

Preliminary N and P budgets for the East and Central Basins have the following findings:

- These preliminary nutrient budgets for Buena Vista Lagoon illustrate that terrestrial loads dominate nutrient cycling in the East Basin, while aquatic primary productivity and internal recycling of N and P have a more important role than terrestrial runoff in the Central Basin.

- The two basins have a vast difference in the amount of carbon and nutrients stored as aquatic primary producer communities in these two basins: in the East Basin, the APP community is dominated by phytoplankton, while in the Central Basin the community is dominated by macroalgae and to a lesser extent, SAV. As a result, the Central Basin supports a much larger biomass annually of primary producers and is much more prone to problems with DO.

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

- Buena Vista Lagoon is currently in a restoration planning phase. Restoration options should include consideration of improving water quality by increase flushing and circulation within the two basins by, at minimum removing emergent marsh, and if possible, increasing circulation by restoring tidal exchange to this estuary. Connections between the basins should be enlarged in order to increase the flushing of the Central Basin. Dredging of fine-grained sediments in the Central Basin and replacement with coarse grained substrates should be considered in order to reduce the benthic sources of nutrients that are driving low DO and excessive plant overgrowth.

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

4.3.2 East Basin Nitrogen and Phosphorus Budgets

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, exceeded dry weather runoff in magnitude (20,431kg versus 12,983 kg respectively, Table 4.4). Winter and spring dry weather runoff (Nov-Apr) represents 44% of the total annual export and 88% of the total dry weather runoff. Terrestrial runoff during summer and fall were low, but not negligible (1616 kg TN).

With respect to relative sources, terrestrial TN and TP input overwhelmed all other sources[1] to the East Basin throughout the year. Direct atmospheric deposition and benthic N fixation were negligible sources of N and P. Terrestrial runoff represented >95% of total TN and TP sources to surface waters (Tables 4.4 and 4.6). Benthic flux of NO_3 acted as a sink for N during the winter, spring, and summer (total of -4,823 kg over 9 months), but then became a minor source of NH_4during the summer and fall, representing 4% of TN sources during that period. Independent estimates of denitrification would account for 265 kg N over 6 months, an order of magnitude less than predicted by rates of benthic flux. Benthic flux represented a sink for SRP during dry weather year round (total of 265 kg SRP annually), while it was a sink for TDP during the winter and a source throughout the rest of the index periods (Table 4.6).

Budgets residuals indicate the quantity of N and P not accounted for in the budget. For N, the N residuals were small during all four index periods, representing 2 to 10% of the TN inputs into the system. While the magnitudes of these inputs are small relative to the wet season, there appear to be additional sinks for N that are unaccounted for. To understand these sinks, it is important to account for the fate of the individual N species (NH_4, NO_2+NO_3, DON, particulate N). For example, benthic flux during the first sampling period resulted in sink of 1806 kg NO_3 (Table 4.5), while TN represented a sink of 991 kg. The net N residual for this time period was 80 kg (Table 4.4). Accounting for the small NH_4efflux (29 kg), this would imply that the East Basin became a source of 776 kg of DON or particulate N. Transect data, which showed a substantial loss of 90 µM NO_2+NO_3 and production of DON across the east basin, corroborate this finding. Calculation of net NO_3 budget for East Basin reveal that 1806 kg of the total 4690 kg watershed NO_3 was lost to benthic influx of NO_3, yielding 2784 kg (Table 4.9). Independent calculation of NO_3 loads into the Central Basin for that quarter, based on NO_3 concentrations from transect data, yield 2337 kg. Thus an additional -547 kg of NO_3 are being lost. There are several unaccounted for sinks for NO_3, including denitrification (Seitzinger 1988) and emergent marsh uptake and storage as biomass (Knight and Kadlec 1996). To balance the budget, relative to the net residual of

[1] The net exchange of groundwater is unknown.

80 kg (Table 4.4), this implies a net source of total of 1,467 kg of DON + particulate N produced by the East Basin, of which benthic flux of DON accounts for 786 kg. Thus, an additional 630 kg of DON + particulate N are being produced by by the basin, but not accounted for. This pattern of unaccounted sink of NO_3 and source of DON was found in all sampling periods. The emergent marsh in the East Basin, dominated by *Scirpus* sp. and *Typha* sp., is expanding and known to have a high standing biomass (~24 kg m^{-2}) that uptakes N, then senesece seasonally. Thus the role of the emergent marsh is a sink for NO_3 and a source of DON is key to the budget for this basin (Kadlec and Knight 1996).

Table 4.4. Comparison of estimated nitrogen source, loss and change in storage terms in the East Basin of Buena Vista Lagoon during wet and dry weather periods (kg N). 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						
Terrestrial runoff	20,431	4,976	6,394	625	992	33,417
N - Fixation	--	86	24	22	20	152
Atmos. Deposition	52	22	22	22	22	142
Sum Source Terms	20,483	5,085	6,440	669	1,034	33,711
Change in Storage						
Benthic N Flux	N/A	-991	-2008	70	-561	-3490
1^0 Producer N	N/A	0	1	-1	0	0
Losses						
Outflow to Central Basin	N/A	4014	3786	687	439	8926
Residual (Sum of sources, losses, and change in storage)	N/A	80	646	52	34	812

Table 4.5. Comparison of loads from watershed versus benthic nutrient flux in the East Basin of Buena Vista Lagoon(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	Benth ic Flux	Water-shed	Benthic Flux
TN	**20,431**	**4,976**	--	6,394		625		992		33,417	--
TDN	**17,430**		-991	6,649	-2,008		70		-561		-3,490
NH_4	**1,695**	**84**	29	0	126	0	86	23	38	6,534	278
NO_3	**14,356**	**4,690**	-1,806	4,733	-2,793	402	-224	0	0	24,180	-4,823
TP	**3,405**	**183**	--	508	--	21	--	50	--	4,168	--
TDP	**2,077**		-43		-196		1		108		-130
SRP	**1,943**	**183**	-149	126	-67	26	-27	31	-23	2,309	-265

With respect to phosphorus, residuals were highest during the winter and fall index periods (47 and 98% of TP inputs), intermediate in the spring and fall (0.4 to 17% of TP inputs). As was the case with N, further examination of the fate of SRP versus TP can help shed light on these residuals. For example, during the first quarter, the watershed provided 183 kg TP, 100% of which was reported as SRP. Benthic flux of SRP provided a sink of 149 kg SRP, yielding a net of 34 kg of SRP. Independent calculation of SRP loads into Central Basin for that quarter, based on SRP concentrations from Site 5 of the transect data, yield 35 kg SRP and 53 kg TP. Benthic flux of TDP (-43 kg), relative to -149 kg flux of SRP, would yield a net benthic flux of + 106 kg dissolved organic P (DOP). Thus, while the budget nearly balances with respect to SRP, there is an additional sink of -87 kg DOP that is not accounted for.

Considerable uncertainty with these budgets exists with respect to the assumption that groundwater is negligible, the effects of the emergent marsh, as well as extrapolation of benthic flux, terrestrial loads from instantaneous measurements during selected days during the index period. Detailed accounting of the ultimate fate of TN and TP and the predominant forms of these nutrients is best done through a dynamic Lagoon water quality model.

Table 4.6. Comparison of estimated phosphorus source and loss terms in the Lagoon during dry weather periods (kg P) in the East Basin of Buena Vista Lagoon. Positive "source" terms indicates source to the Lagoon. 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 and outflow to the Central Basin.

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	3,405	183	508	21	50	4168
Atmos. Deposition	2.60	1.95	1.95	1.95	1.95	10.4
Sum Source Terms	3,408	185	509	23	52	4178
Change in Storage						
Benthic N Flux	--	-42.7	-195.9	0.9	107.5	-130
1^0 Producer P	--	0.0	0.1	-0.1	0.0	0.0
Losses						
Outflow to Central Basin	--	53	222	24	20	319
Residual	--	89	91	0	140	482

4.3.3 Central Basin Nitrogen and Phosphorus Budgets

With respect to relative sources, terrestrial TN input (e.g. via the East Basin) represented 75 - 87% of total sources[2] to the Central Basin surface waters during the winter and spring. Loss of primary producer community biomass represented the remainder of the N sources to Central Basin surface waters. However, during the summer and fall, it became a minor source relative to benthic flux, which represented approximately 75% of TN sources to surface waters during this period (Table 4.7).

