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BENTHIC-PELAGIC COUPLING AS A FUNCTION OF CHANGING ORGANIC INPUTS IN COASTAL ECOSYSTEMS

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BENTHIC-PELAGIC COUPLING AS A FUNCTION OF
CHANGING ORGANIC INPUTS IN COASTAL
ECOSYSTEMS

BY
LINDSEY FIELDS

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
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UNIVERSITY OF RHODE ISLAND

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DOCTOR OF PHILOSOPHY DISSERTATION
OF
LINDSEY FIELDS

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2013

ABSTRACT

Benthic-pelagic coupling links the sediments and the water column in shallow coastal marine ecosystems. Measurements of benthic-pelagic coupling have been made for decades in shallow, estuarine ecosystems, but relatively few measurements have been made in transitional inner continental shelf areas. Accordingly, the Providence River Estuary and mid-Narragansett Bay have many measurements while ecosystems on the Southern New England inner continental shelf have few. However, even in estuarine areas, the reactions and response times of benthic-pelagic coupling to recent anthropogenic and climate-induced changes are poorly constrained.

Recently, a climate-induced oligotrophication has weakened the relationship between the benthos and the water column in Narragansett Bay. When benthic metabolism and nutrient flux measurements were first measured in the 1970s, benthic nutrient regeneration supplied 50 to over 200 percent of the required nitrogen and phosphorus for phytoplankton production. By the mid-2000s, a considerable reduction in benthic fluxes was observed. These decreases were driven by climate-induced ecosystem changes (e.g. altered winter-spring diatom bloom timing, warming water, increased cloudiness, etc.). Similar changes did not occur in the Providence River Estuary, an area in the upper Bay heavily fertilized by effluent from wastewater treatment facilities. I measured benthic fluxes of oxygen, and dissolved inorganic nutrients across two annual cycles in these areas to (1) determine if mid-Bay sediments have responded to the recent return of the traditional winter-spring diatom bloom, and (2) compare benthic-pelagic coupling in two stations at different locations

on a north-south gradient of anthropogenic impacts. I hypothesized that the response time of mid-Bay benthic-pelagic coupling would be fast and regulated on relatively short time scales, and that differences in water column biology (i.e. primary production, phytoplankton biomass) and nutrients between the Providence River Estuary and the mid-Bay would be mirrored in the benthic fluxes. In the mid-Bay, I measured substantial increases in regeneration of ammonium (176%) and phosphate (266%) regeneration compared to rates measured in 2005-2006, and a significant relationship between surface water phytoplankton biomass and sediment oxygen demand ($R^2=0.23$, $p=0.02$). Even though these changes occurred concurrently with the recent return of the winter-spring phytoplankton bloom, the lack of difference in sediment oxygen demand over time indicated either a lack of rapid response or loss of organic matter through water column consumption. Despite strong gradients in some of the drivers of benthic mineralization such as organic matter (phytoplankton biomass) and primary production, I found no significant differences in average benthic nutrient fluxes between the Providence River Estuary and the mid-Bay. This may be due to the export of organic material down-bay before an excess amount can fall to the benthos.

Block Island Sound (BIS) and Rhode Island Sound (RIS) are adjacent, phytoplankton-based ecosystems on the inner continental shelf off Southern New England with contrasting hydrographic regimes. The water column of Block Island Sound is more well mixed as a result of year-round energetic tidal mixing, while Rhode Island Sound typically becomes stratified during the summer. I aimed to examine the effect of hydrography on benthic-pelagic coupling in transitional shelf

areas. To address these goals, I measured parameters in both the water column and the benthos. I compared annual cycles of surface chlorophyll *a* and ^{14}C -measured primary production between these two ecosystems using samples collected over 22 months (chlorophyll) and approximately monthly for 12 months (production). In the benthos, I made the first measurements of biogeochemical fluxes of oxygen and inorganic nutrients at the sediment-water interface in Block Island and Rhode Island Sounds.

I hypothesized that seasonal water column stratification in Rhode Island Sound would result in increased summer nutrient limitation, lower primary production, and reduced biogeochemical exchanges at the sediment-water interface compared to the relatively more well-mixed Block Island Sound, and that stratification would ultimately weaken the link between the benthos and the water column. *In situ* measurements of surface chlorophyll *a* in Block Island Sound and Rhode Island Sound revealed no significant differences in chlorophyll concentrations between the regions. However, the regional validation of satellite chlorophyll *a* data enabled a comparison over a larger extent of space and time that clearly showed higher overall concentrations in Block Island Sound than Rhode Island Sound. Empirical models of primary production indicated that annual primary production was also higher in relatively well-mixed Block Island Sound ($230\text{--}329 \text{ g C m}^{-2} \text{ y}^{-1}$) than in seasonally stratified Rhode Island Sound ($162\text{--}256 \text{ g C m}^{-2} \text{ y}^{-1}$).

Despite the higher rate of euphotic zone primary production in Block Island Sound, benthic metabolism (measured as sediment oxygen demand) was not significantly different between the two areas ($\text{BIS}=953.8 \text{ } \mu\text{mol m}^{-2} \text{ h}^{-1}$; $\text{RIS}=912.2 \text{ } \mu\text{mol m}^{-2} \text{ h}^{-1}$). This lack of differences was likely due to differences in water column

hydrography between the sounds, where the energetic water column mixing in Block Island Sound resuspended organic matter back to the water column to be decomposed before reaching the benthos. Additionally, the seasonal presence of a strong pycnocline in Rhode Island Sound likely prevented mixing of regenerated DIN and DIP to surface waters for use by phytoplankton. Apparent differences in benthic macrofaunal communities between Block Island Sound and Rhode Island Sound translated to differences in dissolved inorganic nutrient fluxes between the two areas, despite the similarities in benthic metabolism. Excretion and irrigation activities by the dense amphipod communities in Block Island Sound caused higher effluxes of DIN ($\text{NH}_4^+=36.9 \mu\text{mol m}^{-2} \text{h}^{-1}$; $\text{NO}_x=23.5 \mu\text{mol m}^{-2} \text{h}^{-1}$) and DIP ($7.2 \mu\text{mol m}^{-2} \text{h}^{-1}$) compared to fluxes in Rhode Island Sound ($\text{NH}_4^+=22.8 \mu\text{mol m}^{-2} \text{h}^{-1}$; $\text{NO}_x=11.1 \mu\text{mol m}^{-2} \text{h}^{-1}$; $\text{DIP}=3.2 \mu\text{mol m}^{-2} \text{h}^{-1}$). These findings indicate that the hydrographic regime of the water column may exert a strong influence on benthic-pelagic coupling dynamics on the Southern New England shelf and in other inner continental shelf ecosystems.

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Many thanks to my committee: Dr. Anne Giblin, Dr. Art Gold, Dr. Pete August, and Dr. Michael Pilson, for providing valuable feedback, encouragement, advice, and inspiration. Thanks to Steve Granger, for teaching me the ways of the Nixon lab and for providing assistance whenever I needed it. I am indebted to Dr. Ivan Valiela, for directing me towards coastal ecology and GSO. Many thanks to Ed Baker, for your hours of assistance, and to Jennifer Specker, for providing a place to conduct my experiments. Thank you to all of those who collaborated on this project: Anne Giblin, Jane Tucker, Sam Kelsey, Bethany Jenkins, Shelley Brown, Jeremy Rich, Amber Hardison, and Lindsay Brin. Working with you all has been a wonderful experience. Many thanks to Rodman Sykes, Jerry, James, and the crew of the *F/V Virginia Marise*, for making much of my fieldwork possible, and for always lending a

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DEDICATION

“Nature should be looked at with the eyes of a child – inquisitive and searching – which do not take anything for granted and question everything.”

Ramon Margalef

I dedicate this work to Dr. Scott W. Nixon, whose unwavering faith, support, and guidance have helped me weather many storms, both large and small, since the first day I stepped into his office. Being his student has inspired me to always strive to be a bit more like him – a better scientist, and a better person.

PREFACE

As described in the URI Graduate School guidelines for thesis preparation, this thesis is organized in a manuscript format. The body of the text is divided into three sections, corresponding to the format of journal articles. The first manuscript will be submitted to *Estuaries and Coasts* with authors L. Fields, S.W. Nixon, C. Oviatt, and R.W. Fulweiler. The second manuscript is under review in *Continental Shelf Research* with authors L. Fields, J. Mercer, K.J.W. Hyde, M. Brush, S.W. Nixon, C. Oviatt, M.L. Schwartz, D. Ullman, and D. Codiga. The third manuscript will be submitted to *Estuarine, Coastal, and Shelf Science* with authors L. Fields, S.W. Nixon, and R.W. Fulweiler. The appendices contain supplemental methods and calculations (Appendix A), additional tables and figures (Appendix B), and data collected as part of this (Appendix C) and past studies (Appendix D).

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CHAPTER 1

PREFACE

Responses of Benthic-Pelagic Coupling to Anthropogenic and Climate-Driven Ecosystem Changes in a Temperate Estuary

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RESPONSES OF BENTHIC-PELAGIC COUPLING TO ANTHROPOGENIC AND CLIMATE-DRIVEN ECOSYSTEM CHANGES IN A TEMPERATE ESTUARY

ABSTRACT

Strong benthic-pelagic coupling is an important characteristic of shallow coastal marine ecosystems. However, previous research has highlighted that a climate-induced oligotrophication in mid-Narragansett Bay, RI (MNB) may weaken this relationship. When benthic metabolism and nutrient flux measurements were first measured in the 1970s, benthic nutrient regeneration supplied 50 to over 200 percent of the required nitrogen and phosphorus for phytoplankton production. By the mid-2000s, climate-induced ecosystem changes had caused a considerable reduction in benthic fluxes. Similar changes did not occur in the heavily fertilized upper Bay (the Providence River Estuary, PRE). We measured benthic fluxes of oxygen, dissolved inorganic nitrogen (DIN: ammonium, nitrate+nitrite), and phosphate across two annual cycles in MNB and PRE to determine if MNB sediments have responded to the recent return of the traditional winter-spring diatom bloom, and to compare benthic-pelagic coupling in two stations at different positions on a north-south gradient of anthropogenic impacts. We hypothesized that the return of the winter-spring bloom would cause a rapid response in mid-Bay benthic-pelagic coupling with increased benthic nutrient flux rates. We observed increases in ammonium (176% increase since 2005-2006) and phosphate (266% increase since 2005-2006) regeneration and a significant relationship between surface water phytoplankton biomass and SOD ($R^2=0.23$, $p=0.02$). However, SOD did not significantly change since the loss of the winter-spring bloom, indicating either a lack of rapid response or loss of organic

matter through water column consumption. Despite strong gradients in some of the drivers of benthic mineralization such as organic matter (phytoplankton biomass) and primary production, there was no such gradient in benthic nutrient fluxes between PRE and MNB. We speculate that this may be due to the export of organic material down-bay before an excess amount can fall to the benthos.

INTRODUCTION

Studies of benthic-pelagic coupling through biogeochemical flux measurements at the sediment-water interface began in lakes in the early 1940s (Mortimer 1941; Mortimer 1942), and later transitioned into marine systems. Harris (1959) made the first quantitative connections between nutrient availability and regeneration in the water column and the benthos with his studies of respiratory fluxes of organisms in Long Island Sound. The first complete annual cycles of benthic metabolism and nutrient regeneration in marine systems were measured almost two decades later in the 1970s (Nixon et al. 1980; Nixon et al. 1976; Rowe et al. 1975). In the years that followed many efforts were made to examine the relationship between the water column and the benthos, and to identify the drivers and patterns of benthic flux variability (e.g. Hargrave 1973; Kelly and Nixon 1984; Nixon 1981; Rudnick and Oviatt 1986). By now, decades of flux measurements have been made in both freshwater and coastal marine systems (e.g. Banta et al. 1995; Fulweiler et al. 2007; Giblin et al. 1997; Hopkinson et al. 2001; Kirby et al. 2007; Pamatmat and Bhagwat 1973), and benthic-pelagic coupling is well established as an important characteristic of coastal ecosystems (Nixon 1981; Soetaert and Middelburg 2009).

In recent year many studies have demonstrated that both long-term climate change can heavily alter the ecology and phenology in the water column and benthos, and the connection between them (e.g. Fulweiler 2007; Grebmeier et al. 2006; Kirby et al. 2007; Nixon et al. 2009; Smith et al. 2010). As a result, benthic-pelagic coupling has been altered (e.g. North Sea, Kirby et al. 2007) or weakened (e.g. Bering Sea, Grebmeier et al. 2006; Narragansett Bay, Fulweiler 2007; Nixon et al. 2009) compared

to the historically strong link that characterized these areas. In addition to climate-induced ecosystem changes, differences in anthropogenic activities over time can also influence benthic-pelagic coupling dynamics in estuaries and coastal marine ecosystems (Grall and Chauvaud 2002; Kelly et al. 1985; Oviatt et al. 1984). For example, management-driven reductions in nutrient loading can elicit responses including decreases in nutrient standing stocks (Krumholz 2012), decreases in primary production (Boynton et al. 2008), or delayed responses (Carstensen et al. 2006).

Narragansett Bay, Rhode Island is a small temperate estuary that is influenced by both climate-induced changes and anthropogenic activities. In the northern, upper reaches of the bay (the Providence River Estuary), effluent from wastewater treatment facilities fertilizes the water. The Seekonk River and Providence River Estuaries receive 82% of the sewage-derived N that discharges directly into Narragansett Bay (Oczkowski et al. 2008). These point sources of nutrients have the most influence on this region of the ecosystem (Nixon et al. 2008). In the middle portion of the Bay, there is comparatively less allochthonous nutrient input, and this results in a down-bay gradient of primary production, surface chlorophyll, and nutrient concentrations (Kremer and Nixon 1978; Oviatt 2008). Field measurements (e.g. Fulweiler and Nixon 2009; Oviatt et al. 2002; Smith et al. 2010), mesocosm experiments (e.g. Keller 1988a; Kelly and Nixon 1984; Oviatt et al. 1995; Oviatt et al. 1984), and long-term monitoring (e.g. plankton, fish, and water quality) over the past four decades have provided a long record of ecosystem functioning and variability.

Over the last decade Narragansett Bay has been subjected to a climate-induced oligotrophication, or a decrease in the rate of the supply of organic matter to an

ecosystem (Nixon 2009; Oviatt et al. 2002). Long-term climate change have resulted in warming water (Nixon et al. 2004, Oviatt 2004) and possible decreases in wind (Nixon et al. 2009; Pilson 2008) have led to a suite of ecological changes in the mid-Bay (Fig. 1-1; Nixon et al. 1995). Among these changes are shifts in phytoplankton bloom magnitude and phenology (Nixon et al. 2009), and loss of the traditional winter-spring diatom bloom (Borkman and Smayda 2009; Oviatt et al. 2002). In the water column, there has been a decreased abundance of demersal epibenthic animals (Collie et al. 2008) and replacement of boreal demersal fish with demersal decapods (Oviatt 2004). In the benthos, ecosystem changes have cumulated in a switch of the sediment net N₂ gas flux to net nitrogen fixation (Fulweiler et al. 2007) and major decreases in benthic metabolism and nutrient regeneration (Fulweiler 2007; Fulweiler and Nixon 2012; Fulweiler and Nixon 2009; Fulweiler et al. 2010; Nixon et al. 2009). This has been proposed as the primary mechanism that led to a major decrease in benthic-pelagic coupling in the mid-Bay in the mid-2000s (Fulweiler and Nixon 2009; Nixon et al. 2009).

However, since previous sediment flux measurements were made in 2005-2006, the winter-spring diatom bloom has reappeared with more regularity and fall/summer blooms have occurred less frequently (Fig. 1-2). It is far too soon to say whether the recent return of the winter-spring bloom is a result of short-term weather variations, or whether it's disappearance since the 1980s was a temporary effect of climate oscillations rather than a long-term directional change. With the switch to a negative North Atlantic Oscillation in the 1990s, colder winters have temporarily returned to temperate northern continental climates (Greene et al. 2012). The return

Fig. 1-1. Map of Narragansett Bay, shown with sediment core collection stations from this study, and from past work. Mid-Narragansett Bay (MNB) was sampled in 1975-1979 by Nixon et al. (1976,1980 and unpub. data), in 2005-2006 by Fulweiler (2007) and Fulweiler and Nixon (2009), and in this study. The Providence River Estuary (PRE) was sampled in 1983-1984 by Nixon et al. (1990a,b) in 2005-2006 by Fulweiler (2007) and Fulweiler et al. (2010), and in this study. Also included in Providence River estuary data are Gaspee Point (GP), sampled in 1983-1984 by Nixon et al. (1990a,b), and Conimicut Point (CP), sampled in 1983-1984 by Nixon et al. (1990a,b) and in 2005-2006 by Fulweiler (2007) and Fulweiler et al. (2010). LTM=long-term plankton monitoring station (Pratt and Smayda 1959; Ryneerson et al. 1999-present), and BR= water quality buoy at Bullock's Reach (Kieman 2004-present).

Fig. 1-2. Mean winter-spring (Jan, Feb, Mar) phytoplankton cell counts in mid-Narragansett Bay (bars) shown with the month of maximum bloom development (measured as chlorophyll *a* concentration). The average contribution of *Skeletonema* spp., the historically most abundant diatom in the winter-spring bloom, is shown in white, and remaining phytoplankton are shown in gray. Dashed line is the winter-spring average total cell count for 1959-1980. 1959-1997 data from Pratt and Smayda (1959); 1999-present data from Ryneerson (1999-present).

of the winter-spring bloom may be due, at least in part, to recent colder winter temperatures resulting from climate oscillation (Keller et al. 1999), but it is too speculative to say how long the negative oscillation may last in the face of global warming. Regardless, we anticipated the recent return of the winter-spring bloom would elicit a fast response in the benthos. Past experiments and field studies have found the sediments of Narragansett Bay to have a fast recovery time, and a rapid response to changes in the quality and quantity of organic matter input (Kelly and Nixon 1984; Nixon et al. 2009; Oviatt et al. 1984).

While climate-induced ecosystem changes have caused oligotrophication and subsequent weakening of benthic-pelagic linkages in mid-Narragansett Bay (Fulweiler et al. 2010), changes of this magnitude have not been seen over time in the upper reaches of the Bay in the Providence River Estuary (Fig. 1-1). There have been no major changes in primary production in this area since measurements were first made in the 1970s (Oviatt 2008; Oviatt et al. 2002; Smith 2011). During the loss of the winter-spring diatom bloom in the mid-bay, sediment oxygen demand and rates of dissolved inorganic nitrogen regeneration in the Providence River Estuary had not declined significantly from historic (1980s) rates (Fulweiler et al. 2010; Nixon et al. 1990a; Nixon et al. 1990b). This is likely because primary production in this intensely fertilized area relies far less on nutrients regenerated from the winter-spring bloom deposition compared to anthropogenic point sources (Nixon et al. 2008). However, imminent management driven changes in the Providence River Estuary and upper Bay area may elicit responses in both the water column and the benthos.

Intense fertilization of the Providence River Estuary and the upper reaches of Narragansett Bay have occurred for over one hundred and forty years (Nixon et al. 2008). In turn these excess nutrients have led to poor water quality (especially occurrences of summer hypoxia; Bergondo et al. 2005; Codiga et al. 2009; Deacutis et al. 2006; Melrose et al. 2007), and prompted management action. New legislation has called for local wastewater treatment facilities to implement tertiary treatment of effluent with the goal of reducing wastewater N loads to the Bay in an attempt to improve water quality conditions and reduce hypoxia. This level of treatment initiated in 2005 involves bacterially-mediated N removal, and when complete (anticipated in 2014), it will be the first time since the early 1970s that N inputs to Narragansett Bay have significantly changed (Nixon et al. 2008). Sewage treatment upgrades have so far resulted in a 17% decrease in total N loads to the Bay (Krumholz 2012). Calculations by Oviatt (2008) suggest that nutrient concentrations in the Upper Bay will need to be reduced by at least 50% before we see a detectable change in primary production. Upon completion, use of tertiary treatment will decrease sewage treatment plant loads by an estimated 30-50% during the summer (Krumholz 2012; Nixon et al. 2008).

The purpose of this study was twofold. The first goal was to quantify the benthic response to the recent return of the winter-spring bloom in mid-Narragansett Bay. Our second objective was to compare benthic metabolism and nutrient regeneration between the mid-Bay and the Providence River Estuary; two regions that are at different locations on the down-bay gradients of anthropogenic impact, nutrient concentrations, and primary production (Oviatt 2008). Our measurements in the

Providence River Estuary can also be used as additional baseline data collected just prior to the complete implementation of tertiary sewage treatment, and the resulting major changes in nutrient loading. Updating the long record of baseline data before any major biological changes occur in the Providence River Estuary will help us to better assess ecosystem responses to changes in nutrient loading. We measured benthic metabolism and inorganic nutrient (N and P) regeneration in mid-Narragansett Bay and the Providence River Estuary from 2010 to 2012 at or near sites measured over the last four decades (Fig. 1-1). We then compared our most recent measurements with those made previously, and put them in the context of a long history of mid-Bay surface chlorophyll measurements (Borkman and Smayda 2009; Pratt 1959; Smayda 1998) and Upper Bay water quality data (Narragansett Bay Water Quality Monitoring Network; Kiernan et al. 2004-present). Finally, we directly compared measurements made in the mid-Bay and the Providence River Estuary.

We expected mid-Bay benthic metabolism and nutrient regeneration to have increased from rates measured five years ago (Fulweiler and Nixon 2009), and to more closely resemble historic values (Nixon et al. 1980; Nixon et al. 1976) in response to the recent return of the winter-spring diatom bloom (Fig. 1-2). We hypothesized that fluxes at the sediment-water interface in the Providence River Estuary would not have changed much over time, because there is no evidence of changes in rates of primary production since previous measurements made in the 1970s and 1980s (Smith 2011). Also, a recent assessment of changes in nutrient inputs and standing stocks suggested that current decreases in nutrient loading are not substantial enough to elicit any major changes (Krumholz 2012). Finally, we hypothesized that the differences in water

column biology (i.e. primary production, phytoplankton biomass) and nutrients between the Providence River Estuary and the mid-Bay would be mirrored in the benthic fluxes. Specifically, we expected rates of exchange at the sediment-water interface to be much higher in the Providence River Estuary than those at the mid-Bay, despite any potential effects from the return of the winter-spring diatom bloom.

MATERIALS AND METHODS

Study Areas

Narragansett Bay is a small (328 km², mean depth 8.6 m), temperate estuary dominated by phytoplankton-based production (Nixon et al. 1995). Although microphytobenthos can contribute up to one third of total primary production in certain times and places in the upper Bay, they contribute very little to total system production compared to phytoplankton, and benthos are net heterotrophic for the majority of the year (Lake and Brush 2011). The annual temperature range of the Bay is around 0 - 24°C, and sediments are composed mostly of clayey silt and sand-silt clay (McMaster 1960). The majority of freshwater enters the Bay at its upper reaches, but salinity is relatively high (around 26-30 psu) because overall freshwater inputs are fairly low (100 m³ s⁻¹; Pilson 1985). Narragansett Bay exhibits strong north-south gradients of primary production, surface chlorophyll, nutrients, and anthropogenic impacts (Kremer and Nixon 1978; Oviatt 2008) which allow for comparisons of the heavily fertilized upper bay (the Providence River Estuary) and the relatively less impacted mid-Bay. The Providence River Estuary is located at the head of the Bay (Fig. 1-1). It is a eutrophic urban estuary that often exhibits strong vertical stratification and experiences intermittent summer hypoxia (Bergondo et al. 2005; Codiga et al. 2009; Deacutis et al. 2006; Melrose et al. 2007), or dissolved oxygen concentrations below around 62.5 – 93.75 µmol L⁻¹ (2-3 mg L⁻¹; Committee on Environment and Natural Resources 2010; Deacutis et al. 2006). It is heavily impacted by anthropogenic nutrient input from both sewage outfalls and land drainage (Nixon et al. 1995). Moving south to mid-Narragansett Bay, there is a small increase

in depth, and a decrease in both surface chlorophyll *a* concentrations and primary productivity (Oviatt 2008) relative to the Providence River Estuary (Fig. 1-1; Table 1-1). Mid-Narragansett Bay has very low summer nutrient concentrations (Nixon et al. 1995), and seldom experiences hypoxic conditions (Deacutis et al. 2006). Studies of benthic metabolism and nutrient regeneration began in the mid-Bay during the 1970s (Hale 1974; Nixon et al. 1980; Nixon et al. 1976), and in the Providence River Estuary during the 1980s (Nixon et al. 1990a; Nixon et al. 1990b). Similar measurements have continued at least once per decade since then (Table 1-1).

Table 1-1. Characteristics over time of the two sampling stations.