Benthic flux acted as a sink for NO_3 during the winter and spring (total of -1984 kg over 6 months), but then became a major source of NH_4 during the summer and fall, representing 75% of TN sources during that period (+3,488 kg ammonium).

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, the Central Basin experiences large NO_3 fluxes into the sediment (-1,573 kg NO_3 over 6 months). During the Nov-Jan index period, NH_4fluxes during these time periods are either negligible or there was net uptake of ammonium. During the 6-month summer and fall index period, high ammonium fluxes out of the sediment were observed (3,495 kg TN) and NO_3 fluxes into the sediments negligble. 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 and SAV blooms, benthic flux of $NH_4$is the dominant source of N to surface waters, provided 92 - 100% of N required to support SAV and macroalgal biomass during the summer and fall. Macroalgae in particular are 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).

[2] The net exchange of groundwater is unknown.

Table 4.7. Comparison of estimated nitrogen source, loss and change in storage terms in the Central Basin of Buena Vista Lagoon during wet and dry weather periods (kg N). 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		4,014	3,786	687	439	8,926
N - Fixation	--	2	0	1	0	4
Atmos. Deposition	--	29	29	29	29	114
Sum Source Terms	--	4,045	3,815	717	468	9,044
Change in Storage Terms						
Benthic N Flux	--	-816	-1,168	2,344	1,558	1,919
1^0 Producer N	--	-589	-1,043	2,583	1,119	2,070
Losses						
Outflow to West Basin	--	3,324	2,541	339	695	6,900
Residual	--	493	1,149	139	211	1,992

Terrestrial input of TP (via the East Basin) was a minor source of phosphorus to the Central Basin, representing a range from a high of 22% of TP sources in the spring to a low of %5 of TP sources in the summer index periods. Benthic flux represented a sink for TP during the winter (-65 kg TP), but was thereafter a source, comprising from 10% in the spring to >95% in the summer and fall index periods (Table 4.8). Benthic flux comprised >99% of SRP sources to surface waters year round. Direct atmospheric deposition was a negligible source of P.

The P budget shows that during peak periods of macroalgal blooms, benthic flux of SRP provides 60 - 100% of the P required to grow the abundance of macroalgae observed. 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 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).

Budget residuals were somewhat larger for the Central Basin then the East Basin (5 - 23% of TN sources and 6 - 97% of TP sources to surface waters). As with the East Basin, there appears to be several unaccounted sources or sinks of N and P. Additionally, measurement of benthic fluxes were much more complicated in this system, and thus there is a wider margin of error anticipated with these budget numbers.

Table 4.8. Comparison of estimated phosphorus sources, loss and change in storage terms in the Central Basin of Buena Vista Lagoon during wet and dry weather periods (kg P). 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 Terms						
Terrestrial runoff	--	53	222	24	20	319
Atmos. Deposition	--	2	2	2	2	10
Sum Source Terms	--	55	225	27	22	329
Change in Storage						
Benthic N Flux		-65	101	455	320	810
1^0 Producer P	--	-261	-462	449	500	226
Loss Terms						
Outflow to West Basin	--	322	115	3	10	450
Residual	--	-71	672	29	-168	914

Table 4.9. Comparison of loads from watershed versus benthic nutrient flux in the Central Basin of Buena Vista Lagoon(kg).

Term	Index Period 1		Index Period 2		Index Period 3		Index Period 4		Annual (Dry)	
	Water-shed	Benthic Flux	Water-shed	Benthic Flux	Water-shed	Benthic Flux	Water-shed	Benthic Flux	Water-shed	Benthic Flux
TN	**4,014**	**--**	3,786		687		439		8,926	--
TDN		-816		-1168		2344		1558		1,919
NH_4	**59**	19	76	-674	12	1717	7	1771	153	2,833
NO_3	**2,337**	-1501	35	-72	4	-103	0	0	2,376	-1,676
TP	**53**	--	222	--	24	--	20	--	319	--
TDP		-65		101	0	455		320		810
SRP	**35**	324	12	186	2	519	2	299	51	1,328

Observations of mass balance made here should be regarded as preliminary. Current estimates of terrestrial loads account only for loads from Buena Vista Creek any nonpoint sources of N and P delivered to Buena Vista Lagoon via storm drains that are not included in this budget. We acknowledge the difficulty in trying to produce whole estuary N budget based on two sites. Estuary-wide nutrient mass balances will be much better refined with a dynamic simulation model that can account better account for variability in wet and dry weather hydrology and other factors controlling the transport and fate of nutrients in the Lagoon.

4.3.2.1 Management Options to Reduce Eutrophication in the Lagoon

These preliminary nutrient budgets for Buena Vista Lagoon illustrate that terrestrial loads dominate nutrient cycling in the East Basin, while aquatic primary productivity and internal recycling of N and P have a more important role than terrestrial runoff in the Central Basin. As a result, the sediment bulk characteristics and net seasonal deposition rates indicate that the East Basin is erosional and that the Central Basin is net depositional and has accumulated a large amount of organic matter in its sediments.

These factors cause a vast difference in the dominant aquatic primary producer communities in these two basins: in the East Basin, the APP community is dominated by phytoplankton, while in the Central Basin the community is dominated by macroalgae and to a lesser extent, SAV. As a result, the Central Basin supports a much larger biomass of primary producers annually and is much more prone to problems with DO. The Lagoon has accumulated a large amount of organic matter in the sediments. Because benthic flux is the major source of N to the Central Basin, 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 in selection of the final alternative:

- Buena Vista Lagoon is currently in a restoration planning phase. Restoration options should include consideration of improving water quality by increase flushing and circulation within the two basins by, at minimum removing emergent marsh, and if possible, increasing circulation by restoring tidal exchange to this estuary. Connections between the basins should be enlarged in order to increase the flushing of the Central Basin. Dredging of fine-grained sediments in the Central Basin and replacement with coarse grained substrates should be considered in order to reduce the benthic sources of nutrients that are driving low DO and excessive plant overgrowth.

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

Storm	Date	TSS (mg/L)	TN (mg/L)	TDN (mg/L)	NH_4 (mg/L)	NO_3 + NO_2 (mg/L)	TP (mg/L)	TDP (mg/L)	SRP (mg/L)	$CBOD_5$ (mg/L)
1	1/7/2008	141	2.02	1.59	0.13	1.33	0.32	0.21	0.22	4.15
2	1/24/2008	300	1.64	1.53	0.21	1.53	0.16	0.14	0.14	3.89
3	2/3/2008	290	--	--	0.13	1.09	0.43	0.18	--	5.3
Average		244	1.22	1.56	0.16	1.32	0.30	0.18	0.18	4.45

AMBIENT NUTRIENT CONCENTRATIONS

Table A2.2. Summary of ambient nutrient concentrations during dry weather.

Station Name	Constituent	Index 1		Index 2		Index 3		Index 4	
		Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
Mass Emission site, Buena Vista Creek	TN	136.0	64.2	180.5	36.5	64.4	15.5	106.5	15.6
	NH4	2.3	0.5	2.2	0.4	2.6	1.9	2.5	0.6
	NO3 + NO2	128.7	85.8	133.6	23.6	41.4	30.4	44.7	15.0
	TP	2.7	1.1	6.5	8.0	1.2	0.3	2.4	0.6
	SRP	2.3	1.3	1.6	0.2	1.2	0.3	1.5	0.1
Lagoon, East Basin	TSS	75.1	108.1	46.2	2.4	12.6	9.6	20.3	9.1
	TN	172.8	78.6	173.2	46.8	63.4	13.1	58.2	16.8
	NH4	3.6	3.1	1.4	0.3	6.7	9.2	1.8	0.9
	NO3 + NO2	113.5	39.6	14.2	12.1	2.1	1.7	2.0	2.0
	TP	6.3	3.8	8.2	1.9	3.3	2.8	2.1	0.9
	SRP	2.9	1.7	0.5	0.7	2.4	2.4	0.2	
Lagoon, Central Basin	TSS	10.2	5.3	27.4	5.1	7.1	2.2	8.1	9.0
	TN	98.9	29.0	114.2	26.8	62.4	19.9	68.4	17.7
	NH4	3.3	4.6	1.7	0.2	3.5	6.0	1.3	0.5

	NO3 + NO2	28.2	17.5	1.2	1.1	1.8	2.3	0.5	0.3
	TP	9.4	4.1	7.5	1.8	2.1	2.8	1.2	0.5
	SRP	5.4	2.6	1.5	0.7	1.3	2.1	0.1	0.1

SEDIMENT DEPOSITION

Table A2.3. Inventory (I) and mass flux (ψ) calculation data.