Parameter		PRE	MNB
Mean station depth, m		3	7.4
Bottom water temperature range, °C		1 – 24	1 – 22
Bottom salinity range, ppt		27 – 31	27 – 31
Grain size ^a , 0-2 cm		78% silt/coarse silt	75% silt/coarse silt
Surface chlorophyll <i>a</i> ^{b,c} , µg L ⁻¹	1970s – 1980s	22.5	8.0
	2000s	11.8 ^d	5.1
	2010s	15.7 ^d	5.7
Euphotic depth, m	1970s – 1980s		1.2 ^f
	2000s	7.2 ^a	7.8 ^g
	2010s		7.4 ^g
Sediment C/N ratio	1970s – 1980s		10 ^h
	2000s ^{a,e}	16.6 ± 5.1	10.3 ± 0.3
	2010s	18.4 ± 0.6	15.1 ± 0.6
Sediment chlorophyll <i>a</i> concentration, mg m ⁻²	1970s – 1980s		
	2000s ^{a,e}	78.2	20.5 ± 14
	2010s	94.5 ± 10.7	55.3 ± 16.8

^aValues from Fulweiler (2007)

^b1970s-1980s value is the annual mean based on 26 sampling dates during 1979 – 1980, from Oviatt et al. (1984); 2000s and 2010s data are from URI GSO long-term plankton monitoring program, <http://www.gso.uri.edu/phytoplankton.htm>. 2010s average reflects only 2010-2011; data for 2012 were unavailable. 2005-2006 measurements have been adjusted to account for a change in methods from extraction of frozen filters to immediate extraction (see text for more details).

^c2000s MNB data include measurements made in 2005-2006, 2010s MNB data include measurements made from Jan 2010-Jan 2012 only

^dValues from Bullock's Reach buoy data in 2005 or 2010-2012. Means represent only time periods during which buoys were recording data, typically June-Sept (see text)

^eValues calculated from Secchi disk measurements made by the URI GSO plankton monitoring program. TO obtain extinction coefficients, we used 1.7/Secchi depth (Holmes 1970)

^fValues from MERL mesocosms; not representative of actual mid-Bay value

^gValues from summer/fall only

^hKelly and Nixon (1984)

Core collection

We collected triplicate sediment cores ($\sim 1200 \text{ cm}^3$ of sediment and $\sim 1 \text{ L}$ of overlying water) from each station nine times over the course of two years (May 2010 – Jun 2012; Table 1-2). We obtained sediment cores from the Providence River Estuary (PRE) using a 4.5 m long pull corer, and cores from mid-Narragansett Bay station (MNB) via SCUBA divers (Fulweiler et al. 2010). The pull corer was equipped with a valve that created suction to help minimize disturbance of sediment structure. In all cases, cores were capped and maintained on deck in a light-tight cooler at near ambient water temperature. We also collected and filtered (down to 0.2 microns) near-bottom water at each station (Fulweiler and Nixon 2009; Hopkinson et al. 2001). We then brought the cores and water to the University of Rhode Island Graduate School of Oceanography's EPSCoR Marine Life Science Facility ~ 2 -4 hours after sample collection. Cores were kept in the dark in a temperature-controlled (at *in situ* bottom water temperature) walk-in environmental chamber. Prior to each incubation, we aerated the overlying water in the cores by gently bubbling with air stones overnight (~ 6 -12 hours), then carefully siphoned off the overlying water and replaced it with new filtered station water (Hopkinson et al. 2001). We were especially careful to maintain the delicate surface flocculent layer of the sediment. We then fit cores with gas tight lids and hooked them into a gravity-fed system where new filtered water was pulled in as water was displaced during sample collection. Magnetic stir bars gently mixed the water at $\sim 40 \text{ rpm}$ to prevent stratification in overlying water without sediment resuspension (Renaud et al. 2008). Concurrently,

Table 1-2. Dates and counts of sediment core collection in mid-Narragansett Bay (MNB) and the Providence River Estuary (PRE) for the current study, and studies we've used for comparison.

	Dates	Area	Count			
			SOD	DIP	NH ₄ ⁺	NO _x
1970s	Jun 1975 - Nov 1977	MNB ^a	130	17	45	10
1980s	Sep 1983 - Oct 1984	PRE ^b	48	45	45	39
2000s	Jul 2005 - Aug 2006	MNB ^c	18	18	18	18
	Jul 2005 to Aug 2006	PRE ^c	24	24	24	24
2010s	May 2010 - Jun 2012	MNB ^d	33	25	31	25
	May 2010 - Jun 2012	PRE ^d	34	31	32	32

^aHale (1974), Nixon et al. (1976;1980)

^bNixon et al. (1990a,b)

^cFulweiler (2007), Fulweiler and Nixon (2009), Fulweiler et al. (2010)

^dThis study

we incubated a biological oxygen demand, or BOD, bottle and collected initial and final samples to account for any water column activity (Suykens et al. 2011).

Core incubations

Throughout the incubation, we collected four samples of overlying water for measurement of phosphate (DIP), ammonium (NH_4^+), and nitrate + nitrite (NO_x). We filtered samples through 0.7 μm binder free Glass Fiber (GF/F) filters (2.5 cm dia) and stored them frozen (-15°C) in acid washed, deionized water-leached polyethylene bottles until analysis (Fulweiler and Nixon 2009; Grasshoff et al. 1999). We used a Hach LDO probe (HQ30) to measure dissolved oxygen (DO) concentrations in the overlying water just prior to each sample collection. Sediment core incubations lasted 6 – 26 hours, and were stopped before dissolved oxygen concentrations in the overlying water reached near-hypoxia ($93.75 \mu\text{mol L}^{-1}$; Fulweiler and Nixon 2009; Hopkinson et al. 2001). We analyzed all nutrient samples on a Lachat QuickChem 2000 flow injection autoanalyzer using standard colorimetric methods (Table 1-3; Grasshoff et al. 1999).

Data analysis

a. Spatial and temporal comparisons

Because inorganic nutrient and dissolved oxygen concentrations decreased linearly over time, we calculated benthic fluxes using linear regressions of the four samples (Clough et al. 2005; Fulweiler and Nixon 2009). From the volume and area

Table 1-3. Analytical methods, accuracy, and precision for analyses.

Parameter	Instrument	Detection Limit ^c	Accuracy, %	Precision, %	Reference
Ammonium ^a	Lachat QuickChem 8000 flow injection analyzer	0.07 µM	2	1	Grasshoff et al. 1999; US EPA Method 365.3
Nitrate+Nitrite ^a	Lachat QuickChem 8000 flow injection analyzer	0.02 µM	2	1	Grasshoff et al. 1999; US EPA Method 353.2
Phosphate ^b	Lachat QuickChem 8000 flow injection analyzer	0.01 µM	6	2	Grasshoff et al. 1999; US EPA Method 365.5
Dissolved oxygen	Hach HQ30 LDO probe	0 mg L ⁻¹	3		Fulweiler and Nixon 2009

^aAccuracy and precision calculated based on a certified nutrient standard

^bAccuracy and precision calculated based on a laboratory nutrient standard

of each core, we scaled fluxes to obtain final rates in $\mu\text{mol m}^{-2} \text{h}^{-1}$ (Hargrave and Connolly 1978; Nixon et al. 1980). We also corrected fluxes for any activity measured in the water column (Fulweiler and Nixon 2009; Hopkinson et al. 2001) using measurements from control BOD bottle incubations. Fluxes out of the sediment are positive values indicating regeneration, and fluxes into the sediment are negative indicating uptake.

We compared fluxes measured across time periods at the mid-Bay (1970s, 2000s, and 2010s) and at the Providence River Estuary (1980s, 2000s, and 2010s). For the sake of brevity, we refer to sampling periods by the decades during which measurements were made (i.e. 1970s, 1980s, 2000s, and 2010s), but it should be noted that measurements were made across only a few (2-6) annual cycles during each decade (Table 1-2). We ran linear regression analyses and tested exponential fits to determine if fluxes were significantly related to incubation temperature. In cases where there was a significant temperature-flux relationship, we used analysis of covariance (ANCOVA) for comparisons. ANCOVAs take a covariate into account (in this case, temperature) and adjust values (fluxes) for this covariate before comparisons (Myers et al. 2010). If we did not detect a significant flux-temperature relationship, then we deemed adjustments for temperature unnecessary and compared means using one-way analysis of variance (ANOVA). We determined significance using a Bonferroni adjusted alpha value of 0.02 for comparisons between the three decades of measurements at each station. We used the same procedure to compare fluxes measured most recently (during this study) between the MNB and PRE station, with significance determined by an alpha of 0.05. In all cases, we conducted post-hoc

multiple comparison tests (Tukey-Kramer HSD tests) when overall ANCOVAs and ANOVAs were significant. All statistics were run using JMP Pro 10 (SAS).

It should be noted that there were some differences between data sets analyzed in this study and temporal comparisons that were previously published (Fulweiler and Nixon 2009; Fulweiler et al. 2010). Specifically, for the mid-Bay station, we have expanded the data set from the mid-2000s by including measurements that were previously unavailable and thus not analyzed by Fulweiler and Nixon (2009). For the Providence River Estuary, analyses by Fulweiler et al. (2010) included historical data collected during the 1970s and additional mid-2000s data that we chose not to include in our analyses. We decided to exclude the 1970s data because measurements were made only for ammonium and phosphate fluxes, not nitrate+nitrate or oxygen fluxes. We excluded some of the stations sampled during the mid-2000s because Fulweiler et al. (2010) sampled throughout the whole Upper Bay, but we chose to focus only on the Providence River Estuary.

b. Outliers

A few obvious outliers were observed, investigated, and excluded from data analysis. If values seemed erroneous (e.g. due to analytical error or bottle effects) and heavily biased the data, they were excluded from analysis. All excluded values were confirmed to be outliers using Mahalanobis distance, a measure of the distance of each point to the center of all values (Stevens 1984). At PRE, we excluded measures of abnormally large DIP uptake ($-123.0 \mu\text{mol m}^{-2} \text{h}^{-1}$), and high SOD ($11477.0 \mu\text{mol m}^{-2} \text{h}^{-1}$) in cores where 1-3 quahogs were present. At MNB, we excluded an extremely

large NH_4^+ regeneration ($1306.9 \mu\text{mol m}^{-2} \text{h}^{-1}$) in a core with signs of burrowing activity. We also excluded a very high DIP efflux ($55.0 \mu\text{mol m}^{-2} \text{h}^{-1}$) from the 1970s data. We measured two instances of very high NO_x uptake at MNB during a single incubation (-251.6 and $-274.9 \mu\text{mol m}^{-2} \text{h}^{-1}$) that were likely due to biogeochemical activity, and analyzed data including and excluding these points.

c. Providence River Estuary hypoxia and water column stratification

Although we bring dissolved oxygen concentrations in cores to saturated levels just prior to incubations, recent hypoxic events may have a legacy effect in the sediment cores. To look for any potential lasting effects of recent hypoxia in cores collected in the Providence River Estuary, we examined relationships between the frequency of bottom water hypoxic events and benthic fluxes using correlation analysis. We also classified sediment core collection dates as hypoxic ($< 93.75 \mu\text{mol L}^{-1}$) or normoxic ($> 93.75 \mu\text{mol L}^{-1}$), and directly compared benthic flux averages between these two conditions using un-pooled Student's T-tests. For this study, we defined the hypoxia threshold to be $< 93.75 \mu\text{mol L}^{-1}$ (3 mg L^{-1} ; Deacutis et al. 2006), based on the Rhode Island state regulated threshold of $90.6 \mu\text{mol L}^{-1}$ (2.9 mg L^{-1}) during the larval recruitment season (May-Oct; RIDEM 2006).

Since the early 2000s, water quality measurements (dissolved oxygen, salinity, pH, temperature, etc.) have been continuously recorded (every 15 minutes) during the spring through fall by buoys throughout the Bay and maintained by collaborators from many institutions as part of the Narragansett Bay Water Quality Monitoring Network (Kiernan et al. 2004-present). The Bullocks Reach buoy in the Providence River

Estuary (Fig. 1-1) was recording data from June to November (in 2012 Apr to Nov) during all three years of our study period (Kiernan et al. 2004-present). We calculated 3-day averages of bottom water dissolved oxygen concentrations for recordings this buoy (Fig. 1-1; Kiernan et al. 2004-present). These averages included the day of sediment core collection plus the two days prior. We chose to use 3-day averages of DO rather than daily values to account for the duration of any hypoxic events that occurred, as the severity of impacts and recovery time of a benthic community are drastically affected by the low-oxygen exposure time (Diaz and Rosenberg 1995).

We assessed two factors that influence the intensity of vertical water column stratification in the Providence River Estuary to determine if any changes have occurred over time: wind speed and salinity. We ran a linear regression to determine if the long-term trend in declining average wind speed in Providence, RI (Pilson 2008) is still occurring, and how much wind speed has changed in the past ~5 years. Daily wind speed data was collected by NOAA (1972-present) at the National Climatic Data Center station on Green St in Providence, RI (TF Green Airport). Additionally, we ran linear regressions to determine if salinity has changed in the surface and bottom waters over time, or if the differences between surface and bottom salinity had changed. We calculated average summer (J,J,A) values using available Bullock's Reach buoy data from 2002-2012 (Kiernan et al. 2004-present).

d. Mid-Bay surface chlorophyll analyses

We examined winter-spring surface water temperature and surface chlorophyll *a* concentrations over time to identify any changes. Temperature and surface

chlorophyll *a* data were recorded from the weekly sampling of D. Pratt, T.J. Smayda, and the URI Graduate School of Oceanography plankton monitoring program since 1959 (Pratt 1959; Ryneerson 1999-present). We used correlation analyses to determine if any relationships existed between surface chlorophyll *a* concentrations and benthic fluxes (1970s – present) at the mid-Bay station (MNB). We compared incubation mean benthic fluxes (mean of triplicate cores) with average surface chlorophyll concentrations measured weekly during the month prior to sediment core collection. Particle sinking rates vary, but the typical range (50-250 m d⁻¹; Fischer and Karakas 2008) is such that detritus probably falls to the bottom of the relatively shallow (around 7.4 m deep) mid-Bay station very rapidly. We chose to include data from the month prior to sediment core collection to account for any delays in decomposition of organic matter on the benthos (Rudnick and Oviatt 1986). There was a change in methods of surface chlorophyll sample analysis from extraction of stored, frozen filters to immediate extraction, and this change caused large differences in measured concentrations (Graff and Ryneerson 2011). We accounted for this by using a linear regression to convert from frozen filters to immediate extraction after July 2008 (frozen = 0.4494*immediate, $R^2 = 0.77$). Our regression analysis was performed using approximately 50 samples that were run using both methods during 2007 – 2008 by Graff and Ryneerson (2011), and the intercept was forced through zero.

RESULTS

Sediment Oxygen Demand

Measures of SOD in the PRE ranged from 541.6 to 5063.4 $\mu\text{mol m}^{-2} \text{h}^{-1}$ (Fig. 1-3a). Our most recent measurements during 2010-2011 of average SOD were significantly higher (1983.3 $\mu\text{mol m}^{-2} \text{h}^{-1}$) than measurements from the mid-2000s (1125.4 $\mu\text{mol m}^{-2} \text{h}^{-1}$) and the 1980s (1234.4 $\mu\text{mol m}^{-2} \text{h}^{-1}$; ANCOVA, $F(2,101)=10.4$, $p<0.0001$; Fig. 1-4a).

At MNB, SOD ranged from 274.7 to 1664.1 $\mu\text{mol m}^{-2} \text{h}^{-1}$ (Fig. 1-3b). The most recent mean SOD (823.0 $\mu\text{mol m}^{-2} \text{h}^{-1}$) was significantly lower than those measured during the 1970s (1200.7 $\mu\text{mol m}^{-2} \text{h}^{-1}$), but not significantly different from SOD measured in the mid-2000s (619.1 $\mu\text{mol m}^{-2} \text{h}^{-1}$; Welch's ANOVA, $F(2,122)=8.4$, $p=0.0006$; Fig. 1-4b).

During our 2010-2012 sampling year, average SOD was significantly higher in the Providence River Estuary than in the mid-Bay (unpooled Student's t-test, $t=5.56$, $p<0.0001$). Rates of sediment oxygen uptake were higher during colder temperatures at PRE compared to rates at similar temperatures in MNB (Fig. 1-3a,b).

Dissolved inorganic nitrogen

At PRE we measured a large range of both NH_4^+ fluxes (-44.3 – 860.4 $\mu\text{mol m}^{-2} \text{h}^{-1}$; Fig. 1-3c) and NO_x fluxes (-444.1 – 221.9 $\mu\text{mol m}^{-2} \text{h}^{-1}$; Fig. 1-3e). There were no significant changes in either component of DIN over time (average NH_4^+ in 1980s=145.2 $\mu\text{mol m}^{-2} \text{h}^{-1}$, 2000s=152.4 $\mu\text{mol m}^{-2} \text{h}^{-1}$, 2010s=171.0 $\mu\text{mol m}^{-2} \text{h}^{-1}$;

Fig. 1-3. Fluxes of oxygen (a,b), ammonium (c,d), nitrate+nitrite (e,f), and phosphate (g,h) at the sediment-water interface in the Providence River Estuary and mid-Narragansett Bay across the annual temperature range. Data from 2010s are from this study, data from 2000s are from Fulweiler (2007), Fulweiler and Nixon (2009), and Fulweiler et al. (2010), data from the 1980s is from Nixon et al. (1990a,b), and data from the 1970s is from Nixon et al. (1976,1980, and unpub. data). PRE data from 2000s and 1980s includes measurements from three different stations in the Providence River estuary, while 2010s data are from only one of these stations. Units are $\mu\text{mol m}^{-2} \text{h}^{-1}$.

Fig. 1-4. Average fluxes (± std. error) of oxygen (a,b), ammonium (c,d), nitrate+nitrite (e,f), and phosphate (g,h) at the sediment water interface over the past 40 years at the Providence River Estuary and the mid-Bay. Letters represent significant differences between averages. Note the different scales on the y-axes for each station. 1970s data from Nixon et al. (1976, 1980, and unpub. data); 1980s data from Nixon et al. (1990a,b); 2000s data from Fulweiler and Nixon (2009), Fulweiler et al. (2010), and Fulweiler unpub. data.

average NO_x in 1980s=-13.6 $\mu\text{mol m}^{-2} \text{h}^{-1}$, 2000s=-9.4 $\mu\text{mol m}^{-2} \text{h}^{-1}$, 2010s=-5.1 $\mu\text{mol m}^{-2} \text{h}^{-1}$; Fig. 1-4c,e).

At the mid-Bay station, the range of NH_4^+ fluxes (-120.3 to 510.8 $\mu\text{mol m}^{-2} \text{h}^{-1}$; Fig. 1-3d) was much larger than that of NO_x fluxes (-47.5 to 91.6 $\mu\text{mol m}^{-2} \text{h}^{-1}$; Fig. 1-3f). We also measured two instances of extremely large NO_x uptake in August 2011 (-251.6 and -274.9 $\mu\text{mol m}^{-2} \text{h}^{-1}$; Fig. 1-3f). Our most recent measurement of average NH_4^+ flux (105.0 $\mu\text{mol m}^{-2} \text{h}^{-1}$) was significantly higher than measurements made during the mid-2000s (38.0 $\mu\text{mol m}^{-2} \text{h}^{-1}$), but not the 1970s (88.7 $\mu\text{mol m}^{-2} \text{h}^{-1}$; Welch's ANOVA, $F(2,84)=5.7$, $p=0.006$; Fig. 1-4d). Our overall average measurement of NO_x flux was heavily impacted by the presence of high uptake (mean including values=-9.9 $\mu\text{mol m}^{-2} \text{h}^{-1}$, mean excluding values=10.4 $\mu\text{mol m}^{-2} \text{h}^{-1}$), though average NO_x fluxes did not significantly change over time regardless of whether or not the two large uptake measurements were included in analysis (average in 1970s=16.9 $\mu\text{mol m}^{-2} \text{h}^{-1}$, 2000s=2.1 $\mu\text{mol m}^{-2} \text{h}^{-1}$; Fig. 1-4f).

There were no significant differences in NH_4^+ or NO_x fluxes between the sampling stations (MNB and PRE) during our study

Dissolved inorganic phosphorus

The range of DIP fluxes measured at PRE in this study were also wide (-39.8 – 86.7 $\mu\text{mol m}^{-2} \text{h}^{-1}$; Fig. 1-3g), but overall mean DIP flux (7.2 $\mu\text{mol m}^{-2} \text{h}^{-1}$) had not significantly changed from rates measured in the mid-2000s (5.0 $\mu\text{mol m}^{-2} \text{h}^{-1}$; Welch's ANOVA, $F(2,90)=6.0$, $p=0.004$; Fig. 1-4g). The mean annual DIP fluxes were drastically higher during the 1980s (38.7 $\mu\text{mol m}^{-2} \text{h}^{-1}$; Fig. 1-4g).

We measured DIP fluxes that ranged from -21.6 to 37.2 $\mu\text{mol m}^{-2} \text{h}^{-1}$ in 2010-2012 (Fig. 1-3h). Our most recent measurement of mean DIP flux (7.7 $\mu\text{mol m}^{-2} \text{h}^{-1}$) was not significantly different from those measured during the 1970s (9.6 $\mu\text{mol m}^{-2} \text{h}^{-1}$) or the mid-2000s (2.1 $\mu\text{mol m}^{-2} \text{h}^{-1}$). However, the mean DIP flux measured in the mid-2000s was significantly lower than 1970s measurements (Welch's ANOVA, $F(2,78)=5.7$, $p=0.006$; Fig. 1-4h).

Average fluxes of DIP were not significantly different between stations (MNB and PRE) during our 2010-2012 sampling period.

Providence River Estuary hypoxia and stratification

Seven of our core collection dates aligned with available buoy data. On three of the seven occasions, we collected sediment cores when the daily average DO concentration was hypoxic (daily average DO concentration $<93.75 \mu\text{mol L}^{-1}$, or 3 mg L^{-1}). Recognizing that the number of hypoxia data points was small, we found no significant relationships between recent (within 3 days) bottom water dissolved oxygen concentrations and benthic fluxes. There were also no significant differences between fluxes measured in cores collected during hypoxic versus normoxic conditions.

Average wind speed during the least windy months of the year (July, August, and September) has continued to significantly decline since records began in Providence in the early 1970s, and has been declining at double the long-term rate since previous benthic flux measurements were made in 2005-2006 (Fig. 1-5). It should be noted, however, that buoys were not functional on every day between July

Fig. 1-5. Average wind speed in Providence, RI during the least windy months of the year (July, August, and September) from 1972 to 2012. Daily wind measurements made by NOAA (1972-present) at the National Climactic Data Center station on Green St, Providence, RI.

and September during most years, so missing data could be an artifact of this analysis. There were no significant changes in summer (J,J,A) salinity in either the surface or bottom waters of PRE over the last decade (2002-2012), nor were there changes in salinity differences between surface and bottom waters.

Mid-Bay surface water chlorophyll a

Average surface water temperature during the winter-spring (J,F,M) increased significantly ($p < 0.0001$) by $\sim 0.03^{\circ}\text{C}$ per year between 1959-2013 ($R^2 = 0.35$; Fig. 1-6a). Surface chlorophyll data were available from 1972-2012, and average winter-spring surface water chlorophyll concentrations declined significantly during this period of time ($y = -0.2x + 424.7$, $R^2 = 0.15$, $p = 0.02$; Fig. 1-6b). There was a significant relationship between SOD and average surface chlorophyll concentrations from the month prior to sediment core collection ($r = 0.48$, $p = 0.02$; Fig. 1-7a). Chlorophyll explained 23% of the variance in SOD during the 1970s-2010s. We found no relationship between average surface chlorophyll concentrations for either NH_4^+ or NO_x fluxes. DIP fluxes at the sediment-water interface measured during the 1970s-2010s were significantly related to average surface chlorophyll concentrations from the month prior to core collection ($r = 0.65$, $p = 0.001$; Fig. 1-7b), and chlorophyll explained 43% of flux variance.

Fig. 1-6. Average winter-spring (J,F,M) surface water temperature (a) and surface chlorophyll *a* concentration (b) at the mid-Bay station over time. 1959-1997 data from Pratt and Smayda (1959); 1999-present data from Ryneerson (1999-present).

Fig. 1-7. Oxygen uptake (a) and phosphate flux (b) relationships with average surface chlorophyll *a* concentrations from the month prior to sediment core collection at the mid-Bay station during the 1970s, mid-2000s, and for the present study (2010-2012). 1970s chlorophyll data are from Pratt and Smayda (1959); 2000s and 2010s chlorophyll data are from Ryneerson (1999-present); 1970s flux data from Nixon et al. (1976, 1980, unpub. data); 2000s data from Fulweiler and Nixon (2009) and Fulweiler unpub. data.