Date	Depth in Core (z, cmbsf)	Core section Thickness (h, cm)	Wet Bulk Density (r, g/cm3)	Be-7 Activity (A, dpm/g)	Be-7 Inventory (I, dpm/cm2)	Total Inventory (I_T, dpm/cm2)	Time Elapsed (days)	Residual Inventory (I_R, dpm/cm2)	New Inventory (I_R, dpm/cm2)	Mean Activity (I_N, dpm/cm2)	Mass Flux (g/cm2)	Mass Flux (g/cm2/day)
Buena Vista Segment Site 1												
15-Nov-07	0-1	1	0.982	-0.301	0	0	initial					
	1-2	1	1.194	-0.895	0							
	2-3	1	1.14	-1.505	0							
	3-4	1	1.16	-0.126	0							
	4-6	2	1.16	-0.647	0							
	6-8	2	1.16	-0.177	0							
21-Jan-08	0-1	1	0.982	5.218	5.12	19.72	67	0	19.723	3.547	5.561	0.083
	1-2	1	1.194	5.863	7							
	2-3	1	1.14	5.814	6.63							
	3-4	1	1.16	-0.482	0							
	4-5	1	1.16	0.84	0.97							
3-Apr-08	0-1	1	0.982	3.341	3.28	12.51	72	7.733	4.776	1.562	3.058	0.042
	1-2	1	1.194	3.63	4.33							
	2-3	1	1.14	1.091	1.24							
	3-4	1	1.16	1.723	2							
	4-5	1	1.16	-0.071	0							
	5-6	1	1.16	0.87	1.01							
	6-8	2	1.16	0.277	0.64							
14-May-08	0-1	1	0.982	0.238	0.23	1.11	41	7.339	-6.232	0.243	-25.636	-0.625
	1-2	1	1.194	0.625	0.75							
	2-3	1	1.14	0.005	0.01							
	3-4	1	1.16	0.104	0.12							
	4-5	1	1.142	-0.174	0							
24-Jul-08	0-1	1	0.982	0.096	0.09	0.24	71	0.44	-0.202	0.074	-2.72	-0.038
	1-2	1	1.194	-0.021	0							
	2-3	1	1.14	0.126	0.14							
	3-4	1	1.16	-0.388	0							

20-Aug-08	0-1	1	0.982	0.047	0.05	1.01	27	0.168	0.838	0.425	1.971	0.073
	1-2	1	1.194	0.803	0.96							
	2-3	1	1.14	-0.526	0							
	3-4	1	1.16	-4.916	0							
30-Sep-08	0-1	1	0.982	-0.196	0	0.86	41	0.59	0.274	0.189	1.451	0.035
	1-2	1	1.194	-0.026	0							
	2-3	1	1.14	0.63	0.72							
	3-4	1	1.16	0.127	0.15							
	4-5	1	1.142	-1.483	0							
Buena Vista Segment Site 2												
15-Nov-07	0-1	1	1.208	1.306	1.58	1.58	initial					
21-Jan-08	0-1	1	1.208	-0.386	0	0	67	0.66	-0.66	0		
	1-2	1	1.001	-1.42	0							
	2-3	1	1.023	-1.174	0							
3-Apr-08	0-1	1	1.001	-0.041	0	0	72	0	0	0		
14-May-08	0-1	1	1.208	1.013	1.22	14.52	41	0	14.517	2.811	5.164	0.1259
	1-2	1	1.001	2.068	2.07							
	2-3	1	1.023	7.821	8							
	3-4	1	1.023	1.784	1.82							
	4-5	1	1.023	1.369	1.4							
	5-6	1	1.023	-1.667	0							
24-Jul-08	0-1	1	1.208	-0.289	0	1.56	71	5.766	-4.21	0.777	-5.417	-0.0763
	1-2	1	1.001	1.554	1.56							
	2-3	1	1.023	-0.532	0							
	3-4	1	1.146	-0.083	0							
	4-5	1	1.051	-0.311	0							
20-Aug-08	0-1	1	1.208	0.144	0.17	0.17	27	1.095	-0.922	0.144	-6.406	-0.2372
	1-2	1	1.001	-1.16	0							
30-Sep-08	0-1	1	1.208	-0.666	0	4.63	41	0.102	4.523	0.887	-5.099	-0.1243
	1-2	1	1.001	-1.275	0							
	2-3	1	1.023	2.411	2.47							
	3-4	1	1.146	0.346	0.4							
	4-5	1	1.051	1.678	1.76							
	4-5	1	1.051	-0.533	0							

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

Table A2.4. 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	0.78	0.10	0.0181	9.1	111.3	12.2	48.9
		1 – 2 cm	0.67	0.06	0.0153	13.0	113.1	8.7	51.5
		2 – 3 cm	0.69	0.06	0.0137	13.4	130.1	9.7	48.7
		3 – 4 cm	0.75	0.06	0.0154	14.6	125.8	8.6	49.5
		4 – 6 cm	0.73	0.09	0.0162	9.5	116.4	12.3	67.0
		6 – 8 cm	1.6	0.15	0.0299	12.4	138.2	11.1	75.1
Index Period 1 - Winter		0 – 1 cm	2.5	0.18	0.0146	16.2	442.4	27.3	34.3
		1 – 2 cm	2.2	0.15	0.0626	17.1	90.8	5.3	32.2
		2 – 3 cm	1.7	0.12	0.0546	16.5	80.4	4.9	19.2
		3 – 4 cm	0.90	0.06	0.0441	17.5	52.7	3.0	13.1
		4 – 5 cm	0.70	0.06	0.013	13.6	139.1	10.2	6.3
		5 – 6 cm	0.65	0.06	0.055	12.6	30.5	2.4	4.8
		6 – 8 cm	0.81	0.06	0.049	15.8	42.7	2.7	12.3
		8 – 10 cm	1.3	0.11	0.094	13.8	35.7	2.6	26.1
		10 – 12 cm	1.3	0.10	0.0078	15.2	430.6	28.4	24.8
Index Period 2 - Spring		0 – 1 cm	2.6	0.20	0.0506	15.2	132.8	8.8	33.3
		1 – 2 cm	2.5	0.18	0.0413	16.2	156.5	9.7	39.0
		2 – 3 cm	2.3	0.16	0.0723	16.8	82.2	4.9	31.4
		3 – 4 cm	3.0	0.22	0.0467	15.9	166.1	10.4	34.7
		4 – 5 cm	2.1	0.18	0.0428	13.6	126.7	9.3	25.1
		5 – 6 cm	1.6	0.10	0.0279	18.7	148.1	7.9	14.0
		6 – 8 cm	1.2	0.06	0.0299	23.3	103.8	4.5	12.9
		8 – 10 cm	1.2	0.08	0.0194	17.5	159.9	9.1	14.3
		10 – 12 cm	0.86	0.09	0.0292	11.1	76.2	6.8	29.1
Index Period 3 - Summer		0 – 1 cm	0.47	0.07	0.0217	7.8	55.9	7.1	3.6
		1 – 2 cm	0.47	0.07	0.0115	7.8	105.4	13.5	4.3
		2 – 3 cm	0.28	0.06	0.0108	5.4	66.8	12.3	5.9
		3 – 4 cm	0.28	0.06	0.0138	5.4	52.3	9.6	4.8
		4 – 5 cm	0.26	0.06	0.0052	5.1	129.2	25.6	5.3
		5 – 6 cm	0.34	0.06	0.0127	6.6	69.0	10.4	6.0
		6 – 8 cm	0.67	0.06	0.0115	13.0	151.1	11.6	12.5
		8 – 10 cm	0.37	0.06	0.0206	7.2	46.5	6.5	19.4
		10 – 12 cm	0.66	0.06	0.0294	12.8	58.0	4.5	33.8
Index Period 4 - Fall		0 – 1 cm	1.0	0.09	0.0138	13.0	187.5	14.5	7.5
		1 – 2 cm	0.8	0.09	0.0136	10.4	151.6	14.6	2.8
		2 – 3 cm	0.48	0.06	0.0162	9.3	76.4	8.2	4.9
		3 – 4 cm	1.2	0.09	0.0146	14.9	203.5	13.7	13.3
		4 – 5 cm	1.5	0.14	0.0248	12.5	156.5	12.5	19.5
		5 – 6 cm	1.4	0.12	0.0274	13.8	133.7	9.7	28.4
		6 – 8 cm	1.2	0.11	0.0240	12.3	125.0	10.2	28.6
		8 – 10 cm	0.67	0.06	0.0263	13.0	65.7	5.0	18.8
		10 – 12 cm	0.72	0.06	0.0250	14.0	74.4	5.3	14.9