DISCUSSION

Temporal changes in the Providence River Estuary

We measured a large (76%) and statistically significant increase in the average benthic metabolic rate from the mid-2000s to the present in the Providence River Estuary (Fig. 1-4a). This increase resulted in the highest average rate of sediment oxygen uptake ever measured in this area. While there are some higher rates of oxygen uptake during the warmer temperatures, this increase in the overall average seems to be driven by higher rates at colder temperatures compared to rates in previous decades (Fig. 1-3a). In coastal ecosystems, organic matter inputs are the most important drivers of benthic metabolism (Hopkinson and Smith 2004), and deposition of additional organic matter at the colder temperatures might explain our observations. Because of the lack of changes in surface water chlorophyll or primary production (Oviatt et al. 2002; Smith 2011), it is unlikely that increases in autochthonous organic matter input are causing this increase in oxygen uptake. A recent study by Lake and Brush (2011) showed that microphytobenthos play a very small role in the shallow areas of the Upper Bay, and that the sediments are net heterotrophic in all but the most shallow areas of the Bay. Therefore, benthic primary production is unlikely to be a major contributing factor to these changes. A cursory look at initial bottom water dissolved oxygen concentrations in sediment cores excludes the possibility that the water is more oxygenated than in the past.

In a mesocosm experiment with Narragansett Bay sediment, Rudnick and Oviatt (1986) showed that there can be a seasonal delay in mineralization of organic matter deposited during colder conditions. They propose that colder temperatures

suppress the metabolic activity of benthos, so not all of the detritus gets decomposed until more favorable (warmer) temperatures for metabolism. However, this is not always the case. For example, Banta et al. (1995) saw a peak in benthic metabolism shortly after the winter-spring bloom (in May) in Buzzards Bay in temperatures as cold as 11°C. Perhaps higher SOD at colder temperatures is indicative of PRE benthos responding on shorter time scales to phytoplankton bloom deposition.

Increasing water temperatures in the Bay (Nixon et al. 2009) may have also contributed to increases in benthic metabolism and thus sediment oxygen uptake. Water temperatures in Narragansett Bay have been increasing over the past few decades at a rate of around 0.03 °C y⁻¹ (Fig. 1-6a). In Narragansett Bay, heterotrophic respiration increases with temperature twice as fast as rates of primary production (Harris et al. 2006; Nixon 2009). Therefore, it would not take much warming for heterotrophic respiration to increase noticeably. Concurrently, changes in water column stratification might exacerbate the situation by keeping sinking organic matter below the pycnocline. The power of wind to mix the water column is related to the cube of wind speed (Niiler and Kraus 1977), and a decline of average wind speed in Providence, RI (Fig. 1-5; Pilson 2008) is indicative that water column stratification in the Providence River Estuary could be increasing. Any possible changes in water column stratification were probably not due to salinity, as salinity profiles have not significantly changed in the past decade.

Benthic fluxes of DIN (ammonium and nitrate+nitrite) have not significantly changed in the Providence River Estuary since the 1980s (Fig. 1-4c,e). Until 2005, the inputs of nitrogen to Narragansett Bay had remained essentially unchanged since the

1970s (Nixon et al. 2008). Because the Fields Point wastewater treatment facility has not yet made the full transition to tertiary treatment, there have been no measurable changes in DIN in the area immediately surrounding our sample station (Krumholz 2012). Because increased benthic metabolism is one of our proposed mechanisms for large sediment oxygen uptake, it might seem contradictory that we did not measure such large increases in DIN regeneration. However, it is possible that other biogeochemical processes such as N removal through denitrification (Fulweiler and Nixon 2012) are inhibiting large increases in regeneration to the water column. A net uptake of NO_x by PRE sediments indicates that nitrate is being removed from bottom waters and used for direct denitrification, dissimilatory nitrate reduction to ammonium (DNRA), or both. Dissimilatory nitrate reduction to ammonium (DNRA) occurs in carbon-rich, reduced conditions (Canfield et al. 2005). It is known as the “short circuit” of the N cycle because it keeps biologically available N in the system as NH_4^+ as opposed to complete N removal (Cole and Brown 1980). There are currently no published rates of DNRA for Narragansett Bay sediments, but it’s importance in the N cycle of other coastal and estuarine ecosystems has been demonstrated (e.g. Gardner et al. 2006; Sorensen 1978). A survey conducted by Kelly-Gerreyn et al. (2001) of studies that measured DNRA in coastal ecosystems around the world found that DNRA can contribute anywhere from 0-98% of the total nitrate reduction in sediments. During their measurements in 2005-2006, Fulweiler et al. (2010) saw similar evidence of DNRA in the Upper Bay sediments.

During the mid-2000s, Fulweiler et al. (2010) measured a significant decrease in phosphate flux magnitude in Upper Bay sediments. Rates of DIP remineralization

have remained basically unchanged since then (Fig. 1-4g). Fulweiler et al. (2010) attributed the observed decrease in phosphate fluxes occurred in response to management changes in the 1990s that called for the removal of P in detergents (Nixon et al. 2008). There was a concurrent decline in the standing stock of phosphate in the water column (Krumholz 2012). Our measurements of phosphate fluxes indicate that rates of benthic DIP regeneration have not changed in PRE since the mid-2000s, despite increases in SOD. It is possible that phosphate sorption reactions (Froelich 1988) are inhibiting large increases in regeneration to the water column.

Benthic-pelagic coupling in the mid-Bay

By the mid-2000s, roughly 20 years after the major shift in phytoplankton bloom phenology that resulted in a nearly 50% decline in *Skeletonema* (diatom) abundance (Borkman and Smayda 2009), benthic nutrient regeneration in mid-Narragansett Bay had drastically changed. Sediment oxygen uptake and annual mean remineralization of both ammonium and phosphate decreased significantly since earlier decades (1970s; Fulweiler and Nixon 2009). The measurements made by Fulweiler and Nixon (2009) were the first indication that climate-induced ecosystem changes could have a major impact on benthic-pelagic coupling in a coastal marine ecosystem. Loss of the winter-spring bloom had a substantial impact on benthic-pelagic coupling dynamics because it provides such a large portion of the total organic matter input to the benthos. In shallow coastal marine ecosystems, roughly 25-50% of organic matter added to the system is consumed by the benthos (Nixon 1981), and much of what is consumed comes from the winter-spring bloom (Graf et al. 1982;

Smetacek 1980). Fast sinking rates of phytodetritus from a winter-spring diatom bloom leave little time for water column degradation (Durbin and Durbin 1981; Smetacek 1980), so the majority of organic material reaches the bottom. In contrast to detritus from summer blooms that is mostly recycled in the water column (Keller et al. 1999; Rudnick and Oviatt 1986), deposition from the winter-spring bloom provides a significant input of organic matter to the benthos (Graf et al. 1982; Smetacek 1980). Although the largest deposition of organic material occurs during a single event (the winter-spring diatom bloom), there is evidence that winter water temperatures in the mid-Bay can cause a seasonal delay in the benthic metabolic response (Rudnick and Oviatt 1986). Because of this, changes in winter-spring depositional events can likely impact the activity of the benthic community throughout the entire year.

During most of the 2000s, the winter-spring (Jan-Mar) standing stock of phytoplankton was minimal compared to the historic average (Fig. 1-2). Since previous benthic flux measurements were made (2005-2006) phytoplankton cell counts have been consistently higher than they were in the previous decade, although there is still much inter-annual variability (Fig. 1-2). The magnitude of benthic ammonium regeneration has significantly increased since the mid-2000s, and both DIP and NH_4^+ fluxes now more closely resemble measurements made during the 1970s (Fig. 1-3d,h; 1-4d,h). The benthic response to ecosystem changes can vary substantially from system to system (e.g. Taylor et al. 2011), but experiments in Narragansett Bay have shown that benthos respond rather quickly (on the order of weeks to months) to major manipulations of nutrient concentrations and organic matter input (Kelly and Nixon 1984; Nixon et al. 2009; Oviatt et al. 1984). We

cannot necessarily say that we have measured a rapid response to changes in the winter-spring phytoplankton bloom phenology, because there was no significant increase in other fluxes, specifically benthic metabolism (measured as SOD). In coastal marine ecosystems, the amount of organic matter consumed by the benthos is linearly related to the amount of total (allochthonous plus autochthonous) organic matter input (Nixon 1981). There is also an established relationship between primary production and benthic metabolism in coastal marine ecosystems (Hargrave 1973). Although surface chlorophyll concentrations are not a direct measure of primary production, they are tightly coupled with rates of ^{14}C uptake (Brush et al. 2002) and there is a strong correlation between primary production and surface chlorophyll concentration in Narragansett Bay (Keller 1988b). Therefore, we can use chlorophyll measurements to provide insight into changes of primary production, and thus benthic-pelagic coupling, in Narragansett Bay over time. We found a significant positive relationship between surface chlorophyll *a* concentrations and fluxes of oxygen and phosphate in the mid-Bay (Fig. 1-7) that is consistent with previous findings in this (Nixon 1981) and other (Hargrave 1973) ecosystems. This relationship was for the entire time series of flux data (1970s, 2000s, and 2010s), though it was driven primarily by the biomass-flux relationship in the 1970s (Fig. 1-7). The significant relationship suggests that benthic fluxes should be responding to the return of the bloom. It's possible that the increases in phytoplankton biomass have not been large enough to elicit a measurable response. Alternatively, perhaps the shift from demersal to pelagic-feeding fish in Narragansett Bay (Collie et al. 2008) has caused such an increase in water column feeding that additional material never reaches the bottom.

Bioturbation and bioirrigation by macrofauna have major impacts on biogeochemistry at the sediment-water interface, and could also amplify the regeneration of ammonium as well as phosphate (Henriksen et al., 1983; Nizzoli et al. 2002). Biogeochemical changes that result from macrofaunal activity include increased depth of the oxic layer, changes in the distribution of porewater constituents, and movement of organic material deeper into the sediments through mixing and defecation (Aller 1982). These changes have been shown to greatly stimulate and/or enhance rates of biogeochemical activity and remineralization (Aller 1982; Dunn et al. 2009; Gilbert et al. 2003; Nizzoli et al. 2002). However, to date, efforts to detect this relationship in Narragansett Bay have failed (e.g. Calabretta 2009). We did not directly quantify the macrofauna present in each core, but visual observations and photographs taken at the beginning of each incubation usually provided sufficient evidence of activity by large macrofauna that may substantially alter sediment biogeochemistry. Perhaps any effect of macrofaunal activity on benthic fluxes was amplified because of the small volume of the sediment cores (i.e. bottle effects).

Site comparison

There are major differences in nutrients, surface chlorophyll, and primary production between the mid-Bay and the Providence River Estuary (Oviatt et al. 2002, Smith 2011). We collected measurements at two different points on the north-south gradient (the Providence River Estuary and the mid-Bay), and expected differences in the water column to be reflected in benthic fluxes. However, we found no such

differences in nutrient fluxes between the two stations. Only sediment oxygen uptake was significantly different between these areas, with a higher average rate in the Providence River Estuary than in the mid-Bay. Earlier studies have conducted similar comparisons between the Providence River Estuary and various down-bay stations, but these were mostly comparisons of stations within the Upper Bay (Fulweiler et al. 2010; Nixon et al. 1990a; Nixon et al. 1990b), or of stations below Conimicut Point (Hale 1974; Nixon et al. 1976). In all past studies, there were inconsistent differences, but a general lack of gradients in benthic fluxes. Perhaps to some extent differences in the water column are not reflected in the benthos because of the short residence time (~3 d; Pilson 1985) of the Providence River Estuary. Phytodetritus that would fuel excess benthic decomposition might get flushed down-bay (south) before large amounts can reach the benthos and be metabolized. Using stable ^{15}N isotope measurements in hard clam (secondary producer) tissue, Oczkowski et al. (2008) found evidence that clams throughout Narragansett Bay are growing on phytoplankton supported by anthropogenic N that is discharged into the Providence River Estuary and Upper Bay. Grazing may also remove a portion of the sinking organic matter before it reaches the bottom. Another possibility is that benthic decomposition rates are higher in PRE as suggested by differences in SOD, but nitrogen removal processes (coupled and direct denitrification) are suppressing apparent differences. Hypoxia that is persistent throughout the summer in Upper Bay bottom waters may be another factor limiting the efficiency of nutrient regeneration.

Shifting baselines

At present, the initial decreases in wastewater nutrient inputs do not appear to have had an effect on benthic fluxes in the Providence River Estuary. Our measurements suggest that benthic remineralization in this area can currently provide up to 28% of the P and 40% of the N required by phytoplankton to maintain the whole-Bay production rate of $290 \text{ g C m}^{-2} \text{ y}^{-1}$ (Smith 2011), although in its current eutrophied state wastewater inputs of N and P probably play a more important role in regulating primary production of the PRE than benthic recycling (Nixon et al. 2008). We anticipate that both the magnitude and the role of benthic remineralization will change in response to the upcoming oligotrophication. Typically, heavy nutrient loading decreases the dependence of primary production on nutrients regenerated from the benthos (e.g. Providence River Estuary, Nixon et al. 2008), even while resulting eutrophication (an increase in the rate of supply of organic matter; Nixon 1995) stimulates an increase in benthic decomposition (Grall and Chauvaud 2002). However, with reduced nutrient inputs from wastewater, primary producers may become more dependent on N and P remineralized from the benthos. Perhaps PRE will shift away from being so heavily influenced by point sources, and will become more dependent on autochthonous OM inputs (tighter benthic-pelagic coupling) as WWTFs complete tertiary treatment upgrades. Studies by others suggest that secondary production will become nutrient limited as wastewater nutrient inputs continue to decline (Oczkowski et al. 2008).

To be able to quantify ecosystem response to the imminent changes in nutrient loading in the Providence River Estuary, we need adequate pre-treatment data for

comparison. It is impossible, however, to establish a “true” baseline because humans have been continuously altering the ecosystem (directly and indirectly) and shifting baselines over time (Duarte et al. 2009). Likewise, it is unlikely that this management action will return the ecosystem to a pristine state, because this idyllic baseline that we strive for does not really exist. Measurements of benthic-pelagic coupling in Narragansett Bay have been collected for the past forty years, and each time could be called a “baseline.” But we argue that continued measurements are worth doing because marine ecosystems are too dynamic to be understood with measurements collected in only one instance. To more thoroughly understand the complexities of ecosystem function and the many impacts of human activities, we need to better understand its variability.

CONCLUSIONS

There have not been many substantial changes in the benthic metabolism and nutrient regeneration in the Providence River Estuary over the past four decades. One change to note is a large increase in rates of sediment oxygen uptake in the Providence River Estuary to a mean higher than measurements in the 1980s and mid-2000s that could possibly be due to increased stratification resulting from climate-induced changes such as decreasing wind speed. The lack of significant changes in primary production or surface chlorophyll *a* concentration over the past few decades (Smith 2011) indicates the increased SOD is not a function of additional autochthonous organic matter inputs. We have established measurements of a “pre-state” condition of the Providence River Estuary prior to any major reductions in wastewater nutrient loading, including information about the variability of the ecosystem over time. Continued monitoring of benthic-pelagic coupling after the completion of implementing tertiary wastewater treatment (anticipated 2014) will be necessary to more definitively predict the long-term responses (and impacts) of ecosystem changes in the Providence River Estuary. We predict a shift away from heavy dependence on point sources of nutrients toward increased reliance on benthic nutrient regeneration.

In mid-Narragansett Bay, we measured substantial increases in ammonium and phosphate regeneration since the benthic-pelagic “decoupling” observed by Fulweiler and Nixon (2009) and Nixon et al. (2009) in the mid-2000s, which may indicate increased macrofaunal activity in this area. We would have expected to see an increase in SOD if the benthos were rapidly responding to the return of the winter-spring diatom bloom. This did not appear to be the case, despite the significant

relationship between phytoplankton biomass and SOD, which confirm the importance of organic matter inputs for benthic fluxes. It is possible that the biomass produced in the winter-spring bloom isn't large enough to elicit a noticeable response in the sediment, or that a shift from demersal to pelagic consumers has caused the majority of additional organic matter to be consumed prior to settling.

Despite strong gradients in some of the drivers of benthic mineralization such as organic matter (phytoplankton biomass) and primary production, there is no such gradient in benthic nutrient fluxes between stations. We speculate that this may be due to the short (~3 d) residence time of water in the Providence River Estuary that moves organic material down-bay before an excess amount can fall to the benthos. Nitrogen removal by coupled and/or direct denitrification may also be suppressing our ability to measure differences in N regeneration.

So far, the initial decreases in wastewater nutrient inputs during the switch to tertiary treatment have not had any measurable effects on benthic fluxes in the Providence River Estuary. As wastewater treatment upgrades are completed, we anticipate that primary producers will shift away from being so heavily influenced by point sources, and will become more dependent on autochthonous OM inputs (tighter benthic-pelagic coupling). Measurements of benthic-pelagic coupling in Narragansett Bay have been collected for the past forty years, and continued measurements are necessary to better understand the complexities of ecosystem function and the many unpredictable impacts of human activities and climate change.

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CHAPTER 2

PREFACE

A Comparison of Surface Chlorophyll, Primary Production, and Satellite Imagery in Two Adjacent Hydrographically Different Sounds off Southern New England, USA

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**A COMPARISON OF SURFACE CHLOROPHYLL, PRIMARY
PRODUCTION, AND SATELLITE IMAGERY IN TWO ADJACENT
HYDROGRAPHICALLY DIFFERENT SOUNDS OFF SOUTHERN NEW
ENGLAND, USA**

ABSTRACT

Block Island Sound (BIS) and Rhode Island Sound (RIS) are adjacent, phytoplankton-based ecosystems on the inner continental shelf off southern New England, USA with contrasting hydrographic regimes. BIS is more well mixed as a result of year-round energetic tidal mixing, while RIS typically becomes stratified during the summer. We compared annual cycles of surface chlorophyll *a* and ^{14}C -measured primary production between these two ecosystems using samples collected over 22 months (chlorophyll) and approximately monthly for 12 months (production) during December 2008 to December 2010. Observed chlorophyll biomass was also used to validate SeaWiFs satellite imagery for the study area to enable comparison between sounds over longer time periods. Additionally, we made direct comparisons of (1) sub-surface versus depth-integrated water sample collection techniques for ^{14}C incubations, and (2) Webb/Platt and BZI empirical models, two methods for scaling primary productivity to daily values; the former based on traditional use of photosynthesis-irradiance curves and the latter based on an empirical light x biomass function. Chlorophyll ranged from 0.27 – 8.58 mg m^{-3} in BIS and 0.17 – 9.76 mg m^{-3} in RIS. The two years of *in situ* measurements revealed no significant differences between BIS and RIS in chlorophyll; however, long-term satellite data clearly showed

higher overall concentrations in BIS than RIS. BIS annual primary production (230-329 g C m⁻² y⁻¹) was also higher than RIS (162-256 g C m⁻² y⁻¹ in RIS; p<0.0001 for all comparisons of daily rates). Overall, our results support the hypothesis that rates of primary production are higher in more well-mixed BIS than in seasonal stratified RIS. Water column stratification in RIS likely creates nutrient limitation that causes the difference in primary production between sounds. The two sampling techniques for ¹⁴C incubations resulted in large differences between computed rates. Values computed with a given method were comparable between sounds, however the use of the depth-integrated approach generated consistently lower production rates than those calculated from sub-surface samples. We cannot conclusively say which method is more accurate, but it is likely that actual production rates are between values calculated from the two methods. Webb/Platt and BZI methods for integrating primary production agreed remarkably well on daily, seasonal, and annual scales for both sounds.

1 INTRODUCTION

The continental shelf occupies less than 10% of the area of the open ocean, yet a considerable amount of primary production occurs there relative to its size (Smith and Hollibaugh, 1993). Roughly 10-33% of oceanic primary production (Knauer, 1993; Longhurst, 1995; Muller-Karger et al., 2005; Smith and Hollibaugh, 1993; Walsh, 1988) and 5-10% of global primary production (Schlesinger, 1997; Walsh, 1988) occurs on the continental margin. These areas are also “hot spots” for biogeochemical processes and play important roles in global nutrient and carbon cycles (Christensen et al., 1987; Muller-Karger et al., 2005; Seitzinger et al., 2002; Smith and Hollibaugh, 1993). The relatively high rates of primary production, physical energy inputs (e.g. tidal and wind energy), and input of organic material from land that are typical of these boundary ecosystems often translate into areas with thriving fisheries of local economic importance (Nixon, 1988; Nixon and Buckley, 2002; Smith and Hollibaugh, 1993). This is certainly the case for the continental shelf of the northwest Atlantic Ocean. The area from the Gulf of Maine to Cape Hatteras, N.C., is one of the most productive shelf ecosystems in the world, where the fishing industry has provided income to the nearby coastal states since the late 17th century, currently producing profits of at least \$1 billion per year (Costanza et al., 1997; Hall et al., 2008; Sherman et al., 1996).

In Southern New England we know surprisingly little about the inner shelf compared to the adjacent shallow, estuarine ecosystems on one hand and the more exposed and deeper mid- and outer shelf on the other. Narragansett Bay, a relatively well-mixed estuary connected to the inner shelf at its southern end, has been well

studied for the past 60 years (Nixon et al., 2009). For example, long-term phytoplankton monitoring studies began in the mid-1950s by D. Pratt, and are continued presently by the URI Graduate School of Oceanography (www.gso.uri.edu/phytoplankton), and characterization of bay-wide primary production was done by Oviatt et al. (2002) and more recently by Smith (2011). Additionally, much work has been done in characterizing the physics, biology, chemistry, and geology in Narragansett Bay, and how they have changed over time (e.g. Desbonnet and Costa-Pierce, 2008; Nixon et al., 2009). Far more is also known about other nearby continental shelf ecosystems, including Gulf of Maine and Georges Bank to the north and the Mid-Atlantic Bight to the south of the southern New England continental shelf ecosystem (e.g. Bigelow, 1924; Bigelow et al., 1940; Cohen, 1976; Colton et al., 1968; Riley, 1941; Sherman et al., 1996; Teal and Kanwisher, 1961; Yentsch et al., 1994).

Block Island Sound (BIS) and Rhode Island Sound (RIS) are adjacent inner continental shelf ecosystems located off the coast of Rhode Island. They are both open-water, phytoplankton-based systems that are dynamically connected to Narragansett Bay, Buzzards Bay, Long Island Sound, Vineyard Sound, and the Atlantic Ocean (Fig. 2-1). RIS transitions into BIS in the area west of Block Island, R.I. Despite their similar mean depths (~30 m), BIS and RIS have different hydrographic regimes that make for an interesting comparison. BIS exhibits cooler surface waters during summer and a relatively more well-mixed water column as a result of strong tidal mixing, while RIS has warmer surface waters and is vertically stratified during the summer (Codiga and Ullman, 2010; Shonting and Cook, 1970).

Fig. 2-1. (a) MODIS satellite mean summer (July-September) sea surface temperature image of Block Island Sound (BIS) and Rhode Island Sound (RIS) for 2002-2007. Note the warmer surface water in seasonally stratified RIS compared with the cooler well-mixed BIS. (b) RIS and BIS boundaries used for this study, shown with surface chlorophyll *a* and C-14 primary production sampling stations.

From the long history of commercial fishing success on the northwest Atlantic shelf as a whole (Sherman et al., 1996), we can assume that Block Island and Rhode Island Sounds are productive, economically important areas. However, very few measurements of phytoplankton biomass have been made in these systems since Riley's study in the late 1940s (Riley, 1952); and until recently, few studies of the two sounds have been published at all. Riley (1952) made the first measurements of surface chlorophyll *a*, cell counts, and species composition in northwestern BIS. Perhaps the only other thorough quantification of phytoplankton in BIS was done by Staker and Bruno (1978a, b). They quantified an annual phytoplankton cycle with chlorophyll *a* samples, cell counts, species identification, and a species diversity index along with measurements of physical and chemical parameters in waters off eastern Long Island (along the outer edge of northwestern BIS, west of Montauk, N.Y.). From 1977 to 1987, some stations on the outskirts of our study area and throughout the Northeast U.S. Atlantic coast were sampled approximately every few months for chlorophyll *a* and primary production (among many other parameters) as part of the Marine Monitoring, Assessment, and Prediction Program (MARMAP; O'Reilly et al., 1987; O'Reilly and Zetlin, 1998; Pearce, 1981; Sherman et al., 1996).

Recently, efforts by the Rhode Island Coastal Resources Management Council (CRMC) to develop an Ocean Special Area Management Plan (OSAMP) for the Rhode Island inner continental shelf and discussions of a wind farm initiative have stimulated interest in studying this area and garnered funding (<http://seagrant.gso.uri.edu/oceansamp/index.html>). This study is a result of that interest and aims to assess and compare annual cycles of surface chlorophyll *a* and

primary production in BIS and RIS using a combination of *in situ* measurements, primary production models, and ocean color satellite data. We hypothesized that the seasonal stratification in RIS would result in increased summer nutrient limitation and lower primary production compared to the more well-mixed BIS. Additionally, we took advantage of our robust data set and conducted comparisons of satellite data, empirical models, and sampling techniques. We used our *in situ* chlorophyll *a* measurements to validate SeaWiFs satellite chlorophyll *a* data of our study areas to extend analysis over a larger extent of space and time, as has been done in nearby inner shelf systems such as Massachusetts Bay (Hyde et al., 2007) and the southern Mid-Atlantic Bight (Pan et al., 2008). We compared different methods for sampling the water column (surface versus entire euphotic zone) for ^{14}C primary production measurements in our study areas, and compared two different widely used methods of modeling an annual cycle of primary productivity (Cole and Cloern, 1987; Platt et al., 1980; Webb et al., 1974). Finally, we discussed these comparisons in the context of a thorough characterization of seasonal physical changes in BIS and RIS using the results of a hydrographic survey conducted at the beginning of each season throughout our sampling year.

2 MATERIALS AND METHODS

2.1 Surface chlorophyll a

For comparisons between BIS and RIS, study area boundaries were assigned following the approximate mean annual surface temperature contours in an attempt to capture differences in the hydrographic regimes between the two sounds (Fig. 2-1a). Surface water samples were collected throughout the study areas from December 2008 through September 2010 during cruises of opportunity by our laboratory personnel, local fishermen, and other assisting scientists. Bucket samples were collected, transferred into opaque polypropylene bottles, and kept in a cooler on ice during transport. The time between water collection and laboratory analysis varied due to circumstance, but typically was about 5 hours. Because samples were collected during cruises of opportunity, they were not collected at regular time intervals or at fixed locations (Fig. 2-1b). The time of collection and GPS coordinates of the station were recorded for each sample.

At the laboratory, three 100 mL aliquots of sample water were filtered onto 0.7 μm Whatman GF/F filters (2.5 cm dia; Aminot and Rey, 2000). Chlorophyll was immediately extracted by placing each filter in a polypropylene centrifuge tube with 10 ml of buffered 90% acetone for 24 hours in a freezer kept at -20°C , a modification of the JGOFS protocol (Graff and Rynearson, 2011; Mantoura et al., 1996). After extraction, samples were mixed for 30 seconds on a Vortex Genie and then centrifuged at 1000 G for 5 minutes (Arar and Collins, 1997). Overlying acetone containing extracts was decanted into clean glass test tubes and read on a Turner 10AU fluorometer. Chlorophyll and phaeopigment concentrations were calculated

following Arar and Collins (1997). Mean chlorophyll *a* and phaeopigment concentrations were calculated from the triplicate samples measured at each station.

2.2 Validation of SeaWiFs chlorophyll *a*

Individual daily merged local area coverage (MLAC) SeaWiFS images were mapped at 1km pixel resolution for the southern New England coast using a cylindrical map projection. The standard SeaWiFS chlorophyll *a* (CHL_OC4) and remote sensing reflectance (R_{rs}) products were derived using SeaDAS 6.2 (R2010, <http://oceancolor.gsfc.nasa.gov/>). A second chlorophyll *a* (CHL_PAN) product was calculated using a regional algorithm developed by Pan et al. (2008; 2010). Around the coordinates of each *in situ* sampling station, a 3x3 pixel array was extracted from the satellite images captured within 6 hours of when each water sample was collected. Standard validation procedures recommend a match-up window of ± 3 hours (Bailey and Werdell, 2006); however, due to the opportunistic nature of the *in situ* sampling, we expanded the time window to ± 6 hours to increase the number of potential match-ups. The geometric means of satellite-derived chlorophyll arrays with five or more valid (cloud-free) pixels were calculated and compared to the *in situ* chlorophyll *a* samples. The geometric mean was used because chlorophyll *a* concentrations are commonly log-normally distributed and the geometric mean reduces the influence of a small number of high or low values (outliers) on the mean compared to the arithmetic mean (Bricaud et al., 2002; Campbell, 1995; Yoder and Kennelly, 2003; Yoder et al., 2002).

A twelve-year time series (1998-2010) of SeaWiFS surface chlorophyll was constructed for BIS, RIS, and the area farther offshore using the Pan et al. (2008; 2010) regional chlorophyll algorithm. The algorithm used here was made for the Mid-Atlantic Bight, an inner continental shelf ecosystem connected to our study area at its southern reaches.

2.3 ^{14}C primary production

Two stations were sampled for carbon-14 (^{14}C) primary production measurements, one in BIS and one in RIS (Fig. 2-1b). Stations were sampled 14 times (approximately monthly) throughout the year 2010. During each sampling day, water samples used to measure euphotic zone production were collected using two different techniques: a Niskin bottle 1 m below the surface (sub-surface samples), and a 1.9 cm diameter hose with a valve at one end (depth-integrated samples; Andreasson et al., 2009; Lindahl, 1986). One exception was on 10 March 2010, when only surface water was sampled. Depth-integrated samples were collected down to 17 m (approximate average euphotic depth) by lowering the hose down into the water column, closing the valve to create suction, and extracting a mixed sample of the entire euphotic zone. From here on, ^{14}C samples will be referred to as sub-surface or depth-integrated, but the final production values for both sampling methods reflect total euphotic zone production. In all cases, sample water was filtered through a 300 μm mesh screen (to remove mesozooplankton) into opaque 1-L polyethylene bottles. The samples were then placed in a cooler filled with seawater to maintain ambient temperature during transportation to the laboratory. While on station, surface and depth-integrated

chlorophyll *a* samples were collected and analyzed (see methods above), and a light profile was taken using a SeaBird CTD equipped with a Biospherical Scalar PAR sensor.

Primary production was measured using a small volume/short incubation time method (Lewis and Smith, 1983; Smith, 2011) and standard ^{14}C procedures (Strickland and Parsons, 1972). For each water sample collected, a series of 18 incubation vials were prepared (16 light and 2 dark). Each 20 mL borosilicate vial was spiked with 100 μL of 10 $\mu\text{Ci/mL}$ ^{14}C stock solution (1 μCi for 5 mL of water), and then 5 mL of sample water was added. Vials were placed into specified locations in an incubation tray and were exposed to different light intensities ranging from 0 to 2,000 $\mu\text{E m}^{-2} \text{ s}^{-1}$. This incubation lasted for 2 hours, and was conducted within 2°C of *in situ* temperature. Upon removal from the incubator, 200 μL of 0.10N HCl was added to each vial, mixed, and gently agitated uncapped in the dark for ~ 40 h to allow all of the unincorporated ^{14}C to be converted to CO_2 gas and removed from the sample. Then, 17 mL of Universol Scintillation Cocktail (MP Biomedicals) was added to each vial. Measurements of ^{14}C converted into organic carbon were made on a Packard TriCarb Liquid Scintillation Counter (Model 2900), and dissolved inorganic carbon was determined by acidifying samples and measuring carbon dioxide released using an O.I. Analytical 1010 total carbon analyzer. Volume-specific primary production was calculated using equations from Strickland and Parsons (1972), and daily rates were obtained by integrating through time and throughout the euphotic zone in 1 m depth increments.

2.4 Models of primary production

Two different numerical models were used to predict daily values of primary production for an annual cycle using our ^{14}C measurements, additional data collected throughout the duration of the project, and supplementary data available from other sources (see Table 2-1 for description of model parameters). Both models end on 30 December 2010, which was the last day of the year that a ^{14}C production measurement was taken.

2.4.1 Webb/Platt model

The Webb/Platt model calculates daily areal photic zone productivity (P_d , $\text{g C m}^{-2} \text{ d}^{-1}$) by fitting hourly photosynthesis-irradiance (P-I) curves using the Webb et al. (1974) model in the absence of photoinhibition, or the Platt et al. (1980) model in the event of photoinhibition. P-I curves were integrated through the water column to the euphotic depth (Z_p) in 1 m increments, and through time to obtain a daily production rate. Hourly irradiance was based on measurements of total solar radiation made every 15 min at a nearby weather station in Kingston, R.I. (National Climatic Data Center, <http://www.ncdc.noaa.gov/crn/report>) and converted to photosynthetically active radiation (PAR, I_o) assuming $\text{PAR} = 0.4363 * \text{Irradiance}$ (Calabretta, 2009). Light data from Kingston, R.I. were deemed appropriate for use after a comparison with light data that we collected in a similar manner from the Block Island airport during August and November 2009 that showed no significant differences (see Appendix B). Daily production on days between ^{14}C incubations was computed from interpolated values of measured production. ^{14}C productivity rates were interpolated to daily values

Table 2-1. Definitions of variables and their units.

Model Parameter	Model	Description	Units
I_0	Webb/Platt, BZI	Ambient photosynthetically active radiation (PAR)	$\mu\text{E m}^{-2} \text{h}^{-1}$ (W/P) $\text{E m}^{-2} \text{d}^{-1}$ (BZI)
Z_p	BZI	Depth of the photic zone (1% light level)	m
k	Webb/Platt, BZI	Light attenuation coefficient	m^{-1}
α	Webb/Platt	Initial slope of the production- irradiance curve	$\text{mg C } \mu\text{E m}^{-1}$
β	Webb/Platt	Degree of photoinhibition	$\text{mg C } \mu\text{E m}^{-1}$
$P_{\max}$	Webb/Platt	Light-saturated rate of production (Webb model)	$\text{mg C m}^{-3} \text{h}^{-1}$
P_s	Webb/Platt	Theoretical value of $P_{\max}$ in the absence of photoinhibition (Platt model)	$\text{mg C m}^{-3} \text{h}^{-1}$
B	BZI	Phytoplankton biomass measured as chlorophyll <i>a</i>	mg m^{-3}
P_d	Webb/Platt, BZI	Daily photic zone primary production rate	$\text{mg C m}^{-2} \text{d}^{-1}$

for the entire year (2010) from the 14 *in situ* measurements by calculating a weighted average production rate for each day that took into account both the measurement before and after a given day, with greater influence from the measurement that was closest in time.

2.4.2 BZI model

The BZI model is an empirical regression for computing daily production rates (P_d) based on the relationship between measured ^{14}C production and the parameter $BZ_p I_o$, where B is phytoplankton biomass measured as chlorophyll *a* (mg m^{-3}), Z_p is the depth of the photic zone (m), defined as the depth of the 1% light level, and I_o is ambient daily PAR (Cole and Cloern, 1987). A separate BZI model was generated for both sampling methods at each station (four models) using our measured ^{14}C production rates, surface or depth-integrated chlorophyll *a* concentrations, and light attenuation measurements, and using daily integrated irradiance measurements from the National Climatic Data Center as described above.

Once the BZI models were constructed, P_d was calculated for an annual cycle (2010) in BIS and RIS using daily interpolated values of model parameters (B , k) and daily irradiance measurements. Daily surface chlorophyll *a* concentrations (B) for BIS and RIS were linearly interpolated between sampling dates ($n=31$ and $n=80$ for BIS and RIS, respectively; Fig. 2-2a,b). Chlorophyll data were used from both the cruises of opportunity and from ^{14}C sampling days. On the majority of sampling days, more than one chlorophyll sample was collected in each study area (see Fig. 2-1 for spread of sampling stations), and in these cases, daily arithmetic mean values were

Fig. 2-2. Daily variable input values for the BZI models (2010 only) shown with *in situ* measurements. (a,b) Surface chlorophyll *a* was linearly interpolated (solid line) for both sounds. Points are the mean of triplicate samples collected at each station throughout the 22 month sampling period. Extinction coefficients (*k*, used to calculate the 1% light level) were extrapolated using the best fit. For (c) BIS, a linear fit was used, and for (d) RIS, a second-order polynomial fit was used.

computed across all stations within BIS and RIS. For k values (calculated from CTD casts), we used a best fit through data over the annual cycle ($n=65$ and $n=67$ for BIS and RIS, respectively) to extrapolate between measurements. For BIS, a linear fit was used ($R^2=0.27$) and although the slope was significantly different from zero ($p<.0001$), the slope was so small that the overall average k value was used for all days in the model to prevent a continuous infinite increase (Fig. 2-2c). For RIS, a second order polynomial fit was used ($R^2=0.45$) to extrapolate daily k values (Fig. 2-2d). Euphotic depths (Z_p) were calculated from k values using Beer's law (Valiela, 1995).

2.5 Statistical analysis

Geometric means of surface chlorophyll a values were compared for the entire sampling period and on an annual basis using Student's t -tests. ^{14}C -measured primary production rates based on sub-surface samples were normalized to biomass (surface chlorophyll a values), P^B_d in $\text{mg C mg chl } a^{-1} \text{ d}^{-1}$, and qualitatively compared between BIS and RIS. Correlation analyses were used to directly compare the Webb/Platt and BZI model outputs to each other, and to test the overall significance of each BZI model (Ricker, 1973). Linear regression analysis was used to determine how much of the variation in primary production could be attributed to chlorophyll a concentrations. Comparisons of modeled daily average primary production between BIS and RIS, and between the different sampling methods (sub-surface and depth-integrated) were done using factorial ANOVA. All analyses were performed in SAS (version 9.3).

2.6 Hydrographic regimes

A hydrographic grid survey was conducted throughout BIS and RIS across an annual cycle from September 2009 to December 2010. Four vessel-based surveys of 48 stations were conducted at the beginning of each season across a 2-3 day period. Vertical profiles of electrical conductivity, temperature, pressure, dissolved oxygen concentration, chlorophyll fluorescence, turbidity, and photosynthetically active radiation were obtained with a hand-lowered package at each stations. Profiles were taken using a SeaBird Electronics SBS 19plus CTD, a Turner Designes SCUFA 2000-007 Fluorometer, and a BioSpherical QSP2300 PAR sensor. Data were processed using SBE Data Processing software, and salinity was calculated from the measured conductivity, temperature, and pressure data (for detailed results from the grid survey, see Codiga and Ullman, 2010; Ullman and Codiga, 2010). Measurements from this survey, and from CTD casts made during sample collection (see above), were used to construct a temperature and salinity record for the two primary production sampling stations. Days in between CTD casts were interpolated using the Natural Neighbor method with Delaunay triangulation.

3 RESULTS

3.1 Hydrography

The CTD casts made at both of our ^{14}C sampling stations throughout the year were consistent with previous studies of temperature and salinity regimes (Fig. 2-3; e.g. Shonting and Cook, 1970; Snooks et al., 1977). In BIS, a weak thermocline forms during the late spring and lasts until the fall (Fig. 2-3a), and there is a weak halocline throughout the year along with fresher surface water in winter and spring (Fig. 2-3b). In RIS, thermal stratification begins in the spring and the system gets more stratified throughout the summer-fall (Fig. 2-3c). There is also very weak salinity stratification at most times throughout the year, and pools of fresh surface water in the winter, spring, and fall (Fig. 2-3d).

3.2. Chlorophyll *a*

During the 22-month sampling period, surface chlorophyll *a* concentrations ranged from $0.27 - 8.58 \text{ mg m}^{-3}$ in BIS and $0.17 - 9.76 \text{ mg m}^{-3}$ in RIS. Average measured euphotic depth (Z_p) was 19.3 m in BIS and 23 m in RIS. Surface chlorophyll *a* concentrations in BIS were at their highest during the fall months, particularly in October (Fig. 2-2a). Concentrations rapidly increased from mid-level chlorophyll values in summer to a fall maximum, and then began to decrease before reaching a second, but smaller, peak in the winter. During the spring (March-May), mean chlorophyll levels were at their lowest, and remained at concentrations of $\sim 1 \text{ mg}$

Fig. 2-3. Annual temperature and salinity at the ^{14}C sampling stations. Black lines indicate days on which CTD casts were taken. (a) Temperature and (b) salinity for BIS, (c) temperature and (d) salinity for RIS.

m^{-3} for the whole season. Concentrations began to increase throughout the summer (June-August) until reaching the fall maximum. The phenology of phytoplankton biomass in RIS followed that of BIS, with a few small differences (Fig. 2-2b). Instead of an increase in chlorophyll concentrations throughout the summer as in BIS, the spring minimum extended throughout the summer in RIS, and mean concentrations remained at $\sim 1 \text{ mg m}^{-3}$ from March – September. Levels then rose sharply to the fall maximum between September and November.

As is typical of chlorophyll concentrations, the data were log-normally distributed, so the geometric means were compared (Campbell, 1995). We excluded one very high outlier from the analysis, which was likely due to analytical error. An unpooled Student's t-test indicated that there was no significant difference in geometric mean surface chlorophyll *a* concentrations between BIS (1.86 mg m^{-3}) and RIS (1.69 mg m^{-3}) for the entire 22 month sampling period, $t=1.53$, $p=0.13$. When only one complete annual cycle was considered (measurements made during 2009 - the only full annual cycle of chlorophyll measurements), the geometric mean surface chlorophyll concentration was significantly higher in RIS (2.1 mg m^{-3} , $n=239$) than in BIS (1.78 mg m^{-3} , $n=200$), $t=2.18$, $p=0.03$; however, values were only different by a small amount (0.32 mg m^{-3}).

After filtering the satellite chlorophyll observations to meet the conditions described above, a sample size of $n=93$ remained for an *in situ* versus satellite match-up. The ship-based measurements and satellite observations derived using the Pan et al. (2008; 2010) regional algorithm had a better fit ($R^2=0.41$, $\text{RMSE}=0.28$) and

exhibited a slope reflective of a nearly 1:1 relationship (Fig. 2-4), compared to the OC4

Fig. 2-4. Reduced major axis regression of *in situ* versus SeaWiFs satellite surface chlorophyll *a* values, with different symbols for BIS, RIS, and samples taken outside of the study areas (“offshore”).

algorithm ($R^2=0.34$, $RMSE=0.3$, $slope=0.66$; data not shown). However, the satellite algorithm tended to overestimate *in situ* chlorophyll at low concentrations, and predict higher chlorophyll concentrations less definitively (Fig. 2-4).

3.2 Primary production

There was a weak but significant correlation between measured primary production and chlorophyll *a* for both sub-surface ($r=0.38$, $p=0.04$) and depth-integrated ($r=0.52$, $p=0.005$) samples when data from both BIS and RIS were combined. When each sound and sampling method was considered individually, however, only depth-integrated production samples from BIS were significantly correlated with chlorophyll *a* ($r=0.67$, $p=0.01$). In RIS, 6% of the variance in ^{14}C -measured sub-surface production and 14% of the variance in measured depth-integrated production was explained by chlorophyll *a*, although neither regression was significant. In BIS, chlorophyll *a* explained 21% of the variance in sub-surface production (not significant) and 45% of the variance in depth-integrated production (significant, $p=0.01$). There was a seasonal pattern in P^B_d in both BIS and RIS that peaked during the summer months and reached its minimum during the winter months (Fig. 2-5). P^B_d ranged from 0.66-28.52 mg C mg chl $a^{-1} d^{-1}$ in BIS, and from 0.86-33.60 mg C mg chl $a^{-1} d^{-1}$ in RIS.

The least squares linear regressions between measured ^{14}C daily primary production and the parameter $BZ_p I_0$ were significant ($p<0.0001$) for the sub-surface models in both BIS and RIS (Fig. 2-6a,b), and for the depth-integrated model in BIS ($p=0.004$; Fig. 2-6c). The regression for the RIS depth-integrated model (Fig. 2-6d) was

Fig. 2-5. Measured (¹⁴C) primary production based on the sub-surface sampling technique normalized to biomass (P^B_d in $\text{mg C mg chl a}^{-1} \text{d}^{-1}$) for BIS (closed circles) and RIS (open circles) throughout the 2010 sampling year.

Fig. 2-6. Empirical regressions of measured daily primary productivity versus the composite parameter $BZ_p I_0$ for (a) BIS sub-surface, (b) RIS sub-surface, (c) BIS depth-integrated, and (d) RIS depth-integrated sampling techniques. Note scale differences on axes.

borderline significant ($p=0.05$). The slopes of the BZI models from both sounds were relatively smaller for the models of depth-integrated samples than for the models of sub-surface samples. For both sub-surface BZI models, the y-intercepts were negative, whereas for both depth-integrated models, the y-intercepts were positive. These deviations of the y-intercept from the origin occur as an artifact of fitting the regression line to the data, and the regression equations should be forced through the origin (Brush et al., 2002). To avoid altering the slope of the regression line, and because none of the y-intercepts were significantly different from zero, we chose not to force the regression lines through the origin. We instead assigned all negative production rates a value of zero when integrating daily rates to seasonal and annual values (Table 2-2).

There were a few instances when the sub-surface BZI model overestimated ^{14}C production, most noticeably during the summer months in BIS, and during the winter and late spring in RIS. The BZI sub-surface model also underestimated production in RIS on one occasion (August 2010, Fig. 2-7b). Overall, the Webb/Platt and BZI model outputs matched very closely for both the BIS and RIS sub-surface sampling technique (Table 2-2; Fig. 2-7a,b), and daily rates calculated for all sampling techniques in both study areas were highly correlated ($r \geq 0.69$, $p < 0.0001$). Agreement between the BZI and Webb/Platt models, while highly correlated, was not as good for the depth-integrated sampling technique as it was for the sub-surface technique in either sound (Fig. 2-7c,d). In BIS, the most noticeable discrepancies were the overestimation of productivity by the BZI model during the summer months, and the underestimation by the same model during the fall (Fig. 2-7c). Likewise, in RIS, the

Table 2-2. Seasonal and annual primary production model outputs for Block Island Sound (BIS) and Rhode Island Sound (RIS). Values given are for both the Webb/Platt (W/P) and BZI models based on sub-surface and depth-integrated sampling techniques. Winter is Dec-Feb, Spring is Mar-May, Summer is Jun-Aug, and Fall is Sept-Nov.

	BIS production, g C m ⁻²				RIS production, g C m ⁻²			
	Sub-surface		Depth-integrated		Sub-Surface		Depth-integrated	
	W/P	BZI	W/P	BZI	W/P	BZI	W/P	BZI
Winter ^a	43	49	54	41	47	45	40	35
Spring ^a	43	48	28	41	34	39	27	33
Summer ^a	134	130	70	84	86	73	36	46
Fall ^a	110	92	93	64	89	82	86	49
Annual ^b	329	318	246	230	256	239	188	162

^aPrimary production given in g C m⁻² season⁻¹

^bPrimary production given in g C m⁻² y⁻¹

Fig. 2-7. Comparison of daily C-14 production measurements, Webb/Platt model outputs, and BZI model outputs for (a) BIS sub-surface, (b) RIS sub-surface, (c) BIS depth-integrated, and (d) RIS depth-integrated sampling techniques.

largest discrepancies between the BZI and Webb/Platt models occurred during the times of minimum and maximum measured productivity. Additionally, the BZI model output in RIS was relatively uniform throughout the year compared to that from the Webb/Platt model and the ^{14}C measurements. That is, the BZI peaks and troughs never reached the extremes of the other model, nor of the ^{14}C measurements (Fig. 2-7d). There were also some instances in all four cases where the models disagreed, but it could not be determined which model was more accurate because there were no accompanying ^{14}C measurements during those time periods (Fig. 2-7).

Based on the sub-surface sampling technique, primary production reached its maximum in August through mid-September in BIS (Fig. 2-7a; Table 2-2). This was followed by a second, but slightly smaller peak in mid-October, after which production levels decreased to their lowest values in the winter. In the winter, a peak about half the size of the maximum peak occurred, followed by a brief minimum in March before a slow rise to two small peaks during the summer (Fig. 2-7a). Primary production based on the sub-surface sampling technique in RIS followed the same pattern as in BIS with just a few exceptions (Fig. 2-7b). The maximum peak of the year, though it occurred at the same time as in BIS (mid-October), was smaller in magnitude. Probably the most obvious difference between BIS and RIS, though, was the much lower summer production in RIS, particularly during June.

Production computed using the depth-integrated sampling method followed the same general trends in both BIS and RIS as their respective sub-surface results, except the overall magnitude was much smaller (on the order of 1.5 times smaller; Fig. 2-7c,d). The only major difference in patterns between sub-surface and depth-integrated

approaches in either sound was the late summer-early fall peak in production, which was absent in the depth-integrated model output, but present in both the sub-surface model output and in the actual measurements (Fig. 2-7b,d).

We evaluated the effects of study area and sampling method on average daily primary production for both BZI and Webb/Platt model outputs using a separate two-way ANOVA for each of the two models. In both cases, data were root transformed to achieve a normal distribution, and a Bonferroni adjusted alpha value of 0.008 was used. For both BZI model outputs and Webb/Platt model outputs, there were no significant interactions between study area and sampling method. Post-hoc multiple comparison test showed that average daily production was significantly higher in BIS (BZI mean=757 mg C m⁻² d⁻¹; Webb/Platt mean=790 mg C m⁻² d⁻¹) than RIS (BZI mean=551 mg C m⁻² d⁻¹; Webb/Platt mean=611 mg C m⁻² d⁻¹) for both sampling methods (BZI model: F(1,1452)=53.24, $p<0.0001$; Webb/Platt model: F(1,1452)=33.67, $p<0.0001$), and daily average production calculated from sub-surface samples (BZI mean=768 mg C m⁻² d⁻¹; Webb/Platt mean=804 mg C m⁻² d⁻¹) was significantly higher than depth-integrated samples (BZI mean=757 mg C m⁻² d⁻¹; Webb/Platt mean=551 mg C m⁻² d⁻¹; BZI model: F(1,1452)=16.02, $p<0.0001$; Webb/Platt model: F(1,1452)=49.88, $p<0.0001$). We also tested the effects of study area and model on average daily primary production for both sampling methods with a two-way ANOVA. Again data were root transformed to achieve a normal distribution, and a Bonferroni adjusted alpha of 0.008 was used. For both sub-surface and depth-integrated sampling methods, there were no significant interactions between study area and model. Post-hoc multiple comparison tests again showed that average

daily production was significantly higher in BIS than in RIS for both sampling methods (sub-surface: mean=892 mg C m⁻² d⁻¹; F(1,1452)=32.95, $p<0.0001$; depth-integrated: mean=681 mg C m⁻² d⁻¹; F(1,1452)=70.16, $p<0.0001$). Additionally, for sub-surface samples, daily average production was significantly higher in Webb/Platt model (804 mg C m⁻² d⁻¹) than in the BZI model (BZI mean=768 mg C m⁻² d⁻¹; F(1,1452)=9.94, $p=0.002$). Computed annual primary production in BIS was 230-329 g C m⁻² y⁻¹, and 161.9-256.1 g C m⁻² y⁻¹ in RIS (range includes data from all models and sampling techniques; Table 2-2).