Pre-liminary Sampling	Segment Site 2	0 – 1 cm	8.7	0.90	0.1015	11.3	221.4	19.6	95.1
Index Period 1 - Winter		0 – 1 cm	4.5	0.47	0.0359	11.2	323.8	29.0	NR
		1 – 2 cm	3.3	0.38	0.0242	10.1	352.3	34.8	NR
		2 – 3 cm	3.2	0.39	0.0756	9.6	109.3	11.4	NR
		3 – 4 cm	3.3	0.39	0.0499	9.9	170.8	17.3	NR
		4 – 5 cm	3.0	0.34	0.0352	10.3	220.2	21.4	61.3
		5 – 6 cm	2.7	0.31	0.036	10.2	193.8	19.1	22.8
		6 – 8 cm	2.6	0.30	0.052	10.1	129.2	12.8	68.8
		8 – 10 cm	2.5	0.27	0.056	10.8	115.3	10.7	60.0
		10 – 12 cm	2.4	0.25	0.093	11.2	66.7	6.0	62.4
Index Period 2 - Spring		0 – 1 cm	NR	NR	NR	NR	NR	NR	76.8
		1 – 2 cm	3.0	0.38	0.0835	9.2	92.8	10.1	50.0
		2 – 3 cm	3.0	0.36	0.0887	9.6	86.5	9.0	69.5
		3 – 4 cm	2.8	0.32	0.0877	10.2	82.5	8.1	80.5
		4 – 5 cm	2.7	0.30	0.0871	10.5	80.1	7.6	52.9
		5 – 6 cm	2.5	0.23	0.0838	12.7	77.1	6.1	71.3
		6 – 8 cm	2.4	0.27	0.0818	10.4	75.8	7.3	67.4
		8 – 10 cm	2.9	0.33	0.0837	10.3	89.6	8.7	61.7
		10 – 12 cm	3.1	0.33	0.0861	11.0	93.0	8.5	75.4
Index Period 3 - Summer		0 – 1 cm	NR	NR	NR	NR	NR	NR	NR
		1 – 2 cm	3.1	0.39	0.0894	9.3	89.6	9.7	68.0
		2 – 3 cm	3.0	0.34	0.0838	10.2	91.2	9.0	94.4
		3 – 4 cm	2.6	0.32	0.0811	9.6	83.4	8.7	95.0
		4 – 5 cm	2.2	0.25	0.0801	10.1	70.0	6.9	99.0
		5 – 6 cm	2.2	0.27	0.0783	9.4	71.6	7.6	98.3
		6 – 8 cm	2.3	0.28	0.0868	9.6	68.7	7.1	96.1
		8 – 10 cm	2.3	0.25	0.0789	10.6	74.7	7.0	96.2
		10 – 12 cm	2.1	0.24	0.0794	10.2	68.0	6.7	89.3
Index Period 4 - Fall		0 – 1 cm	NR	NR	0.0689	NR	NR	0.0	42.0
		1 – 2 cm	2.3	0.28	0.0768	9.6	77.3	8.1	75.0
		2 – 3 cm	2.3	0.30	0.0738	8.8	78.7	9.0	47.6
		3 – 4 cm	2.3	0.30	0.0724	8.9	81.7	9.2	68.8
		4 – 5 cm	4.9	0.25	0.0701	22.8	179.8	7.9	60.7
		5 – 6 cm	1.5	0.20	0.0564	8.9	69.6	7.9	56.9
		6 – 8 cm	1.8	0.25	0.0548	8.4	84.8	10.1	23.1
		8 – 10 cm	0.94	0.13	0.0581	8.4	41.8	5.0	25.0
		10 – 12 cm	0.85	0.13	0.0555	7.6	39.6	5.2	45.6

SEDIMENT POREWATER CONCENTRATIONS

Table A2.5. 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 1/21/08	Segment Site 1	Bottom water	1430	1880	0.00	7.80	76.6	41.0	3690	2670	8.43	3.94	14.7
		0–1 cm	1240	1540	4.40	6.00	75.3	47.8	4830	8680	7.26	3.58	20.0
		1–2 cm	845	1022	0.00	3.40	58.9	63.2	3030	1020	6.38	1.75	27.3
		2–3 cm	593	774	2.20	2.40	47.8	62.8	2610	457	5.76	1.97	29.1
		3–4 cm	266	318	4.00	0.00	18.4	18.4	2570	0.34	6.03	8.06	29.1
		4–5 cm	288	191	161	56.40	10.6	7.2	2580	1.08	6.72	5.19	14.7
		5–6 cm	293	328	4.20	0.00	32.9	35.0	2560	4.12	8.82	15.3	29.1
		7–8 cm	261	280	0.00	0.00	26.1	19.6	2350	3.58	10.7	15.4	60.8
		10–11 cm	189	122	24.2	13.2	12.2	7.20	2270	3.58	10.5	23.3	3.46
		14–15 cm	151	2.25	131	1.30	2.77	1.60	4200	0.51	0.00	0.25	2.28
Index Period 2 – Spring 4/3/08		Bottom water	1790	1680	1.00	0.00	111	25.0	5280	986	10.2	48.4	15.7
		0–1 cm	1680	1640	1.00	0.20	131	35.2	5380	968	10.7	37.6	20.0
		1–2 cm	1480	1490	2.40	0.00	125	59.8	5040	869	12.9	30.4	38.2
		2–3 cm	1260	1310	2.80	0.00	135	66.8	4810	639	14.2	39.4	54.6
		3–4 cm	958	798	3.60	0.60	102	43.8	3460	592	10.8	59.1	52.8
		4–5 cm	500	422	8.00	0.60	66.6	50.4	2460	476	8.94	57.3	41.9
		5–6 cm	360	270	3.60	0.20	58.5	35.0	2170	293	10.1	28.7	41.9
		7–8 cm	218	136	4.40	0.00	29.1	21.2	1880	29.0	8.71	44.8	25.5
		10–11 cm	199	121	4.20	0.60	24.3	16.2	1930	0.00	7.95	50.1	49.2
		13–14 cm	74.2	2.77	15.5	1.30	0.47	0.30	1900	0.66	0.00	0.60	1.28
Index Period 3 – Summer 7/22/08		Bottom water	1410	1286	25.0	0.00	59.5	55.8	3940	548	7.50	6.45	15.7
		0–1 cm	1590	1404	30.4	0.00	69.5	62.4	3930	477	6.42	10.6	21.8
		1–2 cm	1520	1244	17.6	0.00	72.6	68.6	3030	1400	9.18	7.88	18.2
		2–3 cm	1260	1060	21.0	0.00	62.7	59.2	3880	1564	8.85	6.63	16.9
		3–4 cm	933	778	24.2	0.00	46.5	40.2	2830	1100	7.95	5.19	13.1
		4–5 cm	363	360	18.7	0.00	12.7	11.3	1730	652	7.98	10.4	12.2
		5–6 cm	97.8	73.8	20.8	0.00	8.00	6.00	1290	87.2	10.4	8.59	12.9
		7–8 cm	81.6	79.6	18.2	0.00	8.80	7.00	1330	87.8	8.88	6.98	10.8
		10–11 cm	61.9	32.8	21.0	0.00	7.35	5.60	1090	21.6	8.22	7.70	12.9
		13–14 cm	27.5	2.2	3.95	0.00	0.68	0.60	1280	0.00	0.00	0.48	3.00
Index Period 4 – Fall 9/29/08		Bottom water	1670	2390	0.00	0.00	38.6	49.4	3940	6800	5.61	12.4	18.2
		0–1 cm	1990	1980	0.00	0.00	92.8	64.6	3930	6920	5.79	7.16	21.8
		1–2 cm	1300	2360	3.40	1.40	43.6	74.4	3030	6460	5.55	5.19	20.0
		2–3 cm	1550	2280	2.20	0.00	48.9	71.0	3880	6100	6.36	9.31	25.5
		3–4 cm	1640	2140	3.40	1.20	77.9	83.6	2830	5090	6.57	8.24	25.5
		4–5 cm	856	1140	2.60	1.00	54.6	48.0	1730	1870	5.07	4.48	25.5
		5–6 cm	555	716	3.60	1.20	55.3	48.2	1290	770	4.83	11.1	21.8
		7–8 cm	93.2	82.8	4.20	1.20	7.89	8.00	1320	50.6	3.84	13.1	17.7
		10–11 cm	57.8	49.2	4.00	1.20	2.17	2.40	1090	0.00	3.81	21.5	20.0
		13–14 cm	21.5	6.13	8.07	0.77	0.00	0.00	1280	0.00	0.00	1.02	2.00
Index Period 1 – Winter 1/21/08	Segment Site 2	Bottom water	47.0	3.50	3.70	1.30	4.93	3.40	2250	0.24	896	1.31	1.35
		0–1 cm	1300	184	0.00	2.60	249	177	6000	4020	11,900	2.15	200
		1–2 cm	1710	2200	0.00	3.80	280	229	4080	4850	12,800	2.69	182
		2–3 cm	1830	2400	0.00	2.20	127	197	4010	6550	14,000	55.9	54.9
		3–4 cm	1790	2400	0.00	3.40	278	267	4280	4720	13,600	55.9	54.9
		4–5 cm	1960	2480	3.80	4.40	297	252	4150	5700	13,400	3.58	164