4 DISCUSSION

4.1 A comparison of BIS and RIS

4.1.1 Hydrographic regimes

Since the physics of the ocean, in large part, drives the patterns of plankton phenology (Banse, 1994), it is worth briefly describing our current understanding of the nature of the differences in hydrography between BIS and RIS (for a more detailed literature review, see Codiga and Ullman, 2010). Water in the BIS-RIS area originates primarily from the Scotian shelf (Chapman and Beardsley, 1989) and typically passes through the Gulf of Maine, around or across Georges Bank, and across Nantucket Shoals before reaching RIS (Codiga and Ullman, 2010). Although BIS and RIS exchange water with all of the adjacent ecosystems, the estimated long-term mean volume transport exchange with Long Island Sound is an order of magnitude greater than with any other body of water ($23 \pm 5 \times 10^3 \text{ m}^3 \text{ s}^{-1}$; Codiga and Aurin, 2007; Codiga and Ullman, 2010). This interaction has probably the most important influence on the BIS-RIS region (Codiga and Ullman, 2010), and contributes to differences in temperature, salinity, and stratification between the sounds.

Throughout the year, the water column in BIS is much less stratified than the water column in RIS because of differences in tidal currents and, less importantly, freshwater influence. Both sounds have a seasonal temperature cycle that ranges from approximately 3-21°C, but surface waters during spring-summer tend to be cooler in BIS than in RIS because of strong vertical mixing due to tidal currents in Long Island Sound (LIS), which distribute the surface heat flux through the water column in the

LIS outflow region (Fig. 2-1; Codiga and Ullman, 2010). Tidal currents are stronger in BIS than in RIS because LIS has a nearly resonant standing wave response at the M2 frequency, with eastern LIS nearly an anti-node where tidal current amplitudes peak (Codiga and Ullman, 2010). This influence extends to BIS more strongly than RIS because of BIS' proximity to LIS. Seasonal formation of a mid-depth thermocline typically begins in April and breaks down around September in northeastern BIS (Snooks et al., 1977)—farther away from the influence of the LIS outflow—and a similar pattern occurs in western-central and eastern-central RIS that is replaced by nearly homogeneous temperatures in fall and winter due to wind mixing (Shonting and Cook, 1970). During the summer, the stratification peak that occurs in RIS does not occur in BIS because of the stronger tidal currents mixing, which results in BIS being a less-stratified system (Fig. 2-3).

There is a weak annual cycle of salinity in both sounds, and variations are due to the influence of interactions with surrounding estuaries (Snooks et al., 1977). Freshwater influence occurs in BIS to a greater extent than in RIS due to its proximity to LIS (Fig. 2-1), where a strong estuarine exchange flow brings Connecticut River-freshened water out through BIS (Codiga and Ullman, 2010; Hardy, 1972; Hollman, 1974; Ichiye, 1967; Williams, 1969). This exchange influences RIS much less because freshwater flows south out of BIS through the gap between Montauk Point, N.Y., and Block Island (Fig. 2-1a; Ullman and Codiga, 2010).

4.1.2 Surface chlorophyll concentrations on annual and decadal time scales

Peak chlorophyll *a* concentrations in both BIS and RIS occurred as a bimodal pattern (Fig. 2a,b). In an analysis of published reports of annual chlorophyll *a* cycles in northern temperate open coastal ecosystems, Cebrián and Valiela (1999) found that 65% of systems assessed exhibited the same pattern, although the winter-spring peak in BIS and RIS occurred about a month earlier than the majority of systems surveyed. Peaks in both sounds had larger ranges in concentrations than are typical for most open coastal systems, but several of the areas in the Cebrián and Valiela (1999) study exhibited concentrations within the same range as BIS and RIS. A similar bimodal pattern in peak chlorophyll concentrations was also observed in most regions surrounding BIS and RIS on the northeast U.S. continental shelf (Gulf of Maine, Georges Bank, Mid-Atlantic Bight) surveyed as part of the Marine Monitoring, Assessment, and Prediction Program (MARMAP), Northeast Monitoring Program (NEMP) and the Warm Core Ring (WCR) program (O'Reilly and Zetlin, 1998). However, in these areas the highest concentrations occurred during the winter-spring bloom instead of the fall bloom (O'Reilly and Zetlin, 1998).

Variations in phytoplankton biomass in BIS and RIS were likely attributable to a complex array of contributing factors, including biological, chemical, and physical controls. Riley (1952) postulated that physical processes strongly affected both the community size and structure of phytoplankton in BIS. He found evidence that some chemical or biological factors also worked in part to influence phytoplankton populations, but was only able to determine quantitatively that phosphate concentrations and zooplankton quantity were likely not important factors (Riley,

1952). The most thorough zooplankton investigation in the BIS and RIS area was done as part of the MARMAP study in 1977-1981 (Sherman et al., 1981). Since data are from some years ago, and values are for the entire southern New England shelf, a direct comparison to our phytoplankton phenology patterns could not be made.

Despite the *in situ* surface chlorophyll *a* measurements indicating that biomass in RIS may be slightly higher (2009) or not significantly different (entire sampling period) than biomass in BIS, it is strikingly clear that satellite observations over a longer time period tell a different story (Fig. 2-8). Retrieving accurate chlorophyll measurements from remotely sensed ocean color data in coastal areas is more difficult compared to the open ocean due to interference of the optical signal received by the satellite by dissolved and suspended materials in the water (IOCCG, 2000; Morel and Prieur, 1977) and higher concentrations of absorbing aerosols that leads to errors in chlorophyll *a* calculations (Stumpf et al., 2003). However, the development of regional algorithms that are calibrated using *in situ* measurements from the area have greatly improved the accuracy of remotely sensed chlorophyll *a* values in coastal areas, and greatly reduced error associated with satellite observations and post-processing of data in coastal areas (e.g. Hyde et al., 2007; Pan et al., 2008).

Qualitatively, chlorophyll concentrations appear to be higher throughout the entire satellite time series in BIS than in RIS, almost without exception, and the mean annual chlorophyll concentration in BIS (1.5 mg m^{-3}) is nearly double that of RIS (0.86 mg m^{-3}). This supports our original hypothesis that the relatively more well-mixed BIS has more nutrients and higher primary productivity than seasonally stratified RIS. It is likely that this is also true for the 22 months during which statistical comparisons were

Fig. 2-8. Daily interpolated SeaWiFS chlorophyll *a* from 1998 to 2010 in (top) BIS, (middle) RIS, and (bottom) farther offshore than our study areas. Note the colorbar is a log₁₀ scale.

made for *in situ* measurements in BIS and RIS, although it is difficult to determine because of a gap in the satellite record during much of this time period due to extended satellite outages. We cannot rule out the possibility that the data density was insufficient to reveal biomass differences, that our *in situ* measurements accurately reflect the seasonal patterns in phytoplankton abundance throughout BIS and RIS, or that the two years during which we sampled were anomalous. For example, during the late fall-early winter of 2009, there was an intrusion of deep water from the continental slope into RIS, causing anomalies in near-bottom salinity, temperature, density, and possibly nutrients that likely mixed with inner shelf water (Ullman and Codiga, 2010; Ullman et al., 2012). However, the satellite data appear to capture longer-term regional patterns that our measurements do not. Perhaps the differences in results between *in situ* measurements and satellite observations demonstrate a well-known disadvantage of sample collection being limited by resources and logistics. Satellites have the ability to integrate across both space and time in a way that sample collection does not allow.

4.1.3 Possible physical drivers of differences in primary production

In both BIS and RIS the two major peaks (winter and fall) in primary production occurred simultaneously (Fig. 2-7). As with surface chlorophyll, values of primary production calculated with sub-surface models in both sounds were similar to those of other inner continental shelf systems such as Massachusetts Bay (Hyde et al., 2008; Keller et al., 2001; Kelly and Doering, 1997), Georges Bank (O'Reilly et al., 1987; Riley, 1941 as cited in Kuring et al., 1990; Sherman et al., 1996), and the

Northwest Atlantic continental shelf as a whole (Sherman et al., 1996). In BIS and RIS, the annual cycles of production and chlorophyll in both sounds were slightly out of phase with each other; there was a peak in production in late summer, followed by an overlapping peak of both surface chlorophyll and primary production in the fall with the peak in production slightly preceding that of chlorophyll, followed by a winter chlorophyll bloom.

The major difference in primary production between BIS and RIS is that rates of production in stratified RIS never attained the magnitude of those in the more well-mixed water column of BIS, and as a result average daily production and overall annual production was higher in BIS than in RIS. This difference is particularly apparent during the late summer and fall peaks in production calculated from subsurface samples (Fig. 2-7a,b; Table 2-2), and the late summer peaks calculated from depth-integrated samples (Fig. 2-7b,c; Table 2-2). During the summer months, the water column in RIS stratifies (Fig. 2-3). In coastal marine ecosystems, water column stratification results in exhaustion of nutrients in the surface waters as phytoplankton deplete the nutrient supply above the pycnocline (Mann, 2000). The smaller peaks of primary production in RIS compared to BIS during the late summer and fall blooms were likely a result of summer nutrient limitation in surface waters of RIS. If this is the case, then summer productivity in RIS is probably sustained mostly on regenerated nitrogen that quickly overturns to maintain high productivity levels (Cushing, 1989; Malone et al., 1988). A high turnover rate would in part explain why biomass levels remained so low in RIS, and supporting evidence can be seen in the drastic increase in phytoplankton-specific production (P^B_d ; i.e. turnover) in RIS after the onset of

summertime water column stratification (Fig. 2-5). P_d^B was at its highest throughout the entire study area during the warmer months. Zooplankton removal of phytoplankton biomass is also a typical explanation of high production and low chlorophyll during summer in the temperate ocean (Mann and Lazier, 2006), but as previously mentioned, we cannot directly assess this relationship with our data. Sustenance of summer production on regenerated nutrients is typical in estuarine ecosystems (e.g. Chesapeake Bay; Boynton et al., 1982; Malone et al., 1988), and within the thermocline of temperate waters (Cushing, 1989).

4.2 A comparison of primary production models and sampling methods

4.2.1 Empirical methods of primary production

The slopes of the sub-surface BZI regression models were consistent with other highly productive coastal areas (see summary table in Brush et al., 2002), including many shallow estuarine ecosystems such as Narragansett Bay, R.I. (Keller, 1988a; Keller, 1988b). This is surprising, since phytoplankton growth in more open, coastal waters like BIS and RIS tends to be more nutrient-limited than in estuarine systems, resulting in lower overall rates of production (Cebrián and Valiela, 1999; Smith and Hollibaugh, 1993). However, it should be noted that slopes in BZI regression models are sensitive to differences in ^{14}C incubation times (2-24 h), so comparisons between studies are approximate to $\pm 10\%$ depending on differences in ^{14}C measurement techniques (Keller, 1988b). Slopes for depth-integrated BZI regression equations were much smaller (roughly half) than those of the sub-surface BZI models (Fig. 2-6). While these values were well within the range typical of

productive coastal ecosystems (roughly 0.22-1.1; Brush et al., 2002; Keller, 1988b), researchers for all but a few of the systems studied reported slopes greater than 0.65 (summarized in Brush et al., 2002). Slopes of a similar magnitude as our depth-integrated BZI models were measured in Delaware Bay (Pennock and Sharp, 1986) and the Westerschelde estuary, Netherlands (Kromkamp et al., 1995), and it was posited by Brush et al. (2002) that the smaller slopes in these areas were a result of the high turbidity and thus extreme light limitation. The lower slopes in the depth-integrated models may similarly be the result of greater overall light limitation experienced by phytoplankton when integrated over the entire water column compared to sub-surface samples.

Production model outputs for the Webb/Platt models were closely matched to outputs from the BZI models, especially for seasonal and annual rates predicted for sub-surface samples (Table 2-2; Fig. 2-7). There were several occasions where the BZI model output for depth-integrated samples underestimated primary production (Fig. 2-7c,d), and this may have been due to an artifact of fitting a regression line through the data points in the BZI plots. For example, the BZI models were unable to pass through the highest data points in order to fit the rest of the data (Fig. 2-6c,d), so the models inherently could not predict the highest rates of production. This may also be true to some degree for the sub-surface models, and if so, discrepancies caused by this artifact could explain the significant difference found between the two empirical models for daily average production despite the small difference in rates. There were some instances where the two models did not agree (e.g. in BIS during the summer), but there were no actual ^{14}C measurements to determine which model (Webb/Platt or

BZI) was more accurate (Fig. 2-7). Ultimately, despite these minor differences, the models agreed remarkably well at daily, seasonal, and annual scales.

4.2.2 Sub-surface chlorophyll maxima and ^{14}C sampling techniques

During the ^{14}C sampling year, CTD fluorescence data showed that distinct sub-surface chlorophyll maxima (SCMs) occurred four times in each sound and in all seasons except winter. All but twice (both in BIS during spring), the SCMs co-occurred with the thermocline and were located at approximately the same depth. However, an SCM did not occur every time a thermocline was present. In BIS during the spring, LIS exchange flow brings the freshest surface water of the year because of peak Connecticut River discharge, and this results in the formation of a halocline (Fig. 2-3b; Codiga and Ullman, 2010). The spring SCMs in BIS occurred at the same depth as this halocline. All SCMs in both sounds occurred concurrently with, and around the same physical location as, at least some degree of stratification. The largest SCMs in general were always observed in RIS, and most of the highest peaks occurred in RIS during the stratified summer months, with the exception of the largest SCM which occurred during spring and displayed the highest chlorophyll concentrations of the year.

Studies in other areas have also found that SCMs are associated with the pycnocline, and some have reported high rates of primary production in the SCM that contribute significantly to total water column production (Table 2-3; Giovannoni and Vergin, 2012; Weston et al., 2005). Weston et al. (2005) posited that environmental conditions in the pycnocline (where the maximum was located) are most favorable

Table 2-3. Occurrences and characteristics of sub-surface chlorophyll maxima (SCM) in Block Island and Rhode Island Sounds and in other ecosystems where similar measurements were made.

Location	Time of occurrence	Associated with stratification?	Ratio of SCM:surface chlorophyll concentrations	Contribution to total water column production, %	Sampling years
^a Block Island Sound	Spring and summer	Yes thermocline or halocline	4.2 – 7.1 ^f	Exact value unknown, appears small	2010
^a Rhode Island Sound	Spring, summer, fall	Yes, thermocline	3.9 – 15.8 ^f	Exact value unknown, appears small	2010
^b Massachusetts Bay	Spring, summer, fall	In some cases, pycnocline	1.7-14.9 ^g	Exact value unknown, ratio of PP based on surface sample to PP based on mid-depth sample = 0.8-2.5 ^j	1994
^c Sargasso Sea (BATS station)	Summer, spring, fall	Yes, nutricline	4.6 – 9.9 ^h	22-59 ^k	1996-2003; 1989-1990 summers
^d North Sea	Summer	Yes, thermocline	~7.1 – 64 ⁱ	58	2001
^e Eastern North Pacific	Summer	Yes, pycnocline	SCM 2-3 times higher than at other depths in euphotic zone	20-30	1971

^aThis study

^bKelly et al. (1994a; 1994b; 1995a, b;); Libby et al. (1995); measurements made only during spring and summer

^cGiovannoni and Vergin (2012); Michaels et al. (1994)

^dWeston et al. (2005); measurements made only during summer

^eRevelante and Gilmartin (1973); measurements made only during summer

^fRange is min and max of ratios calculated for every individual SCM sampled

^gSurface and SCM values for each CTD cast when SCMs were present were picked off figures (figs in appendices) using DataThief (<http://www.datathief.org>). Ratios for each cast were calculated, and range is min and max of all casts.

^hCalculated using data from Bermuda Atlantic Time-series Station (<http://bats.bios.edu/>) from the same time period as in Giovannoni and Vergin (2012). Mean surface and SCM chlorophyll concentrations were calculated for each year from all summer (J,J,A) cruises, then a ratio for each year was calculated using these averages. Range is the min and max of annual averages.

ⁱCalculated based on surface range and SCM maximum chlorophyll values given by authors. Surface range given as $<1 \text{ mg m}^{-3}$ was interpreted and calculated as $0.1\text{-}0.9 \text{ mg m}^{-3}$.

^jEntire euphotic zone PP (primary production) calculated based on samples taken at discrete depths on the same sampling day. Mid-depth water samples were collected at approximately the same depth as the SCM. Ratios of euphotic zone PP based on surface samples to PP based on mid-depth samples were calculated for each sampling day available. Range is min and max of ratios from all sampling days.

^kSCM and water column production rates were picked off figures for summer months (for consistency with chlorophyll data) in 1989-1990 in Michaels et al. (1994) using DataTheif. Percent contribution was calculated for each month separately, and range is the min and max of monthly values.

during stratified months, because there is less light or nutrient limitation than waters below or above, respectively. They also proposed various mechanisms by which nutrient delivery to the pycnocline occurs. In inner shelf systems like BIS and RIS, the most likely mechanisms for this scenario are tidal mixing, wind mixing, and internal waves. Although there are low light conditions at the depth of the SCM, phytoplankton within these maxima have likely adapted to these conditions.

While some studies have reported elevated rates of primary production within SCMs, this does not appear to be the case in Northeast U.S. inner continental shelf ecosystems, including our study areas (Table 2-3). If SCMs were contributing significantly to euphotic zone production, then rates calculated from depth-integrated samples wouldn't be consistently lower than rates from sub-surface samples. In both BIS and RIS, the primary production from depth-integrated samples (both measured and modeled) was much lower than coincident values calculated from sub-surface samples, even when SCMs were present (Fig. 2-7). At least half of the chlorophyll peaks in SCMs were captured in the depth-integrated sample on six out of eight occasions. The only time there was consistently high productivity throughout the entire euphotic zone was one anomalous event in BIS during the fall maximum, and there are no water column fluorescence profiles available to assess the presence of a sub-surface chlorophyll maximum during this time. Even during the largest SCM in RIS in April, ^{14}C measured sub-surface primary production was $\sim 85 \text{ mg C m}^{-2}$ higher than the depth-integrated rate, despite the SCM being captured in the sample. The lack of elevated productivity within SCMs was also apparent in Massachusetts Bay, an inner continental shelf ecosystem north of our study areas (Kelly et al., 1994a; Kelly et

al., 1994b; Kelly et al., 1995a). These observations imply that accounting for the SCM does not appear to be important when assessing rates of primary production in either BIS or RIS, despite the high chlorophyll concentrations.

We cannot conclusively say whether the sub-surface or depth-integrated ^{14}C sampling technique is a more accurate way to determine total water column production. Production values for both sounds computed from depth-integrated samples were consistently lower than those calculated from sub-surface samples (Table 2-2). Flow cytometry studies in the Sargasso Sea and the North Pacific subtropical gyre have shown that seasonal SCM communities are composed of species that are distinct from those in the surrounding waters (Giovannoni and Vergin, 2012), and these different species are likely to grow at different rates (Hoogenhout and Amesz, 1965). Phytoplankton communities in the SCM in BIS and RIS could be similarly transient, adapted to the lower light conditions characteristic of the SCM, and fixing carbon at a lower rate than phytoplankton closer to the water surface (Fig. 2-7). Water samples collected at different discrete depths throughout the euphotic zone in Massachusetts Bay confirm a non-linear decrease in α , P_{max} , and P_s values with increasing depth (Kelly et al., 1994a; Kelly et al., 1994b; Kelly et al., 1995a). Integrating throughout the entire euphotic zone using model parameters (see Table 2-1) that were derived based on P-I curves for sub-surface samples may therefore overestimate the rate of total water column production. While depth-integrated sampling would eliminate some of that error, a comparison of primary production calculated using model parameter values derived for different discrete depths may

prove useful. It seems likely that the most accurate production rate is somewhere between the sub-surface and depth-integrated value.

5 CONCLUSIONS

Despite similarities in the seasonal cycles of primary production and phenology of phytoplankton biomass (as measured by surface chlorophyll), both annual production and satellite surface chlorophyll are higher in BIS than in RIS. This difference in chlorophyll was not obvious from *in situ* chlorophyll measurements, but was clear in the 12-year time series of satellite chlorophyll data. Physical oceanographic characteristics in the two sounds appear to be the main drivers of these differences, although the influence of chemical and biological factors requires additional investigation. Specifically, our findings support the hypothesis that rates of primary production are higher in the relatively more well-mixed water column of BIS than in seasonally stratified RIS. The water column stratification in RIS likely creates nutrient limitation that causes the difference in primary production between sounds.

Rates of measured (^{14}C) and modeled (Webb/Platt and BZI models) primary production based on the depth-integrated sampling technique were consistently lower than those based on the sub-surface technique. This indicates that despite the presence of a sub-surface chlorophyll maximum in both BIS and RIS during times of stratification, primary production calculated from sub-surface samples is low and sub-surface production does not significantly contribute to total water column production. Actual rates of primary production are likely between those calculated using sub-surface and depth-integrated sampling techniques. Regardless of sampling technique, the Webb/Platt and BZI empirical models of primary production agreed remarkably well at all time scales analyzed.

A plethora of in-depth studies in various disciplines have been conducted in BIS and RIS over the past few years by a number of investigators (e.g. Heiss et al., 2012; Kincaid et al., 2008; Ullman and Codiga, 2010), and their results have sparked additional interest and further exploration. Re-evaluating these results as additional work is conducted will allow us to put our data into context with other chemical, biological, physical, and geological processes that are presently occurring in these two systems. We are only just beginning to understand the ecosystem dynamics of these areas and establish a baseline of knowledge that will assist with management issues such as the potential for wind farm development, and give us the ability to understand and predict ecosystem response to global environmental change.

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CHAPTER 3

PREFACE

Benthic Metabolism and Nutrient Regeneration in Hydrographically Different Regions on the Inner Continental Shelf of Southern New England

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BENTHIC METABOLISM AND NUTRIENT REGENERATION IN HYDROGRAPHICALLY DIFFERENT REGIONS ON THE INNER CONTINENTAL SHELF OF SOUTHERN NEW ENGLAND

ABSTRACT

We examined the effect of hydrography on benthic-pelagic coupling in transitional inner continental shelf areas. From Oct 2009 to Jul 2012, we measured sediment oxygen demand (SOD), benthic inorganic nutrient fluxes, and sediment characteristics (chl *a* and phaeopigment content, C/N ratio, grain size, and organic matter content) in two regions of the Southern New England continental shelf approximately seasonally: a seasonally stratified ecosystem (Rhode Island Sound), and an adjacent, more well mixed ecosystem (Block Island Sound). Despite the higher rate of euphotic zone primary production in Block Island Sound, benthic metabolism (measured as sediment oxygen demand) was not significantly different between the two areas (BIS=953.8 $\mu\text{mol m}^{-2} \text{h}^{-1}$; RIS=912.2 $\mu\text{mol m}^{-2} \text{h}^{-1}$). This lack of differences in SOD was likely due to differences in water column hydrography between the sounds, where the energetic water column mixing in Block Island Sound resuspended organic matter back to the water column to be decomposed before reaching the benthos. Additionally, the seasonal presence of a strong pycnocline in Rhode Island Sound likely prevented mixing of regenerated DIN and DIP to surface waters for use by phytoplankton. Apparent differences in benthic macrofaunal communities between Block Island Sound and Rhode Island Sound translated to differences in dissolved inorganic nutrient fluxes between the two areas, despite the similarities in benthic metabolism. Excretion and irrigation activities by the dense amphipod communities in Block Island Sound caused higher effluxes of DIN (NH_4^+ =36.9 $\mu\text{mol m}^{-2} \text{h}^{-1}$; NO_x =23.5 $\mu\text{mol m}^{-2} \text{h}^{-1}$) and DIP (7.2 $\mu\text{mol m}^{-2} \text{h}^{-1}$).

$^2 \text{ h}^{-1}$) compared to fluxes in Rhode Island Sound ($\text{NH}_4^+=22.8 \text{ } \mu\text{mol m}^{-2} \text{ h}^{-1}$; $\text{NO}_x=11.1 \text{ } \mu\text{mol m}^{-2} \text{ h}^{-1}$; $\text{DIP}=3.2 \text{ } \mu\text{mol m}^{-2} \text{ h}^{-1}$). These findings indicate that the hydrographic regime of the water column may exert a strong influence on benthic-pelagic coupling dynamics on the Southern New England shelf and in other inner continental shelf ecosystems.