		5–6 cm	1120	2620	7.20	3.60	178	290	4250	4130	13,900	3.22	158
		7–8 cm	1760	2440	7.80	5.20	293	282	4530	10,800	13,500	9.13	673
		10–11 cm	2030	2640	3.80	5.00	282	286	4720	6130	13,300	2.86	120
		13–14 cm	13,400	6.00	3.40		2.21	4.20	4260	40.5	230	0.36	
Index Period 2 – Spring 4/3/08		Bottom water	50.6	0.60	0.60	0.00	0.95	0.50	1620	0.00	990	0.66	0.56
		0–1 cm	1210	1000	7.00	0.40	79.9	65.6	3710	2310	1040	21.5	9.37
		1–2 cm	1350	992	1.40	0.20	86.5	62.0	3710	851	903	44.8	9.47
		2–3 cm	1230	986	1.80	0.00	91.3	55.0	3510	1220	856	43.0	7.10
		3–4 cm	1420	1052	3.60	0.00	96.1	62.4	3370	700	835	60.9	7.10
		4–5 cm	713	583	1.60	0.10	44.7	36.9	3460	273	311	57.3	6.55
		5–6 cm	653	495	1.70	0.20	44.6	28.1	3530	196	306	71.6	6.73
		7–8 cm	607	484	1.90	0.30	41.4	34.1	3670	519	305	64.5	6.37
		11–12 cm	631	503	3.30	0.10	41.9	32.3	3600	109	291	59.1	6.19
		13–14 cm	1170	1050	3.00	0.40	75.0	62.8	3650	752	936	53.7	7.10
Index Period 3 – Summer 7/22/08		Bottom water	50.2	3.10	1.60	0.00	1.18	0.60	246	0.00	1120	0.42	0.25
		0–1 cm	3510	3600	18.6	0.00	394	338	4490	3840	9640	5.64	41.9
		1–2 cm	3530	3800	27.6	0.00	380	354	4530	6530	11,100	8.24	47.3
		2–3 cm	3120	3330	43.8	0.00	302	264	3870	4410	12,600	6.80	43.7
		3–4 cm	3320	3570	38.0	0.00	342	300	4270	4080	12,800	10.2	49.2
		4–5 cm	3050	4190	74.6	0.00	321	328	4170	2980	11,700	15.9	49.2
		5–6 cm	3460	3670	77.0	0.00	327	280	4240	7160	9870	17.7	41.
		6–7 cm	3360	3510	141	0.00	330	288	4280	3390	10,400	10.6	41.9
		9–10 cm	2930	2330	84.6	0.00	204	152	3970	2720	4300	8.24	25.5
		13–14 cm	3250	3300	47.0	0.00	261	294	4750	2070	7140	6.09	38.2
Index Period 4 – Fall 9/29/08		Bottom water	50.1	2.58	1.30	0.00	0.36	0.00	246	0.00	705	0.70	6.73
		0–1 cm	1380	1940	3.40	3.60	81.6	82.2	4490	19,300	5030	12.0	54.6
		1–2 cm	1510	1950	3.40	0.00	98.7	42.2	4530	43,900	6680	3.22	56.4
		2–3 cm	1370	2090	9.00	6.20	75.5	74.6	3870	51,100	5750	3.94	54.6
		3–4 cm	1730	1640	2.00	0.00	93.9	38.2	4270	41,900	3160	2.33	49.2
		5–6 cm	1330	1580	4.60	0.00	59.3	41.6	4240	35,300	4050	3.40	38.2
		6–7 cm	1490	1770	5.80	0.00	71.7	39.2	4170	28,000	3300	8.95	34.6
		7–8 cm	1640	1660	2.20	0.00	65.7	62.2	4280	27,200	2820	4.48	30.9
		10–11 cm	742	1890	2.00	0.00	23.7	46.4	3970	16,000	1040	2.86	15.1
		13–14 cm	1640	2170	2.40	0.00	79.5	77.6	4750	9170	843	15.0	11.3

WATER COLUMN TRANSECT DATA

Table A2.6. Transect data for each index period during ebb tide (constituents are in mmol/L, 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	101.7	166.5	1.30	144.1	1.70	2.59	2.10	1.30	6.3	77.4
	2	164.4	157.2	1.30	64.6	1.40	3.39	3.05	0.70	20.0	97.5
	3	136.9	131.5	1.65	72.9	2.15	2.52	2.54	1.00	44.5	69.6
	4	126.0	77.0	1.20	59.0	2.40	1.89	0.70	0.60	28.3	62.7
	5	106.4	99.8	1.20	65.9	2.10	1.35	1.69	1.20	22.5	61.5
	6	118.3	73.1	2.00	18.8	2.85	9.04	7.75	5.00	11.0	120.2
	7	87.5	73.1	2.30	17.2	2.80	7.71	7.18	4.80	10.5	144.2
	8	101.8	71.4	1.60	22.9	3.30	8.42	7.64	5.60	14.5	113.5
	9	114.4	95.9	1.10	31.1	3.90	9.88	8.97	5.80	10.5	74.1
	10	89.9	61.0	1.50	27.6	3.60	8.64	7.15	6.29	14.0	84.7
Index Period 2 Spring	1	144.5	54.1	1.30	28.5		3.41	0.00	0.30	46.5	499.3
	2	65.9	28.4	1.20	1.40		1.42	0.00	0.20	94.4	364.4
	3	55.2	38.9	1.10	0.60		3.32	0.00	0.20	176.7	342.1
	4	49.2	25.2	1.30	0.60		3.05	0.00	0.10	184.0	227.0
	5	112.5	48.1	1.80	0.70		7.81	1.16	0.50	111.0	281.2
	6	64.4	49.5	1.70	1.00		2.35	0.00	0.70	43.0	195.2
	7	99.7	28.0	1.80	1.00		8.58	1.18	0.90	48.5	141.7
	8	67.7	46.6	1.70	0.70		2.25	0.65	0.70	66.7	136.0
	9	86.5	50.2	1.40	0.90		4.43	0.89	1.00	36.0	166.4
	10	70.9	61.5	1.20	0.60		3.46	1.39	1.70	32.7	87.7
Index Period 3 Summer	1	44.5	28.5	0.80	0.00		1.41	0.34	0.20	14.2	57.2
	2	37.4	35.6	1.45	0.30		0.81	0.54	0.35	34.9	50.4
	3	62.3	35.1	1.00	0.60		2.61	0.30	0.20	87.1	73.2
	4	23.1	59.0	1.10	0.60		0.66	0.63	0.20	90.2	64.8
	5	72.7	53.4	1.80	0.90		2.72	0.43	0.20	73.0	68.4
	6	28.1	69.2	0.80	0.70		0.19	0.50	0.20	2.8	4.9
	7	50.6	73.2	1.20	1.45		0.85	0.41	0.20	31.4	11.6
	8	29.0	64.4	0.80	0.80		0.17	0.37	0.20	2.5	1.3
	9	38.0	59.3	1.00	1.00		0.13	0.33	0.00	10.0	13.8
	10	30.8	52.5	1.20	5.10		0.10	0.27	0.10	9.0	4.5
Index Period 4 Fall	1	80.8	43.4	0.80	0.00		4.31	1.31	0.20	12.7	190.9
	2	89.9	39.1	0.90	0.00		5.01	1.07	0.20	41.0	173.6
	3	65.6	35.7	1.60	0.60		2.89	0.78	0.20	36.7	117.5
	4	84.5	42.8	2.00	0.50		5.09	1.63	0.30	54.2	89.0
	5	111.0	45.5	1.15	0.00		6.27	0.94	0.20	115.2	93.5
	6	94.4	45.9	0.90	0.70		5.08	0.74	0.30	13.0	56.1
	7	49.4	53.6	0.50	1.10		0.42	0.32	0.10	0.50	9.3
	8	52.6	55.9	0.80	0.50		0.82	0.36	0.20	0.80	8.5
	9	94.7	77.3	1.10	0.00		1.31	0.68	0.05	17.2	34.4
	10	82.3	70.5	1.20	0.70		1.34	0.49	0.00	6.3	22.7

Table A2.7. 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	232.2	170.5	1.60	133.1	1.80	6.17	1.28	0.70	16.0	569.6
	2	148.7	126.5	0.90	110.5	2.10	2.68	1.07	1.00	23.7	150.5
	3	81.1	127.9	1.60	84.1	2.70	1.89	0.86	0.60	62.5	96.1
	4	105.2	133.6	2.20	49.7	3.00	1.58	0.00	0.30	40.0	102.8
	5	113.2	127.8	2.00	61.9	2.30	1.55	1.20	0.70	33.2	97.5
	6	115.4	121.1	1.60	14.9	3.40	8.94	6.27	4.30	21.0	214.9
	7	87.6	56.1	1.00	9.65	2.35	6.97	4.75	4.25	11.2	134.7
	8	85.9	57.0	1.20	13.7	3.10	9.07	6.05	5.05	15.0	101.9
	9	112.0	66.0	0.90	10.1	2.40	10.1	4.94	4.70	14.0	188.7
	10	92.0	63.3	0.90	20.8	3.00	8.97	6.94	6.29	12.0	92.1
Index Period 2 Spring	1	157.2	94.9	1.30	51.6		1.57	0.00	0.30	34.0	366.2
	2	147.0	46.1	1.80	4.90		8.28	0.00	0.20	120.0	360.5
	3	133.6	43.6	1.90	0.80		8.60	0.00	0.10	96.0	200.8
	4	72.7	41.0	1.90	0.80		2.61	0.00	0.10	113.3	202.5
	5	101.4	34.6	2.50	1.30		4.74	0.00	0.20	93.2	279.8
	6	72.7	29.4	0.70	0.00		2.01	0.00	0.20	57.4	162.9
	7	47.2	29.8	1.10	0.70		1.82	0.00	0.80	49.3	189.6
	8	114.9	34.8	0.90	1.00		7.51	0.00	0.70	62.0	198.8
	9	90.8	42.6	1.10	1.40		5.83	0.00	0.70	48.0	144.2
	10	72.7	30.4	1.40	2.60		3.04	0.00	1.00	50.0	130.8
Index Period 3 Summer	1	41.6	31.3	0.40	0.00		1.16	0.27	0.20	9.3	35.2
	2	48.3	24.9	1.30	0.50		1.12	0.38	0.20	32.5	26.1
	3	52.3	59.8	5.30	0.00		2.01	1.08	0.30	50.0	51.7
	4	45.2	54.2	1.30	1.30		1.90	0.73	0.20	59.1	53.4
	5	69.1	42.4	0.63	0.00		2.28	0.31	0.23	41.6	40.5
	6	68.6	62.5	6.80	0.70		1.44	0.51	0.30	48.3	7.1
	7	43.3	24.0	1.10	0.80		0.49	0.00	0.20	2.5	0.0
	8	73.5	50.5	0.80	1.10		0.58	0.35	0.20	5.7	0.0
	9	52.1	37.1	0.60	0.95		0.88	0.11	0.05	3.3	3.8
	10	39.2	60.7	1.80	1.90		0.58	0.85	0.30	6.0	8.5
Index Period 4 Fall	1	71.4	46.5	0.50	0.00		3.34	1.36	0.20	23.0	237.6
	2	62.9	37.4	1.10	0.50		2.95	5.22	0.20	78.0	140.2
	3	58.5	50.3	0.90	0.00		2.27	1.06	0.20	35.0	98.8
	4	91.8	56.1	1.90	1.20		5.08	1.26	0.30	190.4	85.4
	5	47.1	45.1	0.70	0.00		2.15	0.87	0.20	47.0	80.1
	6	54.1	44.4	0.70	0.00		1.83	0.35	0.10	9.6	39.5
	7	53.4	104.3	0.50	0.00		0.75	5.45	0.20	1.3	12.0
	8	54.2	41.6	0.90	0.00		0.76	0.12	0.00	2.0	12.1
	9	83.2	64.6	0.75	0.25		1.30	0.33	0.00	16.7	73.5
	10	67.1	62.5	0.60	0.00		0.82	0.27	0.20	3.0	13.4

PRIMARY PRODUCER BIOMASS AND /OR PERCENT COVER

Table A2.8. Means and standard deviations of suspended chlorophyll a and benthic chlorophyll a concentrations during each index period.

Index Period	Site	Mean Suspended Chlorophyll a (mg/m^3)
Index Period 1 Winter	Segment Site 1	4.41 ± 0.71
Index Period 2 Spring		1.06 ± 1.07
Index Period 3 Summer		2.05 ± 0.31
Index Period 4 Fall		6.31 ± 1.05
Index Period 1 Winter	Segment Site 2	10.73 ± 1.24
Index Period 2 Spring		4.65 ± 6.07
Index Period 3 Summer		4.50
Index Period 4 Fall		2.45 ± 0.35

Table A2.9. Macroalgae total percent cover and biomass by species during each index period.