1 INTRODUCTION

Benthic-pelagic coupling, or the link between the benthos and the water column, is a cyclical dynamic in aquatic ecosystems; water column phenomena affect the benthos, and sediment recycling of nutrients and organic matter fuel water column production (Boynton et al., 1995; Nixon, 1981; Nowicki and Nixon, 1985; Rudnick and Oviatt, 1986). Water column organic matter (phytoplankton, zooplankton feces, etc.) has various fates. It may sink out of the water column to be buried in the sediment or metabolized by the benthos through uptake of particles by active filtration or direct consumption of deposited material (Hale, 1974; Valiela, 1995; Hopkinson et al., 2001; Woulds et al., 2009). Resuspension of this deposited organic matter back into the water column by tidal and storm currents may lead to oxidation in the water column. When benthic communities metabolize the energy and nutrients (e.g. carbon, nitrogen, and phosphorus) in this organic matter, they consume oxygen and other terminal electron acceptors, while simultaneously regenerating inorganic nutrients to the water column (Hargrave, 1973; Zeitzschel, 1980; Nixon, 1981; Oviatt et al., 1984). Benthic-pelagic coupling is an important characteristic of coastal ecosystems (Rowe et al., 1975), and many estuarine ecosystems have been well studied, for example Chesapeake Bay (Zeitzschel, 1980; Garber, 1982) and the Delmarva Peninsula (Reay et al., 1995), Narragansett Bay (Nixon, 1981; Fulweiler and Nixon, 2009), and Alfacs Bay, Spain (Vidal and Morgu, 2000). However, such measurements are relatively less common in continental shelf sediments, and there is still much to be learned about benthic flux dynamics in these transitional ecosystems.

The magnitude and variability of benthic fluxes is driven largely by inputs of organic material from the water column (Hargrave, 1973; Kelly and Nixon, 1984; Hopkinson and Smith, 2005). Hargrave (1973) demonstrated a positive relationship between water column primary production and benthic metabolism (measured as sediment oxygen uptake), and posited that his findings might reflect a stronger relationship between organic matter supply and benthic community metabolism than that of metabolism and temperature. Just over a decade later, organic matter addition experiments by Kelly and Nixon (1984) found direct evidence of the influence of organic matter inputs on benthic fluxes of oxygen and nutrients. Several other factors can contribute to benthic flux variability, but to a lesser extent than inputs of organic material (Hopkinson and Smith, 2005). The relative importance of such factors is debatable, and may vary across systems (Hopkinson and Smith, 2005). For example, site-specific temporal changes in benthic respiration are typically strongly related to temperature (e.g. Nixon et al., 1976; Giblin et al., 1997). Sediment disturbance from animal activity also exerts a major influence on benthic flux magnitude and variability (Aller, 1982; Aller et al., 1983).

There are many phenomena that impact organic matter production and loading, and thus influence the seasonality, magnitude, and variability of oxygen uptake and nutrient recycling at the sediment-water interface. Many studies in both freshwater and coastal marine ecosystems have addressed the effect of water column stratification on either nutrient cycling (e.g. Petihakis et al., 2005; Bruce et al., 2008; Kim et al., 2009) or particle sinking (e.g. Gibbs, 2001), both of which play obvious roles in benthic-pelagic coupling. Though the presence of a pycnocline can decrease the sinking

velocity of detritus and other particles (Yamamoto, 1984), resuspension caused by a well-mixed water column or deep mixed layer results in an increase in the amount of organic matter consumed in the water column (Hargrave, 1973). The presence of water column stratification also inhibits mixing of regenerated nutrients up to the surface waters (Mann, 2000). In coastal marine ecosystems, benthic nutrient remineralization is responsible for a large portion of the N and P required by phytoplankton (Rowe et al., 1975; Nixon et al., 1976). However, during times of year when the water column is stratified, primary production in surface waters is supported largely by recycled nitrogen in surface waters instead of remineralized nutrients from the benthos (Malone et al., 1988; Cushing, 1989).

The overall objective of this study was to examine the effect of water column stratification on benthic-pelagic coupling in transitional shelf ecosystems. We directly compared three years of measurements of benthic fluxes (oxygen, ammonium, nitrate+nitrite, phosphate, and dissolved silica) and sediment characteristics (photopigments, C/N ratio, and organic matter content) between two adjacent, phytoplankton-based inner continental shelf ecosystems of similar depth (~30 m) with differing hydrographic regimes. The first ecosystem, Block Island Sound, was relatively more well mixed while the second area, Rhode Island Sound, was seasonally stratified (Fig. 3-1). We hypothesized that differences in water column stratification between Block Island and Rhode Island Sounds would induce differences in organic matter input to the benthos and the distribution of recycled nutrients that would impact both the magnitude of benthic fluxes and the strength of benthic-pelagic coupling. Specifically, we expected the benthic flux magnitudes to be lower, and the link

between the water column and the benthos to be weaker in a seasonally stratified system compared to a relatively well-mixed system.

Fig. 3-1. Map of study areas and stations (opaque circles) on the Southern New England continental shelf.

2 MATERIALS AND METHODS

2.1 Study areas

We focused our sampling efforts in two regions on the Southern New England continental shelf, Block Island Sound and Rhode Island Sound, which are adjacent inner shelf ecosystems located off the coast of Rhode Island (Fig. 3-1). The sounds are connected to Narragansett Bay, Buzzards Bay, Long Island Sound, Vineyard Sound, and the Atlantic Ocean (Fig. 3-1). They are both open-water, phytoplankton-based systems with similar mean depths (~30 m), but have contrasting hydrographic regimes. Strong tidal mixing causes a relatively well-mixed water column in Block Island Sound, whereas Rhode Island Sound is vertically stratified during the summer (Shonting and Cook, 1970; Codiga and Ullman, 2011). The thermal stratification in Rhode Island Sound results in summer nutrient limitation, which is likely the cause of lower surface chlorophyll *a* concentrations and primary production in Rhode Island Sound than in Block Island Sound (Table 3-1; Fields, 2013).

From October 2009 to August 2012 we sampled three stations in fine-grained, depositional areas (Fig. 3-1). We visited two stations approximately seasonally throughout the entire ~3 year period (one station in Block Island Sound [BIS], and one in Rhode Island Sound [RIS2]), and another station in Rhode Island Sound (RIS1) once per season over one annual cycle (Fig. 3-1).

Table 3-1. Characteristics of Block Island and Rhode Island Sounds. Mean values of sediment characteristics include data from both stations in Rhode Island Sound (RIS1 and RIS2). Additional details can be found in Heiss et al. (2012).

	Block Island Sound (well-mixed)	Rhode Island Sound (seasonally stratified)
Depth (m)	34	39
Surface Water Chlorophyll <i>a</i> ^a ($\mu\text{g L}^{-1}$)	1.9	1.7
Water Column Primary Production ^a ($\text{g C m}^{-2} \text{y}^{-1}$)	230 – 329	188-256
Euphotic Depth ^a (m)	19	23
Molar C/N ^b	9.2 ± 0.3	8.8 ± 0.9
Organic Matter Content ^b (%)	6.1 ± 0.2	3.6 ± 0.6
Sediment Chlorophyll Content ^c ($\mu\text{g cm}^{-2}$)	36.0 ± 3.5	26.7 ± 4.0
Sediment Phaeophytin ^c Content ($\mu\text{g cm}^{-2}$)	78.7 ± 14.6	82.4 ± 13.0

^aValues are from Fields et al. (2012). Primary production measurements in Rhode Island Sound were not measured separately at each station, but rather includes measurements based on ^{14}C sampling at RIS1 and empirical model calculations using data from many (>100) stations throughout RIS.

^bTop 1 cm of sediment

^cInventory of the top 5 cm of sediment

2.2 Field collection

On each sampling trip we collected triplicate sediment cores with a 0.25 m² box corer containing three pre-mounted PVC sub-cores (Hopkinson et al., 2001). Cores were pre-mounted to minimize disturbance of the surface flocculation layer and to conserve the vertical architecture of the sediment. Cores were capped and maintained on deck in a dark cooler filled with bottom water and ice during transportation back to the lab. Concurrently with sediment core collection, we collected near-bottom station water filtered to 0.2 microns to remove water column biota (Hopkinson et al., 2001; Fulweiler and Nixon, 2009).

2.3 Analytical methods

We incubated cores in a water bath in a dark, temperature-controlled (at *in situ* bottom water temperature) walk-in environmental chamber at the University of Rhode Island Graduate School of Oceanography's EPSCoR Marine Life Science Facility. We left the cores uncapped with air stones gently bubbling through the overlying water overnight (8-12 h) prior to incubations (Hopkinson et al., 2001; Fulweiler, 2007). Also before incubations, we carefully siphoned off the overlying water in each core and replaced it with 0.2 µm filtered station bottom water (Hopkinson and Smith, 2005) to eliminate the effect of water column activity during incubations. We then fit the cores with gas-tight covers (leaving no gas headspace) with attached magnetic stir bars that slowly and continuously stirred the overlying water throughout the incubation (~40 rpm) to prevent stratification but without resuspension (Renaud et al., 2008). The incubation set up was a gravity-fed system that pulled new filtered

seawater into each core as sample water was drawn. In addition to the sediment cores, we incubated a biological oxygen demand bottle containing the filtered station water to measure any water column activity that may have occurred (Suykens et al., 2011).

We monitored dissolved oxygen (DO) concentrations in the overlying water on four occasions throughout the incubation using a Hach LDO probe. Oxygen levels were allowed to drop by at least $62.5 \mu\text{mol L}^{-1}$ (2 mg L^{-1}), but incubations were stopped before oxygen levels reached near-hypoxic conditions ($< 3 \text{ ppm}$; Hopkinson et al., 2001; Fulweiler, 2007; Fulweiler et al., 2008). Incubations lasted anywhere from 8 to 32 hours.

Immediately after measuring DO concentration, we collected samples of overlying water for analysis of dissolved inorganic nutrients, including ammonium (NH_4^+), nitrate+nitrite ($\text{NO}_3^- + \text{NO}_2^-$ or NO_x), phosphate (dissolved inorganic phosphorus, DIP), and dissolved silica (DSi). In some cases (around 20% of the time), only three samples were collected due to either rapidly decreasing DO concentrations or experiment logistics. We collected samples directly into acid washed polypropylene syringes for filtration, and then stored sample water in acid washed and deionized water-leached polyethylene bottles. We filtered sample water for NH_4^+ , NO_x , and DIP through $0.7 \mu\text{m}$ binder free Glass Fiber (GF/F) filters (2.5 cm diameter) and then froze samples (-15°C) until analysis (Fulweiler and Nixon, 2009; Grasshoff et al., 1999). To avoid contamination of DSi samples with glass, we used $0.45 \mu\text{m}$ HA nitrocellulose filters. DSi samples were stored at room temperature until analysis (Grasshoff et al., 1999). Nutrient concentrations were measured using standard

colorimetric methods (Grasshoff et al., 1999) on a Lachat QuickChem 8000 flow injection autoanalyzer.

2.4 Q_{10} temperature coefficients

On one occasion in August 2010, we conducted an experiment to measure the Q_{10} temperature coefficient for benthic metabolism at the BIS, RIS1, and RIS2 stations. A Q_{10} coefficient is the rate of change in metabolism as a consequence of a 10°C increase in temperature, providing an indication of temperature sensitivity (Weston et al., 2005). We did this by performing four incubations at different ambient temperatures on the same set of cores. First, we incubated the cores at *in situ* (15°C) temperature, then at 5°C higher and lower (20°C then 10°C), and finally at 15°C again to ensure that the cores had not significantly changed over the course of the incubations. Prior to each of the four incubations, we changed the temperature setting of the environmental chamber and re-aerated the water overlying the cores with air stones for 4-5 days to allow adequate time for them to equilibrate at the new set temperature. We also replaced the overlying water of the cores with filtered station water held at the same temperature. We measured the DO concentrations of overlying water throughout each incubation in the same manner described above.

2.5 Site characterization

After each incubation, we collected sediment samples from the top 5 cm of each core in 1 cm increments for C/N ratio, and sediment photopigment (chlorophyll *a* and phaeophytin) analyses, and froze all samples until analysis. We also collected

sediment at 0-2 cm and 4-6 cm on two occasions from each station for grain size analysis. Percent C and N were measured in 1 cm increments in oven-dried and ground samples using a Eurovector elemental analyzer at the Boston University Stable Isotope Laboratory. We extracted sediment chlorophyll in 100% acetone and read them on a Beckman AU Spectrophotometer (Lorenzen, 1967; Strickland and Parsons, 1972). Grain size analysis was performed on a Malvern Mastersizer 2000 at the U.S. Environmental Protection Agency Atlantic Ecology Laboratory (Narragansett, RI).

2.6 Data analysis

Nutrient and DO concentrations changed linearly with time, so we calculated fluxes for the volume and area of each core using four-point linear regressions of concentration over incubation time (Clough et al., 2005; Fulweiler and Nixon, 2009). In cases where the final sample was collected after a long period of time (on the order of 24-48 h since previous sample), and the drop in DO became non-linear, the last point was excluded. However, fluxes were not calculated with fewer than three measurements. We scaled flux values by volume and area of the sediment core to obtain net rates in $\mu\text{mol m}^{-2} \text{h}^{-1}$ and corrected for any changes in the overlying water (Hargrave and Connolly, 1978; Nixon et al., 1980). Nutrient fluxes into the sediment (uptake) were assigned negative values, and effluxes were assigned positive values. In May 2010, we measured a small uptake of DIP in both the RIS1 cores and in the control BOD bottle, and this resulted in abnormally large uptake of DIP after correction for controls. We attributed this to error in measurements of control samples and excluded these values from analyses.

We calculated Q_{10} temperature coefficients for each individual core three times: with a temperature change from 15°C to 20°C, from 20°C to 10°C, and from 10°C to 15°C using the following equation (Streeter and Phelps, 1925):

$$Q_{10} = \left(\frac{R_2}{R_1} \right)^{\frac{10}{T_2 - T_1}}$$

Where R_1 and R_2 =rates of benthic metabolism, and T_2-T_1 =temperature change. We compared the Q_{10} values calculated for the initial and final incubations at 15°C using un-pooled Student's t-tests. To determine if there were significant differences in mean Q_{10} coefficients between stations, we conducted a one-way analysis of variance (ANOVA). We calculated two abnormally high Q_{10} values (around 9-10) at RIS1 and RIS2, and conducted statistical analyses with and without these two values to eliminate any bias they might cause.

We compared mean annual fluxes between BIS, RIS1, and RIS2 for SOD and all nutrient fluxes accounting for temperature differences when appropriate using analysis of covariance (ANCOVA), or using one-way ANOVA. When we found a significant flux-temperature relationship by regression analysis, we used ANCOVA, and we used ANOVA when there was no flux-temperature relationship, or when the assumptions of an ANCOVA were not met (Myers et al., 2010). We ran planned contrasts, a statistical test including only variables of interest that is planned prior to knowledge of results from additional tests, to compare fluxes between Block Island Sound (BIS) and Rhode Island Sound (RIS1+RIS2 combined; Myers et al., 2010). We compared sediment characteristics (organic matter content, C/N ratio, chlorophyll *a*, and phaeophytin content) in the similar manner. We also calculated the ratio of ammonium flux to nitrate+nitrite fluxes ($\text{NH}_4^+/\text{NO}_x$) measured in each core, and

compared stations using ANCOVA or ANOVA in the same manner described above. We identified one very high $\text{NH}_4^+/\text{NO}_x$ outlier (189.6 at RIS2), and after confirming its status as an outlier using Mahalanobis distance (a measure of distance of each point to the center of all values; Stevens, 1984), it was excluded from analysis. While we did not measure fluxes during every month of the year at BIS, RIS1, and RIS2, we did make measurements at least once per season, so temporal patterns were qualitatively compared on a seasonal basis. We made these comparisons based on the average fluxes measured in triplicate cores from each station during individual incubations.

We used correlation analyses to determine if there were any significant relationships between benthic fluxes and bottom water temperature, surface water chlorophyll *a* concentration, and euphotic zone primary production (Ricker, 1973). Measurements of surface chlorophyll *a* and models of euphotic zone primary production were made in Block Island and Rhode Island Sounds by Fields et al. (2012) between Jan 2010 and Jan 2011 on 5 occasions that overlapped with our sediment core collections. For these overlapping dates, we calculated 3-day averages of surface chlorophyll concentration and average daily primary production. We used 3-day averages because particle sinking rates typically vary from 50-250 m d^{-1} (Fischer and Karakas, 2008), and probably wouldn't take longer than a few days to reach the benthos in a ~35 m water column, regardless of the presence of a pycnocline. To account for any delays in remineralization of deposited material (Rudnick and Oviatt, 1986; Hopkinson and Smith, 2005), we also calculated daily average primary production for the month prior to core collection.

For comparisons of means using ANOVAs and ANCOVAs, we used fluxes measured in individual cores for analyses (n=3 per station for each incubation). However, to avoid autocorrelation, we conducted correlation analyses using incubation means for each station. All statistics were run using JMP Pro 10 (SAS).

3 RESULTS

3.1 Sediment oxygen uptake

For the entire study area, SOD measured in individual cores ranged from ~0 to 2161.3 $\mu\text{mol m}^{-2} \text{h}^{-1}$ (Fig. 3-2a). There were no significant differences in average SOD between stations (Table 3-2). After pooling stations to compare the two sounds to each other using planned contrasts, we found no significant differences in SOD between Block Island Sound (BIS; mean=953.8 $\mu\text{mol m}^{-2} \text{h}^{-1}$) and Rhode Island Sound (RIS1 + RIS2; mean=912.2 $\mu\text{mol m}^{-2} \text{h}^{-1}$; Fig. 3-3).

In Block Island Sound, trends of SOD were fairly consistent between years. At this station, SOD was lowest during the winter, and reached a maximum in the spring (Fig. 3-4a). The only major inconsistency between years was the appearance of a second peak in SOD that we found in late summer-fall on two occasions (Fig. 3-4a). At RIS2, the minimum SOD also occurred during the winter (Fig. 3-4a). In 2010, rates of SOD were low during the spring and reached maximum uptake in the fall, but in 2011, rates of SOD in RIS2 closely matched trends in BIS and peaked in the spring (Fig. 3-4a). Annual mean rates of SOD at RIS2 were significantly higher during year two (Sep 2010 – Sep 2011) than during years one and three ($F(2,32)=7.1$, $p=0.003$). There were no significant differences in mean SOD between the three sampling years at BIS.

Table 3-2. Annual mean ($\pm$ std. err) oxygen and nutrient fluxes across the sediment-water interface, flux ratios, and Q_{10} temperature coefficients for stations (BIS, RIS1, and RIS2) measured over one to three annual cycles. Units are $\mu\text{mol m}^{-2} \text{h}^{-1}$. Superscript letters within each row denote significant differences between stations, where values with different letters are significantly different from each other. Net N_2 flux data $\pm$ standard error are from Heiss et al. (2012) and include data from the first annual cycle only. Ratios were calculated by taking the ratio of average fluxes of N ($\text{NH}_4^+ + \text{NO}_x + \text{N}_2\text{-N}$), P (PO_4^{3-}), and O_2 for the study period.

	BIS	RIS1	RIS2
O_2 uptake	953.8 ± 88.2	1135.4 ± 141.6	835.8 ± 75.9
NH_4^+ flux	$36.9^a \pm 7.7$	$10.0^b \pm 6.8$	$27.1^{ab} \pm 5.4$
NO_x flux	23.5 ± 3.4	8.7 ± 16.6	11.9 ± 4.8
PO_4^{3-} flux	$7.2^a \pm 1.4$	$0.9^b \pm 1.0$	$3.9^{ab} \pm 1.0$
DSi flux	327.8 ± 42.2	179.2 ± 38.7	221.2 ± 38.1
$\text{N}_2\text{-N}$ flux	45 ± 5	53 ± 9	39 ± 6
O_2/N	9.1	15.8	10.7
N/P	14.6	79.7	20.0
N/Si	0.3	0.4	0.4
Q_{10}	2.6	3.3	2.8

Fig. 3-2. Benthic fluxes of (a) oxygen, (b) ammonium, (c) nitrate+nitrite, (d) phosphate, and (e) dissolved silica plotted across the annual temperature range for all stations sampled. Each point represents a flux measured in one sediment core. Cores were collected and incubated across a time span of nearly 3 years, so proximity of symbols along the x axis does not necessarily indicate proximity of sediment core incubations.

Fig. 3-3. Differences in average measurements of benthic fluxes, sediment characteristics (chlorophyll *a*, phaeophytin, C/N, and organic matter content), and daily euphotic zone primary production between Block Island Sound and Rhode Island Sound. Ratios larger than 1 indicate that higher averages were measured in Block Island Sound than in Rhode Island Sound, and values smaller than 1 indicate that averages were higher in Rhode Island Sound. Block Island Sound measurements are from the BIS station and Rhode Island Sound measurements are from RIS1 and RIS2 combined. The cases where means were significantly different from each other are identified with black symbols. Average daily production values were calculated from a complete annual cycle of modeled primary production in each sound (data from Fields et al., 2012).

Fig. 3-4. (a) Oxygen, (b) dissolved inorganic nitrogen, (c) phosphate, and (d) dissolved silica fluxes over time shown with sediment chlorophyll/phaeopigment ratio at BIS and RIS2 stations. Bars are averages of triplicate cores from each incubation, and error bars are standard error of the mean. Shaded areas are used to facilitate the distinction of seasons

3.2 Dissolved inorganic nitrogen

We measured NH_4^+ fluxes that ranged from an uptake of $-29.0 \mu\text{mol m}^{-2} \text{h}^{-1}$ to a regeneration of $183.2 \mu\text{mol m}^{-2} \text{h}^{-1}$ and NO_x fluxes that ranged from -94.6 to $79.8 \mu\text{mol m}^{-2} \text{h}^{-1}$ (Fig. 3-2b,c). The average NH_4^+ flux at BIS was significantly higher than at RIS1 (Welch's ANOVA, $F(2,81)=3.65$, $p=0.04$; Table 3-2), and planned contrasts revealed no significant differences in mean NH_4^+ flux in Block Island Sound (BIS; mean= $36.9 \mu\text{mol m}^{-2} \text{h}^{-1}$) and Rhode Island Sound (RIS1+RIS2; mean= $22.8 \mu\text{mol m}^{-2} \text{h}^{-1}$). There were also no significant differences in mean NO_x flux between individual stations (Table 3-2), though there was a significant difference between Sounds in average NO_x flux (Block Island Sound mean= $23.5 \mu\text{mol m}^{-2} \text{h}^{-1}$; Rhode Island Sound mean= $11.1 \mu\text{mol m}^{-2} \text{h}^{-1}$; $F(1,80)=4.3$, $p=0.04$; Fig. 3-3).

In most instances, we found NH_4^+ fluxes were larger in BIS than those concurrently measured at RIS2 (Fig. 3-4b). At both stations, a peak in NH_4^+ regeneration occurred in the spring, followed by a second, larger peak in the late summer and/or early fall (Fig. 3-4b). One exception to this was at BIS in 2010, when a spring peak did not occur. Maximum NO_x regeneration occurred in the late spring at BIS during all sampling years, and at RIS2 in 2010 (Fig. 3-4b). Although the peak NO_x regeneration typically preceded the peak NH_4^+ regeneration by a few months, the uptake and minimum flux magnitude of total DIN occurred around the same times of year at both stations (Fig. 3-4b). We found significant differences in mean NO_x flux between sampling years at both stations; at BIS, the mean flux measured in year three was significantly higher than in year one ($F(2,34)=4.4$, $p=0.02$), and at RIS2, year two was significantly higher than year one (Welch's ANOVA, $F(2,32)=7.43$, $p=0.004$).

There were no significant differences in mean NH_4^+ flux between years at either BIS or RIS2.

The magnitude of NO_x fluxes exceeded that of NH_4^+ fluxes in 53% of the individual cores examined throughout the study. Ratios of $\text{NH}_4^+/\text{NO}_x$ fluxes ranged from 0.01 – 45.65 (excluding one high outlier of 189.63). NH_4^+ contributed the most to total mean DIN fluxes during the summer, while NO_x tended to dominate during the spring (Fig. 3-4b). The only station where NH_4^+ was the major contributor to average DIN fluxes during all seasons was RIS2. During the summer, the largest DIN fluxes and ratios were observed, and in the fall DIN fluxed into the sediment and was comprised mostly of NO_x in Rhode Island Sound (Fig. 3-4b). Instances of both net DIN uptake and minimum regeneration were driven primarily by NO_x uptake as opposed to NH_4^+ fluxes (Fig. 3-4b). However, there were no significant differences of $\text{NH}_4^+/\text{NO}_x$ flux ratios between seasons for the dataset as a whole or at any station except BIS (summer ratio was significantly higher than spring and fall; $F(3,33)=4.5$, $p=0.008$). A one-way ANOVA on natural log (ln) transformed data revealed no significant differences in annual mean $\text{NH}_4^+/\text{NO}_x$ flux ratio between stations (BIS = 3.4; RIS1 = 2.0; RIS2 = 6.5).