Site	Date	Dry Biomass (g/m2)										Total % Cover	
		U. intestinalis		Chara Sp.		Rhizoclonium		Seagrass		Total Biomass			
		avg	SE	avg	SE	avg	SE	avg	SE	avg	SE	avg	SE
1	1/22/08	0	0	0	0	0	0	0	0	0	0	0	0
	4/11/08	0	0	0	0	0	0	0	0	0	0	0	0
	7/21/08	0	0	0	0	0	0	0	0	0	0	0	0
	9/29/08	0	0	0	0	0	0	0	0	0	0	0	0
2	1/22/08	0	0	0	0	0	0	0	0	0	0	100	0
	4/11/08	0.6	0.3	0	0	0	0	0	0	0.6	0.3	100	0
	7/21/08	218.8	36.9	0	0	0	0	0	0	218.8	36.9	100	0
2 (ankle deep water)	9/29/08	0	0	361.2	150.3	36.1	36.1	0	0	645.6	144.9	100	0
2 (waist deep water)	9/29/08	0	0	62.6	50.7	50.3	11.1	819.7	183.9	932.7	146.1	100	0

RATES OF EXCHANGE BETWEEN SURFACE WATERS AND SEDIMENTS – BENTHIC FLUX

Table A2.10. Benthic Fluxes for all index periods in the Lagoon.

Time	Site	Light/ Dark	Benthic Flux (mmol m^{-2} d^{-1})												
			DO	TCO_2	TDN	TDP	DOC	NH_4	NO_3	DIN	SRP	DON	DOP	Fe	Mn
Index Period 1 - Winter	S	Chamber 1 light	0.17	4.24	-3.12	-0.01	-1320	-0.03	9.28	9.25	0.00	-14.6	-0.01	-0.17	-0.51
		Chamber 3 light	2.86	28.7	101	0.71	-536	-0.09	1.20	1.12	0.86	0.29	-0.15	-0.61	0.07
		light avg	**1.51**	**16.5**	**49.0**	**0.35**	**-927**	**-0.06**	**5.24**	**5.18**	**0.43**	-7.17	-0.08	**-0.39**	**-0.22**
		light stdev	**1.91**	**17.3**	**73.7**	**0.51**	**552**	**0.04**	**5.71**	**5.75**	**0.61**	10.6	0.09	**0.31**	**0.41**
		Chamber 2 dark	-5.78	10.8	51.2	-0.55	-303	-0.32	32.2	31.9	-0.79	19.3	0.25	-0.43	-0.38
		Chamber 4 dark	-5.98	13.8	58.7	-1.20	-593	-0.25	-2.75	-3.00	-0.65	71.1	-0.46	-0.58	0.11
		dark avg	**-5.88**	**12.3**	**54.9**	**-0.88**	**-448**	**-0.28**	**14.7**	**14.4**	**-0.72**	45.2	-0.10	**-0.51**	**-0.14**
		dark stdev	**0.14**	**2.13**	**5.28**	**0.46**	**205**	**0.05**	**24.7**	**24.8**	**0.11**	36.6	0.50	**0.10**	**0.35**
Index Period 2 - Spring		Chamber 1 light		15.7	21.0	-1.87	46.1	0.02	-7.58	-7.56	-0.29	28.5	-1.59	-1.26	-0.51
		Chamber 3 light	-36.6	15.5	20.9	-2.18	-768	-0.38	-10.3	-10.7	0.07	31.6	-2.54	-0.58	-0.68
		light avg	**-36.6**	**15.6**	**20.9**	**-2.02**	**-361**	**-0.18**	**-8.93**	**-9.11**	**-0.11**	30.0	-2.07	**-0.92**	**-0.59**
		light stdev		**0.19**	**0.01**	**0.21**	**575**	**0.28**	**1.91**	**2.19**	**0.25**	2.18	0.68	**0.48**	**0.11**
		Chamber 2 dark	-48.7	-38.1	-3.78	-1.75	-1310	-0.99	-6.51	-7.50	-0.29	20.9	-1.46	0.22	-1.04
		Chamber 4 dark	-109	15.4	34.4	-1.50	-400	-0.08	1.66	1.59	-0.29	32.8	-1.21	-0.30	-1.07
		dark avg	**-78.9**	**-11.4**	**15.3**	**-1.62**	**-856**	**-0.53**	**-2.42**	**-2.96**	**-0.29**	26.8	-1.34	**-0.04**	**-1.05**
		dark stdev	**42.7**	**37.9**	**27.0**	**0.18**	**645**	**0.65**	**5.78**	**6.42**	**0.00**	8.40	0.18	**0.37**	**0.02**
Index Period 3 - Summer		Chamber 1 light	18.9	91.6	-1.14	-0.22	-418	-2.78	-0.90	-3.68	0.38	2.54	-0.59	-3.08	-0.08
		Chamber 3 light		63.5	-11.3	-0.60	66.4	-0.10	-1.19	-1.29	0.23	-9.99	-0.83	-0.44	0.59
		light avg	**18.9**	**77.5**	**-6.21**	**-0.41**	**-176**	**-1.44**	**-1.04**	**-2.48**	**0.30**	-3.73	-0.71	**-1.76**	**0.25**
		light stdev		**19.9**	**7.17**	**0.27**	**342**	**1.90**	**0.20**	**2.10**	**0.11**	8.86	0.17	**1.87**	**0.47**
		Chamber 2 dark	-323	32.5	-2.99	0.12	-14.8	-1.04	-0.43	-1.47	-0.15	-1.52	0.27	-0.60	-0.27
		Chamber 4 dark	-43.6	12.9	-3.39	-0.08	905	-0.15	-0.91	-1.05	-0.38	-2.34	-0.06	0.24	0.42
		dark avg	**-37.9**	**22.7**	**-3.19**	**0.02**	**445**	**-0.59**	**-0.67**	**-1.26**	**-0.26**	-1.93	0.10	**-0.18**	**0.08**
		dark stdev	**8.01**	**13.8**	**0.28**	**0.14**	**650**	**0.63**	**0.33**	**0.97**	**0.16**	0.58	0.23	**0.59**	**0.49**
Index Period 4 - Fall		Chamber 1 light	155	34.9	8.70	0.10	-361	0.29	0.43	0.72	-0.29	7.98	0.40	0.26	-0.63
		Chamber 3 light	110	71.9	6.08	-0.13	-155	-0.44	-0.66	-1.10	-0.15	8.72	0.01	0.15	-0.61
		light avg	**133**	**53.4**	**7.39**	**-0.01**	**-258**	**-0.07**	**-0.11**	**-0.19**	**-0.22**	8.35	0.20	**0.20**	**-0.62**
		light stdev	**32.1**	**26.1**	**1.85**	**0.17**	**146**	**0.52**	**0.77**	**1.29**	**0.10**	0.53	0.27	**0.08**	**0.01**
		Chamber 2 dark	-52.6	-3.47	20.3	-0.15	-180	-0.22	0.37	0.15	0.00	18.4	-0.22	-0.32	-0.45
		Chamber 4 dark	-54.2	32.2	10.2	-0.18	-56.8	-0.66	-0.37	-1.03	0.00	11.2	-0.18	0.02	-0.52

		dark avg	**-53.4**	**14.4**	**15.2**	**-0.16**	**-118**	**-0.44**	**0.00**	**-0.44**	**0.00**	14.8	-0.20	**-0.15**	**-0.49**
		dark stdev	**1.16**	**25.2**	**7.12**	**0.03**	**86.9**	**0.31**	**0.52**	**0.83**	**0.00**	5.10	0.02	**0.25**	**0.05**
Index Period 1 - Winter	Segment Site 2	Chamber 1 light	-10.9	59.9	53.8	0.74	130	11.1	10.6	21.7	5.36	32.1	-4.61	0.12	-0.07
		Chamber 3 light	-129	152	84.4	1.48	24.9	7.54	-6.15	1.39	1.91	147	-1.45	-1.02	8.87
		light avg	**-69.8**	**106**	**69.1**	**1.11**	**77.6**	**9.33**	**2.23**	**11.6**	**3.63**	89.5	-3.03	**-0.45**	**4.40**
		light stdev	**83.3**	**65.4**	**21.7**	**0.52**	**74.6**	**2.53**	**11.8**	**14.4**	**2.44**	81.2	2.24	**0.80**	**6.32**
		Chamber 2 dark	-46.2	145	25.4	1.69	548	-11.7	-15.1	-26.8	0.67	52.1	1.03	1.00	2.25
		Chamber 4 dark	-62.1	109	27.1	1.21	65.0	-11.5	-10.8	-22.2	5.85	85.5	8.44	2.41	0.00
		dark avg	**-54.2**	**127**	**26.2**	**1.45**	**307**	**-11.6**	**-12.9**	**-24.5**	**3.26**	68.8	4.74	**1.70**	**1.12**
		dark stdev	**11.3**	**25.2**	**1.27**	**0.34**	**342**	**0.15**	**3.06**	**3.22**	**3.67**	23.6	5.24	**1.00**	**1.59**
Index Period 2 - Spring		Chamber 1 light	-149	94.4	-24.2	3.82	-363	-5.42	-0.86	-6.28	2.64	-17.9	1.18	-4.77	-0.78
		Chamber 3 light	-124	57.8	45.4	1.34	-659	22.1	-1.66	20.5	-3.29	6.24	6.72	-3.73	2.01
		light avg	**-137**	**76.1**	**10.6**	**2.58**	**-511**	**8.35**	**-1.26**	**7.09**	**-0.32**	-5.82	3.95	**-4.25**	**0.62**
		light stdev	**18.3**	**25.9**	**49.2**	**1.75**	**209**	**19.5**	**0.57**	**20.0**	**4.19**	17.1	3.92	**0.74**	**1.97**
		Chamber 2 dark	-36.6	84.8	1.56	0.85	-84.3	-12.9	-0.88	-13.8	1.00	15.4	-0.15	-2.37	-1.02
		Chamber 4 dark	-246	211	-37.3	-1.69	-608	-13.9	-1.07	-15.0	-11.8	-16.2	10.08	-1.89	-3.12
		dark avg	**-141**	**148**	**-17.9**	**-0.42**	**-346**	**-13.4**	**-0.97**	**-14.4**	**-5.39**	-0.44	4.96	**-2.13**	**-2.07**
		dark stdev	**148**	**89.2**	**27.4**	**1.80**	**371**	**0.70**	**0.14**	**0.83**	**9.03**	22.4	7.23	**0.34**	**1.48**
Index Period 3 - Summer		Chamber 1 light	-133	13.6	-4.17	-0.81	-256	2.67	1.06	3.72	-0.11	-6.66	-0.56	-0.02	0.03
		Chamber 3 light		11.8	8.01	-0.10	630	1.62	-0.44	1.18	0.00	8.19	-0.10	0.63	0.44
		light avg	**-133**	**12.7**	**1.92**	**-0.45**	**187**	**2.14**	**0.31**	**2.45**	**-0.06**	0.76	-0.33	**0.30**	**0.24**
		light stdev		**1.29**	**8.61**	**0.51**	**626**	**0.74**	**1.06**	**1.79**	**0.08**	10.5	0.33	**0.46**	**0.29**
		Chamber 2 dark	-217	5.35	1.98	0.13	341	4.54	0.44	4.98	0.44	-3.35	-0.31	-0.84	1.06
		Chamber 4 dark	-298	-0.15	13.3	0.40	-360	9.05	-0.82	8.23	0.59	5.13	-0.19	-0.81	2.32
		dark avg	**-257**	**2.60**	**7.62**	**0.26**	**-9.53**	**6.80**	**-0.19**	**6.61**	**0.51**	0.89	-0.25	**-0.83**	**1.69**
		dark stdev	**56.9**	**3.89**	**7.97**	**0.19**	**496**	**3.19**	**0.89**	**4.08**	**0.11**	6.00	0.09	**0.03**	**0.88**
Index Period 4 - Fall		Chamber 1 light	-130	22.0	-542	-3.31	377	0.10	-0.25	-0.15	0.00	-541	-3.31	-5.47	-0.29
		Chamber 3 light	-89.9	24.9	-47.9	-0.21	22.8	-4.33	4.33	0.00	0.00	-47.9	-0.21	0.19	0.26
		light avg	**-110**	**23.4**	**-295**	**-1.76**	**200**	**-2.12**	**2.04**	**-0.08**	**0.00**	-295	-1.76	**-2.64**	**-0.01**
		light stdev	**28.0**	**2.04**	**349**	**2.19**	**250**	**3.13**	**3.24**	**6.37**	**0.00**	349	2.19	**4.01**	**0.39**
		Chamber 2 dark	-144	117	-75.8	0.94	830	5.96	-0.30	5.66	1.55	-81.5	-0.61	-0.83	-0.01
		Chamber 4 dark	-90.2	112	-22.5	-0.30	16.8	-2.17	2.71	0.55	0.00	-25.7	-0.30	0.67	-0.20
		dark avg	**-117**	**114**	**-49.1**	**0.32**	**423**	**1.90**	**1.21**	**3.10**	**0.78**	-53.6	-0.46	**-0.08**	**-0.11**
		dark stdev	**38.2**	**2.93**	**37.7**	**0.88**	**575**	**5.75**	**2.13**	**7.88**	**1.10**	39.4	0.22	**1.06**	**0.14**

DATA ON ADDITIONAL FACTORS CONTROLLING BENTHIC FLUX

Table A2.11. 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)	0	0	509	0	0	509	0	1020
		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)	0	0	0	0	0	509	0	509
		Average	**0**	**0**	**127**	**0**	**0**	**255**	**0**	**382**
		Standard Deviation	**0**	**0**	**255**	**0**	**0**	**294**	**0**	**488**
Index Period 2 Spring		Chamber 1 (light)	0	0	1020	0	0	0	0	1020
		Chamber 2 (dark)	0	0	0	0	0	3060	0	3060
		Chamber 3 (light)	0	0	0	0	0	0	0	0
		Chamber 4 (dark)	0	0	509	0	0	0	0	509
		Average	**0**	**0**	**382**	**0**	**0**	**764**	**0**	**1146**
		Standard Deviation	**0**	**0**	**488**	**0**	**0**	**1530**	**0**	**1340**
Index Period 3 Summer		Chamber 1 (light)	0	0	509	0	0	0	0	509
		Chamber 2 (dark)	0	0	0	0	0	0	0	0
		Chamber 3 (light)	0	0	0	0	0	1020	0	1020
		Chamber 4 (dark)	0	0	509	0	0	0	0	509
		Average	**0**	**0**	**255**	**0**	**0**	**255**	**0**	**509**
		Standard Deviation	**0**	**0**	**294**	**0**	**0**	**509**	**0**	**416**
Index Period 4 Fall		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)	0	0	509	0	0	0	0	509
		Average	**0**	**0**	**127**	**0**	**0**	**0**	**0**	**127**
		Standard Deviation	**0**	**0**	**255**	**0**	**0**	**0**	**0**	**255**
	Segment Site 2	Chamber 1 (light)	0	0	0	0	0	0	0	0

Index Period 1 Winter		Chamber 2 (dark)	0	0	0	0	509	0	0	509
		Chamber 3 (light)	0	0	0	0	509	0	0	509
		Chamber 4 (dark)	0	0	0	0	509	0	0	509
		Average	**0**	**0**	**0**	**0**	**382**	**0**	**0**	**382**
		Standard Deviation	**0**	**0**	**0**	**0**	**255**	**0**	**0**	**255**
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)	--	--	--	--	--	--	--	--
		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	0	0	509	0	0	509
		Chamber 2 (dark)	0	0	0	0	509	0	0	509
		Chamber 3 (light)	0	0	2040	0	509	0	0	2550
		Chamber 4 (dark)	509	0	509	0	509	0	509	2040
		Average	**127**	**0**	**637**	**0**	**509**	**0**	**127**	**1400**
		Standard Deviation	**255**	**0**	**964**	**0**	**0**	**0**	**255**	**1050**
Index Period 4 Fall		Chamber 1 (light)	0	0	0	0	0	1530	0	1530
		Chamber 2 (dark)	0	0	509	0	0	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**	**127**	**0**	**0**	**382**	**0**	**509**
		Standard Deviation	**0**	**0**	**255**	**0**	**0**	**764**	**0**	**720**