3.3 Phosphate

DIP fluxes at the sediment-water interface ranged from -7.5 to 32.3 $\mu\text{mol m}^{-2} \text{h}^{-1}$ (Fig. 3-2d). A one-way ANOVA revealed a significantly higher mean DIP flux at BIS than at RIS1 ($F(2,76)=3.6$, $p=0.03$; Table 3-2). We ran planned contrasts that revealed a higher average DIP flux in Block Island Sound (BIS; mean=7.2 $\mu\text{mol m}^{-2} \text{h}^{-1}$

¹) than in Rhode Island Sound (RIS1 + RIS2; mean=3.2 $\mu\text{mol m}^{-2} \text{h}^{-1}$; $F(1,76)=7.2$, $p=0.01$; Fig. 3-3).

Temporal patterns of DIP fluxes were similar between stations during roughly half of the sampling period (Jan 2011 – Jul 2012; Fig. 3-4c). At both stations, we measured peak regeneration during the fall of the second annual cycle (Sep 2010 – Sep 2011), but during year one, BIS was highest in the fall while RIS2 peaked during the spring (Fig. 3-4c). In BIS, mean annual DIP flux was significantly higher during year 3 (Sep 2011 – Sep 2012) than the other years (Welch's ANOVA, $F(2,34)=0.85$, $p=0.003$).

3.4 Dissolved silica

We observed a remarkably wide range of DSi fluxes (-300.0 to 1169.1 $\mu\text{mol m}^{-2} \text{h}^{-1}$), which included three instances of very large uptake (Fig. 3-2e). We found no significant differences between stations using ANOVA (Table 3-2). Planned contrasts between Block Island Sound (BIS) and Rhode Island Sound (RIS1 + RIS2) revealed a significantly higher mean DSi flux in Block Island Sound (mean=327.8 $\mu\text{mol m}^{-2} \text{h}^{-1}$) than in Rhode Island Sound (mean=210.5 $\mu\text{mol m}^{-2} \text{h}^{-1}$; $F(1,80)=5.0$, $p=0.03$; Fig. 3-3).

General temporal patterns of DSi regeneration were similar between stations and between sampling years, including a spring/fall maximum and a winter minimum (Fig. 3-4d). We measured peak DSi regeneration in the fall at BIS during all sampling years. At RIS2, we observed some of the highest rates of DSi regeneration each fall, but the largest DSi flux was measured in the summer at RIS2 (Fig. 3-4d). Net DSi

uptake was measured at RIS2 in Jan 2010. We found strong DSi uptake in a few individual cores (Fig. 3-2e), but these values were not reflected in mean fluxes per incubation. There were no significant differences in Si flux between sampling years at either station.

3.5 Q_{10} temperature coefficients

We measured the highest Q_{10} temperature coefficients at RIS1 (range 1.8 – 3.7, mean=3.3), followed by RIS2 (range 1.5 – 3.0, mean=2.8), and finally BIS (range 1.6 – 4.8, mean=2.6). Un-pooled Student's T-tests indicated that SOD calculated during the first and last incubations of the experiment (both run at 15°C) were not significantly different from each other. This suggested that using multiple incubations on this set of cores was appropriate. Regardless of whether the outliers were included or excluded in analysis, we found no significant differences in mean Q_{10} temperature coefficients between stations, or between Block Island Sound (BIS) and Rhode Island Sound (RIS1 and RIS2).

3.6 Flux-temperature relationships

SOD was significantly related to temperature ($p=0.002$), but temperature explained only 11% of the variance in rates. NO_x fluxes were also significantly related to temperature, though very little variance was accounted for with this relationship ($R^2=0.06$, $p=0.02$). We found no significant relationship between temperature and fluxes of NH_4^+ , DIP, or DSi.

SOD, while variable, did not show a clean increase with temperature and rates measured at the highest temperatures were of similar magnitude to values measured at the lowest temperatures (Fig. 3-2a). Fluxes of both NH_4^+ and NO_x were mostly directed into the sediment (uptake) at the highest incubation temperature (Fig. 3-2b,c). We measured both maximum and minimum DIP regeneration and maximum DIP uptake at the highest temperatures (16.5-17.5°C; Fig. 3-2d). We measured maximum DSi regeneration and the few instances of very large DSi uptake at the highest incubation temperatures (Fig. 3-2e).

3.7 Additional stations characteristics

All sediment characteristics measured except phaeopigment content (sediment chlorophyll, C/N ratio, and organic matter content) were higher in Block Island Sound than in Rhode Island Sound, though planned contrasts revealed a significant difference only for organic matter content ($F(1,13)=8.5$, $p=0.01$; Table 3-1). Benthic C remineralization (converted from SOD using an RQ of 1) was significantly correlated with measurements of average daily primary production from 3 days prior to sediment core collection ($r=0.73$, $p=0.02$; Fig. 3-5), but was not significantly correlated with average daily production of the month prior to core collection. When the intercept of the linear regression was forced through zero, daily average production for the day of core collection plus two days prior explained 34% of the variance in benthic C mineralization ($p<0.0001$; Fig. 3-5). The slope of the regression (0.2) indicates 20% of the most recently fixed C was remineralized on the benthos.

Fig. 3-5. The relationship between daily average primary production and benthic C remineralization (as measured by sediment oxygen demand) at stations in Block Island and Rhode Island Sounds (BIS and RIS2). Averages of primary production are from the day of core collection plus the two preceding days.

4 DISCUSSION

4.1 Stratification and the strength of benthic-pelagic coupling

On an annual basis, there is a significantly higher rate of primary production in Block Island Sound compared to Rhode Island Sound (Table 3-1; Chapter 2). This difference was not reflected in our measurements of benthic metabolism, as there was no significant difference in sediment oxygen uptake between the Sounds. Also, a smaller percentage of annual net primary production was respired on the benthos of Block Island Sound compared to Rhode Island Sound (C equivalent of sediment oxygen consumption; Fig. 3-6). We propose that these findings were largely driven by differences in the hydrographic regimes of the two sounds. The water column in Block Island Sound is much less stratified than the water column in Rhode Island Sound primarily due to differences in tidal energy (Codiga and Ullman, 2011). Because of mixing in the water column of Block Island Sound, sinking organic material is probably repeatedly resuspended, resulting in a larger proportion being consumed and/or decomposed in the water column than in the sediment. Hargrave (1973) established a relationship between sediment oxygen uptake, primary production, and mixed layer depth using data from various lakes, bays, and coastal areas. He found that absolute benthic C mineralization (calculated from measures of SOD) increased with increasing rates of primary production, but was inversely proportional to mixed layer depth. The result is an increase in the relative amount of organic matter that is oxidized in the water column rather than in the sediment, and thus a shift towards pelagic communities playing an increasingly important role in this respect (Hargrave, 1973).

Fig. 3-6. A mass balance of annual nitrogen cycling in (a) Block Island Sound and (b) Rhode Island Sound. Units are mmol N m⁻² d⁻¹ and numbers in parentheses are the percent of total remineralized N, unless otherwise indicated. Numbers with an asterisk (*) are actual measurements, and other values are stoichiometric mass balance calculations. Calculations were performed using the C/N ratio of fresh algae (6.625) and of the top 1 cm in each area (BIS=9.0, RIS=8.8). Denitrification measurements from Heiss et al. (2012). Diagrams adapted and modified from Hopkinson et al. (2001).

If we apply our measurements of benthic DIN and DIP regeneration to the total area of each sound, the benthos of Block Island Sound could support up to 16% of the N and 35% of the P required for annual primary production (Table 3-1). The benthos of Rhode Island Sound could support up to 13% of the N and 19% of the P required for annual primary production in this area (Table 3-1). These potential contributions are small relative to those calculated for other coastal ecosystems (e.g. 40% of N and 29% of P in Boston Harbor; Giblin et al., 1997), and suggest that allochthonous inputs of nutrients may be important for euphotic zone primary production. These calculations also suggest that the benthos account for similar proportions of primary production requirements in each area despite differences in flux magnitude. However, not all of the nutrients regenerated on the benthos in Rhode Island Sound are necessarily available for use by primary producers in the euphotic zone. When the water column stratifies, the pycnocline prevents mixing of surface and bottom water (Taft et al., 1980), causing regenerated nutrients to be trapped in the bottom waters (Petihakis et al., 2005). Fields et al. (2012) proposed that the resulting nutrient limitation in surface waters of Rhode Island Sound was also responsible for lower summertime primary production and high phytoplankton turnover rate (P/B ratio). If we think of the “strength” of benthic-pelagic coupling as the proportion of total primary production supported by benthic nutrient regeneration (as opposed to allochthonous inputs or nutrients recycled in the water column), then differences in hydrography appear to play an important role in determining the strength of this link.

4.2 Differences in macrofauna

Sediment reworking and bioirrigation by macrofauna change the distribution of porewater constituents and organic material within the sediment (Aller, 1982; McClain et al., 2003). While we did not quantify benthic biomass and species in our sediment cores, visual observations suggest that there was animal activity in both Sounds, but a more apparent macrofaunal community in the sediments of Block Island Sound than of Rhode Island Sound. In 88% of the sediment cores collected from Block Island Sound, we observed thick (~few cm) amphipod mats (*Ampelisca spp.*) on the sediment surface. In Rhode Island Sound, only 39% of cores exhibited any obvious signs of macrofaunal activity (amphipod mat, the polychaete *Nephtys incisa*, or burrows). These observations are consistent with a survey of macrobenthic invertebrates conducted in the 1950s-1960s by Theroux and Wigley (1998), who found a higher density and biomass in Block Island Sound than Rhode Island Sound. They also noted that over 50% of the invertebrate density on the Southern New England Shelf was comprised of crustacea, followed by annelids, mollusks, and echinoderms (Theroux and Wigley, 1998). Our measurements of the vertical distribution of chlorophyll content in the sediment provided further evidence of differences in macrofaunal activity between the Sounds. Within the top 5 cm of sediment, we found maximum chlorophyll concentration to be below the top centimeter 91% of the time in Block Island Sound and only 73% of the time in Rhode Island Sound. This suggests that reactive organic material was mixed down more frequently in Block Island Sound than in Rhode Island Sound. Benthic infaunal activity such as burrowing increases the mixing of organic matter into the bulk sediment (Aller, 1982; Andersen and

Kristensen, 1988). There may also be differences in benthic community composition between the two areas, but our observations of macrofauna are not sufficient to determine this. Differences in community composition may be relevant because differences between species in feeding behavior and burrowing/irrigation activities can result in different impacts on biogeochemical fluxes. For example, surface deposit feeders do not have an affect on sedimentation rate of organic material, whereas suspension feeders actively bring organic matter from overlying water into sediment through their filtering and excretion (Nizzoli et al., 2002). Also, different species of benthic infauna can cause either increases or decreases in nitrate release from the sediment depending on the depth of their burrowing and their amount of irrigation activity (Henriksen et al., 1983).

We measured a significantly larger stock of accumulated organic material in the sediment of Block Island Sound than in Rhode Island Sound, which may seem contradictory to our explanation of differences in SOD between the sounds. However, this difference in organic matter content was likely driven by the differences in macrofaunal abundance between the sounds rather than passive delivery of sinking organic material to the bottom. The presence of dense amphipod mats and associated tubes in Block Island Sound could account for at least some of the higher organic matter content. There was a lack of significant differences in other sediment characteristics (chlorophyll and phaeophytin concentration) that inform the quality and age of organic matter, which further supports this idea. Sediment photopigments are typically considered a good representation of the amount of reactive organic matter in sediments (Furlong and Carpenter, 1988), and it has been proposed that phaeophytin

concentration could help specify the age of phytodetritus, as it is the degradation product of chlorophyll (Banta et al., 1995).

Excretion by macrofauna, and specifically the amphipod communities, might also account for the higher efflux of dissolved inorganic nitrogen in Block Island Sound despite the lack of differences in metabolism (sediment oxygen uptake; Fig. 3-3). The excretion of benthic infauna has been shown to constitute a large portion of the total ammonium efflux, and is responsible for increasing the benthic DIN regeneration compared to sediments without bioturbation (Henriksen et al., 1983). Nizzoli et al. (2002) found a significant positive correlation between amphipod biomass and ammonium efflux in their measurements of intact sediment cores from a coastal lagoon. Even if macrofaunal abundance was similar between the sounds, the nearly constant irrigation of burrows by amphipods would subsequently flush excretion products into the water overlying the sediment (Henriksen et al., 1983) and create a relatively higher DIN flux. The ratios of N/P and O₂/N fluxes measured in Block Island Sound more closely resemble the Redfield ratio typically seen in phytoplankton (Redfield, 1958) compared to flux ratios in Rhode Island Sound (Table 3-2). This could also be indicative of excretion of freshly deposited, labile organic matter.

4.3 Drivers of benthic fluxes and their relative importance

We found significant differences in fluxes both between stations, and within stations across time. This highlights the heterogeneity of the benthic environment on both spatial and temporal scales. Between 25-50% of total organic material in

shallow, coastal marine systems is remineralized by the benthos (Nixon, 1981). In continental shelf ecosystems, however, the proportion of organic matter mineralized by the benthos is relatively smaller. Seitzinger and Giblin (1996) used data from sixteen continental shelf regions to determine a linear relationship that suggests only around 16% of the C produced in surface waters is mineralized on the benthos (assuming an RQ of 1). The annual calculated benthic C mineralization in Block Island Sound and Rhode Island Sound constituted a higher proportion of average primary production than is typical of continental shelf areas, and instead falls within the range that is typical of more shallow coastal systems. This could be due to the fact that rates of primary production in both sounds are higher than typical open coastal ecosystems (Cebrián and Valiela, 1999). However, there was no significant relationship between benthic C mineralization and the average daily production of the month prior to core collection, and benthic C mineralization explained only 34% of the variance in the rate of more recently fixed C (3 days prior to core collection; Fig. 3-5). This contrasts with the strong relationships observed in other studies of shallow coastal (Nixon, 1981) and shelf systems (Seitzinger and Giblin, 1996), though the other comparisons were made with annual values across multiple ecosystems rather than measurements of smaller time scales within the same region.

Benthic fluxes of highest magnitude were almost always measured at mid-range temperatures, while decreases in flux magnitude and/or nutrient uptake occurred at the highest incubation temperatures (Fig. 3-2). This lack of a clear relationship with temperature is indicative that organic matter inputs appear more important in driving flux magnitude than temperature. The importance of organic matter input in

controlling the magnitude and variability of sediment oxygen demand and nutrient fluxes was demonstrated by organic matter addition experiments performed by Kelly and Nixon (1984). Higher rates of benthic respiration during mid-range temperatures in the spring have been attributed to deposition of the winter-spring diatom bloom in other temperate coastal marine ecosystems (Banta et al., 1995).

Our measurements of Q_{10} in Block Island and Rhode Island Sounds provided information about the sensitivity of benthic community metabolism to temperature changes in these areas that can be compared to other ecosystems, and can be used to inform the relative importance of temperature compared to other flux drivers (e.g. organic matter inputs). In our study areas, Q_{10} values suggested that the rate of sediment oxygen uptake would approximately triple with a 10°C temperature rise (Table 3-2). For comparison, a Q_{10} measurement of benthic metabolism of 1.9 was made in silty sediments of a Scottish semi-enclosed bay of a similar annual temperature range to our study areas (Davies, 1975), and measurements in a tidal sand flat in Nova Scotia between 6-14°C revealed a Q_{10} of 6.5 (Grant, 1986). In Block Island Sound, our measurements captured an approximately 10°C temperature difference between winter (~5°C) and spring (~14°C), and winter and summer (~16°C). Our measured Q_{10} value indicated that benthic metabolism would increase by an average of 2.6 times the winter value, but instead we measured increases of SOD during both the spring and summer that were nearly 5 times that of winter rates (Fig. 3-4a). This suggests that other factors, such as seasonal changes in organic matter inputs to the benthos, were exerting a stronger influence on sediment oxygen demand than was temperature. Similar observations were made in other ecosystems

(e.g. Loch Thurnaig, Scotland; Davies, 1975). Measurements of Q_{10} made over the same temperature range in Rhode Island Sound were similar to those in Block Island Sound (Table 3-2). However, the $\sim 10^{\circ}\text{C}$ temperature change between seasons did not elicit the expected response; SOD occurred at approximately the same rate during winter and summer, and only increased by $\sim 50\%$ between winter and fall (Fig. 3-4a). It is not uncommon to find differences in the timing of response to fresh organic matter inputs (Hopkinson and Smith, 2005), and such differences could explain our observations. Sometimes, there is an immediate response by the benthos to organic matter deposition (e.g. Banta et al., 1995), while other times there could be a lag in response on the order of months (e.g. Hargrave, 1978; Rudnick and Oviatt, 1986). Such delays in response could be driven by temperature (Hargrave, 1978; Rudnick and Oviatt, 1986) or community composition (Hopkinson and Smith, 2005). For example, colder water temperatures and a predominately microbially-mediated respiration would tend to cause greater response lags than warmer temperatures and an abundance of macrofauna (Rudnick and Oviatt, 1986; Hopkinson and Smith, 2005).

4.4 Benthic fluxes in sandy sediments

It is important to note that the Southern New England inner shelf is comprised mostly of coarse-grained, sandy sediment as opposed to silty, fine-grained sediments. In fact, permeable, relict sands comprise around 70% of all continental shelf sediment (Emery, 1968). The organic matter content of sandy sediments is much lower than that of fine-grained sediments because of differences in surface area, but this does not necessarily mean that sediment respiration and associated nutrient regeneration is low

(Hopkinson and Smith, 2005). There is typically no significant relationship between sediment organic matter content and SOD because a large majority (>90%) of this organic matter is adsorbed to mineral grains and so is unavailable to microbes and macrofauna (Mayer, 1994; Hopkinson and Smith, 2005). Additionally, despite the lack of filter feeders and bioturbators in coarse-grained areas, advective transport caused by the interaction of bottom currents and sediment topography brings particulate organic matter deep into the sediment (Huettel and Rusch, 2000). Field and laboratory experiments have shown that the flux of organic C in sands can be up to 9 times higher than those in fine-grained sediment (Huettel and Rusch, 2000), and that solute transport rates are likely greater in more permeable sediments (Falter and Sansone, 2000).

Theroux and Wigley (1998) conducted a survey of macrobenthic invertebrates in the 1950s-1960s of the area between Maine and New York and reported ancillary grain size data from their grab samples. Their data indicate that virtually all of the Block Island Sound-Rhode Island Sound study area (Fig. 3-1) is composed of sandy sediment, with a very small area of silt-clay in southern Rhode Island Sound (Theroux and Wigley, 1998). It is possible that their sample resolution was not fine enough to detect the silty areas sampled for this study, or that the sediment composition in some areas has changed over time. For discussion purposes, we scale our measured rates of benthic nutrient regeneration in fine-grained sediments to the entire area. This is often done in the literature for other continental shelf ecosystems (e.g. Rowe et al., 1975; Banta et al., 1995; Hopkinson et al., 2001; Heiss et al., 2012). However, without some quantification of rates in sandy sediments on the Southern New England shelf, it is

difficult to say how rates measured in fine-grained sediments compare. Though Theroux and Wigley (1998) did not measure rates of metabolism and nutrient regeneration, they did indicate that both the density and biomass of benthic invertebrates were highest in coarser grained sediment, and some of the highest measurements occurred in the Southern New England shelf region.

4.5 Benthic nitrogen cycle

Annual mean flux values suggest that fine-grained sediments on the Southern New England shelf are generally net sources of NH_4^+ and NO_x to the overlying water (Table 3-2). Most inner shelf systems typically report that ammonium fluxes comprise a larger portion of DIN fluxes than NO_x , although there are exceptions (Hopkinson et al., 2001). This is likely because inorganic nitrogen is remineralized from organic matter as ammonium, whereas an additional process (nitrification) is required for ammonium to be converted to NO_x . On the Southern New England shelf, however, NO_x fluxes contributed the majority to DIN fluxes relative to ammonium fluxes in approximately half of the individual cores examined throughout the study. In Massachusetts Bay, a nearby inner shelf ecosystem, ammonium fluxes tended to dominate total DIN fluxes (Hopkinson et al., 2001), but in recent years, the relative contributions of ammonium fluxes have decreased and those of NO_x have increased (Tucker et al., 2009). Over the same course of time, rates of denitrification had decreased in Massachusetts Bay (Tucker et al., 2009), which could explain the shifts in DIN flux composition. Net N_2 fluxes in offshore Southern New England sediments were within the range of those measured in other continental shelf areas, and rates of

denitrification calculated from past measurements of primary production (Riley, 1941) suggest that denitrification rates may have decreased over time in this area (Heiss et al., 2012). However, we can only speculate about changes in denitrification rates and the potential impacts on DIN flux composition because no other measurements of denitrification in this area have been made.

A switch to strong uptake of DIN species during the warm fall temperatures is likely indicative of a change in nitrate reduction processes. This occurred in both Block Island Sound and Rhode Island Sound during the fall (Fig. 3-4b). We suggest that this is indicative of direct denitrification occurring in these inner shelf sediments. Heiss et al. (2012) measured rates of net denitrification in the sediments of our stations on the same set of sediment cores that we incubated for inorganic nutrient fluxes. Based on the relationship between net N_2 gas flux and nitrate fluxes at the sediment-water interface, they concluded that coupled nitrification-denitrification played an important role on the Southern New England shelf, as is typical in most continental shelf ecosystems (e.g. Devol, 1991; Hopkinson et al., 2001). However, their data also suggested that sediments of Block Island and Rhode Island Sounds were capable of both coupled and direct denitrification, and that these sites may switch between nitrate sources depending on nitrate availability of the overlying water and oxic layer depth (Heiss et al., 2012).

4.6 Silica on the inner continental shelf of Southern New England

Both the magnitude of silica fluxes and the concentration of sediment chlorophyll in our study areas were much larger than is typical of inner continental shelf ecosystems (e.g. Hopkinson et al., 2001). DSi regeneration more closely resembled rates measured in shallow, anthropogenically impacted areas (e.g. Boston Harbor, Giblin et al., 1997; Narragansett Bay, Nixon et al., 1976; Nixon et al., 2009), as did sediment chlorophyll concentrations (e.g. Narragansett Bay; Fulweiler et al., 2010; Lake and Brush, 2011). We attribute both of these trends to high primary production and phytoplankton biomass in surface waters (Hansen and Josefson, 2003). Peaks of surface chlorophyll *a* concentration in Block Island Sound (8.6 mg m^{-3}) and Rhode Island Sound (9.8 mg m^{-3} ; Fields, 2013) were larger than is typical for most northern temperate open coastal systems, and were similar to those most commonly found in enclosed coastal ecosystems (e.g. estuaries, embayments, and coastal lagoons) in the same geographic region (Cebrián and Valiela, 1999).

If rates in fine-grained depositional areas are similar to those in sandy sediments, we calculate that benthic Si regeneration could provide the required Si for diatoms to contribute up to 99% of total annual primary production in Block Island Sound and 78% of total annual primary production in Rhode Island Sound. Diatoms require Si on an approximately 1:1 molar ratio to N (Brzezinski, 1985), and the majority of Si is regenerated from the sediment as opposed to in the water column prior to settling (Conley et al., 1993). As with other regenerated nutrients, at least some of the DSi regenerated from the benthos is probably unavailable for use in the surface waters of Rhode Island Sound when a pycnocline is present. However, given

the large contribution, benthic Si regeneration is likely extremely important in the Si cycle of both Block Island and Rhode Island Sounds. To put this in perspective, similar calculations done for Si fluxes in depositional areas of Massachusetts Bay (another inner shelf system on the Northwest Atlantic shelf) found that diatoms can comprise up to only 37% of total phytoplankton primary production in that area (Hopkinson et al., 2001).

On three occasions, we measured remarkably high uptake of Si (-90 to $-300 \mu\text{mol m}^{-2} \text{h}^{-1}$) in individual cores. Typically, silica uptake by the sediments is never reported in coastal marine ecosystems when benthic production does not occur (e.g. Gehlen et al., 1995; Hopkinson et al., 2001). All three instances of high Si uptake occurred during times of year when the water column in the surrounding area was well-mixed, and during peak water column primary production and chlorophyll concentrations (Fields, 2013). We propose that strong wind and tidal mixing rapidly carried diatoms to the sediment surface, where luxury Si uptake occurred in the dark for a short time prior to cell death. We incubated cores in the dark, and the cores are held for up to a few days before incubations begin. However, diatoms are capable of surviving in dark sediments for long periods of time (months – years; Smayda and Mitchell-Innes, 1974; Itakura et al., 1997; Lewis et al., 1999) without loss of pigments (Veuger and van Oevelen, 2011), and culture studies have shown that diatoms can take up Si in the dark, even after incorporation into frustules ceases (Chisholm et al., 1978; Jiang, 2009). Many studies have shown that diatoms are capable of luxury Si uptake (uptake in excess of necessary concentrations for cell growth), and can store soluble Si

in large internal pools (Raven, 1997; Martin-Jézéquel et al., 2000; Tozzi et al., 2004; Thamatrakoln and Hildebrand, 2008).

5 CONCLUSIONS

The differences in euphotic zone primary production between Block Island Sound and Rhode Island Sound were not reflected in benthic metabolic rates (sediment oxygen demand). The similarities in mean annual rates of sediment oxygen uptake were likely due to differences in water column hydrography between relatively more well-mixed Block Island Sound and seasonally stratified Rhode Island Sound. The increased time of organic matter in the water column of the more well-mixed system allowed for more water column decomposition of material before it reached the benthos. Additionally, the seasonal presence of a strong pycnocline in Rhode Island Sound likely prevented mixing of regenerated nutrients into surface waters where they could be used by phytoplankton. These findings indicate that the hydrographic regime of the water column (i.e. differences in stratification) may have a strong influence on benthic-pelagic coupling dynamics on the Southern New England inner continental shelf.

Another major influence on benthic flux variability was that of macrofaunal activity. Apparent differences in benthic community structure between Block Island Sound and Rhode Island Sound translated to differences in dissolved inorganic nutrient fluxes between the two areas, despite the similarities in benthic metabolism. Larger effluxes of DIN and DIP from sediments of Block Island Sound were attributed to the excretion and burrow irrigation activities of the amphipod communities that were prevalent in the majority of sediment cores collected. Though we observed macrofauna in cores from Rhode Island Sound, obvious differences in the dominant

species, and perhaps differences in density, did not elicit such large increase in nutrient effluxes.

Measures of Q_{10} temperature coefficients and a mass balance analysis of C and N flow through the ecosystems revealed the relative importance of organic matter inputs compared to temperature effects in our study areas. Block Island Sound and Rhode Island Sound are highly productive areas with benthic activity reflected in high metabolic rates and nutrient regeneration. The link between the water column and the benthos is apparent in both of these regions, though the differences in hydrographic regimes demonstrate the important effects of water column stratification on benthic-pelagic coupling dynamics in shelf ecosystems.

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APPENDIX A – ADDITIONAL METHODS AND CALCULATION DETAILS

A-1. SURFACE CHLOROPHYLL SAMPLE ANALYSIS – METHODS AND CALCULATIONS

Triplicate samples were run for each surface water sample collected for analysis of chlorophyll *a*. All steps of this analysis were performed in the dark. Immediately upon return to the lab (shortly after collection), 100-ml aliquots of sample were filtered through Whatman Binder-Free GF/F Filters (2.5 cm dia, 0.7 µm) using vacuum filtration. Filters were placed in 100 mL of ice cold 90% acetone (HPLC quality, >99%) for extraction. Filters were allowed to extract for 24 hours on ice, in the dark.

After extraction, samples were agitated on a Vortex Genie for ~30 seconds, then centrifuged for 5 minutes at 1000 G. Overlying acetone was carefully decanted and read before and after acidification with 2 drops of 10% hydrochloric acid on a Turner 10AU fluorometer.

Chlorophyll and phaeophytin concentrations are calculated by:

$$chl\ a = K \frac{F_m}{F_m - 1} * (F_b - F_a) * \frac{v}{V}$$

$$phaeo\ a = K \frac{F_m}{F_m - 1} * [(F_m * F_a) - F_b] * \frac{v}{V}$$

Where:

K = sensitivity coefficient

F_m = max acid ratio F_b/F_a of pure chlorophyll *a* standard

F_b = fluorescence before acidification

F_a = fluorescence after acidification

F_o = fluorescence signal of sample

v = extract volume (L)

V = volume filtered (L)

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A-2. SEDIMENT CHLOROPHYLL SAMPLE ANALYSIS – METHODS AND CALCULATIONS

Methods follow protocols developed by A. Giblin, J. Tucker, and S. Kelsey (Marine Biological Laboratory, Woods Hole, MA).

The top 5 cm of sediment cores were sub-sampled into cylinders 1 cm in height. Samples were placed in centrifuge tubes, and immediately wrapped in foil and stored frozen until analysis. Duplicate samples were collected for measurements of wet-dry weights. Samples were thawed (but not allowed to warm) and sonicated with a probe sonicator for 30 seconds. Samples were then extracted overnight (~16 hours) on ice in 35 ml* of 100% acetone (HPLC quality, >99%), and were resuspended (shaken) once or twice during extraction. Following extraction, samples were centrifuged for 10 minutes at 1000 G, without allowing samples to warm. Then samples were kept on ice until each one was run.

Samples were read before and after acidification with 2 drops of 0.6N hydrochloric acid on a Beckman AU Spectrophotometer at 750 and 665 nm. 750 nm readings were subtracted from corresponding 665 nm readings. Chlorophyll and phaeophytin concentrations were calculated by:

$$chl\ a(mg/m^3) = \frac{(26.7(665_o - 665_a) * v)}{V * I}$$

$$phaeo\ (mg/m^3) = \frac{(26.7(1.7 * 665_a) - 665_o) * v}{V * I}$$

Where:

665_o = extinction before acidification

665_a = extinction after acidification

v = volume of acetone used for extraction (ml)

V = volume of sediment extracted (L)

I = path length of the cuvette

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*This amount was adjusted for the water content of the sediment, so that the final acetone concentration is near 90%.

A-3. ¹⁴C PRIMARY PRODUCTION CALCULATIONS

For each water sample collected, a production versus irradiance (P-I) curve was created based on sample incubations.

Fig. A-1. Example of a P-I curve for a sample from Block Island Sound (BIS).
Courtesy J. Mercer.

For each water sample collected, a production versus irradiance (P-I) curve was created based on sample incubations. One of two models was chosen to fit the P-I curve, depending on whether or not photoinhibition occurred. In the case of photoinhibition, we used the model by Platt et al. (1980) as follows:

$$P(I) = P_{sb}(1 - e^{-a})e^{-b}$$

Where:

$P(I)$ = primary production at irradiance I , corrected for dark fixation

P_{sb} = theoretical maximum production without photoinhibition

$a = \frac{\alpha I}{P_{sb}}$ where α is the initial slope of the light dependent rise in production

$$b = \frac{\beta I}{P_{sb}} \text{ where } \beta \text{ is a term relaying the degree of photoinhibition}$$

In cases where no photoinhibition occurred, we used the model by Webb et al. (1974) as follows:

$$P(I) = P_{max}(1 - e^{a'})$$

Where:

$P(I)$ = primary production at irradiance I , corrected for dark fixation

P_{max} = light saturated maximum production

$$a' = \frac{\alpha I}{P_{max}} \text{ where } \alpha \text{ is the initial slope of the light-dependent rise in production}$$

These equations were calculated through the euphotic zone in 1 meter depth increments, and for each hour of daylight. To determine light penetration through the water column, we used Beer's Law:

$$I_z = I_o e^{-kz}$$

Where:

I_z = light irradiance at depth Z

I_o = incident irradiance at surface ($Z=0$)

K = extinction coefficient, determined by

- (1) using a light profile collected with a CTD and taking the slope of a regression of: $\ln(\frac{I_z}{I_o})$ versus depth
- (2) using a Secchi disk reading and calculating k after Holmes (1970), $1.7/\text{depth}$

A-4. BENTHIC FLUX CALCULATIONS AND EXAMPLE REGRESSIONS

Four measurements were made of each parameter throughout the course of a sediment core incubation. We incubated triplicate cores from each station. Fluxes were calculated using the four-point linear regression, scaled using the volume and area of the core, and then corrected for control core measurements.

Fig. A-2. Changes in ammonium concentration over time during an incubation of triplicate sediment cores collected from Block Island Sound (BIS).

$$water\ vol. = (average\ water\ height) * (core\ radius)^2 * \pi$$

$$flux = \frac{(slope * water\ vol.)}{area\ of\ core}$$

Fig. A-3. Example regressions of oxygen, nitrate+nitrite, and phosphate over incubation time shown for triplicate cores at various stations and times of year.

A-5. SEDIMENT CORE INCUBATION SETUP

Figure A-3. Diagram of individual core setup (left) and the magnetic turntable (right).
Approximate location of overlying water and sediment are shown with the core.
Drawings are not to scale.

APPENDIX B – SUPPLEMENTARY FIGURES AND TABLES

B-1. SURFACE CHLOROPHYLL, PRIMARY PRODUCTION, AND PHYSICAL DATA

Fig. B-1. Extinction coefficients calculated using Secchi disk depth ($1.7/\text{Secchi depth}$; Holmes, 1970) or CTD light profiles (Beer's Law; Valiela, 1995) in Block Island Sound. Plots are over the entire collection period or plotted together over one annual cycle. Overall mean extinction coefficients calculated for Secchi disk and CTD data are indicated with lines.

Fig. B-2. Extinction coefficients calculated using Secchi disk depth ($1.7/\text{Secchi depth}$; Holmes, 1970) or CTD light profiles (Beer's Law; Valiela, 1995) in Rhode Island Sound. Plots are over the entire collection period or plotted together over one annual cycle. Overall mean extinction coefficients calculated for Secchi disk and CTD data are indicated with lines.

Fig. B-3. Comparison of extinction coefficients calculated using Secchi disk depth (1.7/Secchi depth; Holmes, 1970) or CTD light profiles (Beer's Law; Valiela, 1995) in Block Island and Rhode Island Sounds. Measurements were made concurrently at the same stations on two sampling days (Jun 10, 2010 and Aug 28, 2010).

Fig. B-4. Comparison of hourly irradiance data collected from sensors at the National Climactic Data Center weather station on Flagg Rd in Kingston, RI, and a sensor deployed at the Block Island airport.

Fig. B-5. Example CTD profiles of density at Block Island Sound (top row) and Rhode Island Sound (bottom row). Density data are binned in 1 meter depth increments. It should be noted that data were collected during a year of anomalous conditions (Ullman and Codiga, 2010).

Fig. B-6. Monthly average surface chlorophyll concentrations in Block Island and Rhode Island Sound plotted over weekly measurements of surface chlorophyll in mid-Narragansett Bay (Bay data is from GSO plankton long-term monitoring program).

Fig. B-7. Comparison of daily modeled primary production calculated using two different models (BZI and Webb/Platt) based on (top) sub-surface or (bottom) depth-integrated water samples in Block Island Sound

Fig. B-8. Comparison of daily modeled primary production calculated using two different models (BZI and Webb/Platt) based on (top) sub-surface or (bottom) depth-integrated water samples in Rhode Island Sound.

B-2. BENTHIC FLUX-TEMPERATURE RELATIONSHIPS AND COMPARISONS BETWEEN ALL STATIONS

Fig. B-9. Sediment oxygen uptake plotted against temperature for each station. Shown with linear fits through the data.

Fig. B-10. Benthic ammonium fluxes plotted against temperature for each station. Shown with linear fits through the data.

Fig. B-11. Benthic nitrate+nitrite fluxes plotted against temperature for each station. Shown with linear fits through the data.

Fig. B-12. Benthic phosphate fluxes plotted against temperature for each station. Shown with linear fits through the data.

Fig. B-13. Benthic dissolved silica fluxes plotted against temperature for each station. Shown with linear fits through the data.

Table B-1. One-way ANOVA to compare fluxes of oxygen, ammonium, nitrate+nitrite, and phosphate between all stations. Different letters indicate significant differences in each flux between stations, and “ns” indicates no significant difference.

	SOD (mg m ⁻² h ⁻¹)		NH ₄ ⁺ (μmol m ⁻² h ⁻¹)		NO _x (μmol m ⁻² h ⁻¹)		DIP (μmol m ⁻² h ⁻¹)	
F	10.4		5.4		ns		ns	
p	<0.0001		0.0005		ns		ns	
<u>Station</u>	<u>Mean</u>	<u>Diff</u> s	<u>Mean</u>	<u>Diff</u> s	<u>Mean</u>	<u>Diff</u> s	<u>Mean</u>	<u>Diff</u> s
PRE	71.2	A	171.0	A	-18.8		3.0	
MNB	28.7	B	141.4	A	-9.9		7.7	
BIS	30.5	B	36.9	B	23.5		7.2	
RIS2	26.7	B	27.1	B	11.9		3.3	
RIS1	36.3	B	10.0	B	8.7		5.4	

B-3. ANALYSES OF STATIONS ON THE INNER CONTINENTAL SHELF

Fig. B-14. Benthic fluxes of oxygen, ammonium, nitrate+nitrite, phosphate, and dissolved silica over time for stations in Block Island and Rhode Island Sounds.

Fluxes are averages of triplicate sediment cores per incubation. Error bars are standard error.

Fig. B-15. Sediment oxygen uptake and benthic silica fluxes measured across the annual temperature cycle at BIS, RIS1, RIS2, and three additional stations on the Southern New England Shelf that were sampled opportunistically on one-two occasions. Symbols are numbers (1-12) that represent the month during which each core was collected.

Fig. B-16. Benthic ammonium and nitrate+nitrite fluxes measured across the annual temperature cycle at BIS, RIS1, RIS2, and three additional stations on the Southern New England Shelf that were sampled opportunistically on one-two occasions. Symbols are numbers (1-12) that represent the month during which each core was collected.

Fig. B-17. Benthic phosphate fluxes measured across the annual temperature cycle at BIS, RIS1, RIS2, and three additional stations on the Southern New England Shelf that were sampled opportunistically on one-two occasions. Symbols are numbers (1-12) that represent the month during which each core was collected.

Fig. B-18. Benthic fluxes of dissolved inorganic nitrogen plotted against initial concentrations of various N species. Symbols distinguish between six stations sampled on the Southern New England continental shelf.

Fig. B-19. Histogram of ammonium/nitrate+nitrite flux ratios in sediment cores from our offshore sampling stations.

Fig. B-20. Ratio of ammonium/nitrate+nitrite fluxes in sediment cores plotted against fluxes of dissolved inorganic nitrogen. Symbols distinguish between our offshore sampling stations, and dashed line references an equal (1:1) contribution of ammonium and nitrate+nitrite fluxes to DIN fluxes.

Fig. B-21. Benthic fluxes of DIN versus fluxes of DIP at the three offshore stations measured across at least one complete annual cycle. DIN/DIP ratios were calculated for each station (above) including all fluxes, and (below) including nutrient regeneration only (excluding uptake). Dashed line is a reference of the Redfield N:P ratio (16:1).

Fig. B-22. (top) Dissolved silica regeneration versus DIN regeneration, and (bottom) sediment oxygen uptake versus phosphate regeneration at our offshore sampling stations. Si/DIN and O/DIP ratios were calculated for each of the three stations (BIS, RIS1, and RIS2) that were sampled over at least one annual cycle. Dashed lines are reference lines of the Redfield ratios of Si/N (1:1) and O/P (138).

Table B-2. Correlation matrix of benthic fluxes, initial nutrient concentrations, and environment characteristics for cores collected from 2009-2012 at the Block Island Sound (BIS) sampling station. Correlation coefficients that are significant at the $p < 0.05$ level are shaded in gray.

BIS	Temp	SOD	NH ₄ ⁺ flux	NO _x flux	DIP flux	Si flux	Sed. Chloro	Sed. Phaeo	%OM, 0-1cm	C/N, 0-1cm	Initial [NH ₄ ⁺]	Initial [DIP]	Initial [NO _x]	Initial [Si]
Temp		0.58	0.26	0	0.5	0.57	-0.09	-0.44	-0.5	0.24	0.07	-0.15	-0.46	0.49
SOD	0.58		0.37	-0.03	-0.19	0.39	-0.2	0.18	0.16	0.11	0.12	-0.01	-0.27	0.77
NH ₄ ⁺ flux	0.26	0.37		0.08	-0.01	0.03	0.14	0.05	0.24	0.73	0.73	0.4	-0.54	0.4
NO _x flux	0	-0.03	0.08		0.53	0.02	-0.46	0.34	-0.23	-0.44	0.46	0.22	0.13	-0.24
DIP flux	0.5	-0.19	-0.01	0.53		0.21	-0.3	-0.3	-0.38	0.04	0.34	-0.02	-0.11	-0.11
Si flux	0.57	0.39	0.03	0.02	0.21		-0.05	-0.03	-0.47	0.27	-0.13	-0.77	-0.68	0.34
Sed. Chloro	-0.09	-0.2	0.14	-0.46	-0.3	-0.05		0.02	-0.09	0.32	0.08	0.19	-0.13	-0.04
Sed. Phaeo	-0.44	0.18	0.05	0.34	-0.3	-0.03	0.02		0.45	-0.32	0.38	0.11	0.18	0.03
%OM, 0-1cm	-0.5	0.16	0.24	-0.23	-0.38	-0.47	-0.09	0.45		0.56	0.52	0.41	0.2	0.45
C/N, 0-1cm	0.24	0.11	0.73	-0.44	0.04	0.27	0.32	-0.32	0.56		0.4	-0.12	-0.65	0.44
Initial [NH ₄ ⁺]	0.07	0.12	0.73	0.46	0.34	-0.13	0.08	0.38	0.52	0.4		0.53	-0.23	0.13
Initial [DIP]	-0.15	-0.01	0.4	0.22	-0.02	-0.77	0.19	0.11	0.41	-0.12	0.53		0.38	0
Initial [NO _x]	-0.46	-0.27	-0.54	0.13	-0.11	-0.68	-0.13	0.18	0.2	-0.65	-0.23	0.38		-0.43
Initial [Si]	0.49	0.77	0.4	-0.24	-0.11	0.34	-0.04	0.03	0.45	0.44	0.13	0	-0.43	

Table B-3. Correlation matrix of benthic fluxes, initial nutrient concentrations, and environment characteristics for cores collected from 2009-2012 at a Rhode Island Sound (RIS2) sampling station. Correlation coefficients that are significant at the $p < 0.05$ level are shaded in gray.

RIS2	Temp	SOD	NH ₄ ⁺ flux	NO _x flux	DIP flux	Si flux	Sed. Chloro	Sed. Phaeo	%OM, 0-1cm	C/N, 0-1cm	Initial [NH ₄ ⁺]	Initial [DIP]	Initial [NO _x]	Initial [Si]
Temp		0.48	0.14	-0.12	0.17	0.69	0.07	-0.36	-0.54	-0.66	0.29	0.55	0.46	0.69
SOD	0.48		-0.14	0.29	0.28	0.68	-0.1	-0.1	-0.69	-0.57	-0.26	0.23	0.46	-0.04
NH ₄ ⁺ flux	0.14	-0.14		0.4	0.7	-0.14	0.08	0.19	0.45	-0.38	0.64	0.04	0.09	0.51
NO _x flux	-0.12	0.29	0.4		0.44	-0.39	-0.37	0.36	-0.49	-0.26	0.18	0.23	0.1	-0.05
DIP flux	0.17	0.28	0.7	0.44		0.19	-0.29	0.35	0.25	-0.4	0.17	-0.17	0.43	0.23
Si flux	0.69	0.68	-0.14	-0.39	0.19		0.22	-0.33	-0.45	-0.36	-0.1	0.05	0.33	0.19
Sed. Chloro	0.07	-0.1	0.08	-0.37	-0.29	0.22		-0.07	0.42	0.1	0.38	0.1	-0.21	0.11
Sed. Phaeo	-0.36	-0.1	0.19	0.36	0.35	-0.33	-0.07		0.57	-0.19	0.13	-0.03	0.02	-0.12
%OM, 0-1cm	-0.54	-0.69	0.45	-0.49	0.25	-0.45	0.42	0.57		0.61	0.11	-0.57	-0.47	-0.2
C/N, 0-1cm	-0.66	-0.57	-0.38	-0.26	-0.4	-0.36	0.1	-0.19	0.61		-0.23	-0.49	-0.39	-0.55
Initial [NH ₄ ⁺]	0.29	-0.26	0.64	0.18	0.17	-0.1	0.38	0.13	0.11	-0.23		0.54	-0.13	0.7
Initial [DIP]	0.55	0.23	0.04	0.23	-0.17	0.05	0.1	-0.03	-0.57	-0.49	0.54		0.38	0.68
Initial [NO _x]	0.46	0.46	0.09	0.1	0.43	0.33	-0.21	0.02	-0.47	-0.39	-0.13	0.38		0.45
Initial [Si]	0.69	-0.04	0.51	-0.05	0.23	0.19	0.11	-0.12	-0.2	-0.55	0.7	0.68	0.45	

Table B-4. Results of principal component analysis run on data collected at offshore stations (see chapter 3). Five of the thirteen principal components (PC) accounted for 80.1% of the variance in data. Shaded variables are most strongly associated with the respective vector ($|r| > 0.5$). Initial bottom water concentrations of NO_x and NH_4^+ were log normally (ln) transformed to achieve a normal distribution before analysis.

	PC1	PC2	PC3	PC4	PC5
Temperature	0.44	0.10	0.26	-0.25	-0.23
SOD	0.20	0.33	0.25	0.44	-0.20
NH_4^+ flux	0.06	0.53	-0.17	-0.06	-0.08
NO_x flux	-0.35	0.28	0.31	-0.15	0.09
DIP flux	0.01	0.29	0.30	-0.35	0.51
DSi flux	0.36	0.24	0.22	0.18	0.03
Sed. Chloro	0.21	0.19	-0.37	0.22	0.03
Sed. Phaeo	-0.32	0.32	0.04	0.45	-0.02
Sed. %OM	0.01	0.17	-0.46	0.19	0.45
Initial NO_x	-0.05	-0.11	0.50	0.32	0.18
Initial NH_4^+	-0.19	0.40	-0.10	-0.38	-0.40
Surf. Chloro	0.26	-0.15	0.04	0.07	0.62
BZI daily PP	0.50	0.07	-0.06	-0.12	-0.04
EIGENVALUE	3.09	2.61	1.92	1.40	1.38
% Explained	23.81	20.07	14.79	10.79	10.62

B-4. ANALYSES OF STATIONS IN NARRAGANSETT BAY

(a) 2010s

(b) 2000s

(c) 1980s

Fig. B-23. Benthic DIN fluxes plotted against DIP fluxes over time in mid-Narragansett Bay. Regression lines and DIN/DIP ratios were done using regeneration only (closed circles).

Fig. B-24. Benthic fluxes of oxygen, phosphate, and ammonium measured in mid-Narragansett Bay shown over time with concurrent measures of bottom water dissolved oxygen concentrations. Fluxes are means of triplicate cores from each incubation, shown with standard error bars. Dissolved oxygen concentrations are the averages of the day of core collection plus two days prior (3 day averages). Dissolved oxygen data are from Kiernan et al. buoy data; see chapter 1 text for URL).

Fig. B-25. (a) Average wind speed in Providence, RI and (b) the relationship between the number of hypoxic days (average daily dissolved oxygen concentrations $< 93.75 \mu\text{mol L}^{-1}$) and cubed wind speed during the least windy months of the year (July, August, and September) from 1972 to 2012. Daily wind measurements made by NOAA (1972-present) at the National Climactic Data Center station on Green St, Providence, RI, and dissolved oxygen concentration data from Kieman (2004-present).

APPENDIX C – DATA

C-1. SURFACE CHLOROPHYLL AND PRIMARY PRODUCTION DATA

Table C-1. Measurements of ^{14}C primary production made in Block Island Sound (BIS) and Rhode Island Sound (RIS) during 2010. Sampling method indicates whether samples were collected throughout the entire euphotic zone using a hose (“hose”), or collected at sub-surface depth using a Niskin bottle (“Niskin”). Model indicates the equation used to calculate euphotic zone primary production. The Platt model was used in cases of photoinhibition, and the Webb model was used when no photoinhibition was measured. See chapter 2 for definition of model parameters. Measurements made by J. Mercer.

Date	Station	Sampling Method	Chlorophyll (mg m^{-3})	^{14}C Primary Production ($\text{mg C m}^{-2} \text{ d}^{-1}$)	Model	Extinction Coefficient (m^{-1})
1/19/10	BIS	Hose	4.55	181	Platt	0.27
1/19/10	BIS	Niskin	5.97	130	Platt	0.27
1/19/10	RIS	Hose	6.07	99.73	Platt	0.29
1/19/10	RIS	Niskin	6.07	161.67	Platt	0.29
2/5/10	BIS	Hose	4.80	1196	Platt	0.33
2/5/10	BIS	Niskin	5.03	660	Platt	0.33
2/5/10	RIS	Hose	3.77	308.90	Platt	0.28
2/5/10	RIS	Niskin	4.30	700.89	Platt	0.28
3/10/10	BIS	Niskin	1.40	231	Platt	0.19
3/10/10	RIS	Niskin	1.31	354.26	Webb	0.19
4/14/10	BIS	Hose	1.45	339	Platt	0.21
4/14/10	BIS	Niskin	1.33	667	Webb	0.21
4/14/10	RIS	Hose	2.49	349.05	Platt	0.19
4/14/10	RIS	Niskin	0.88	434.73	Platt	0.19
4/30/10	BIS	Hose	2.20	873	Platt	0.22
4/30/10	BIS	Niskin	2.10	1140	Platt	0.22
4/30/10	RIS	Hose	1.05	374.95	Platt	0.22
4/30/10	RIS	Niskin	0.94	427.33	Platt	0.22
5/12/10	BIS	Hose	0.78	115	Platt	0.19
5/12/10	BIS	Niskin	1.40	239	Platt	0.19
5/12/10	RIS	Hose	0.84	267.34	Platt	0.14
5/12/10	RIS	Niskin	0.84	376.25	Platt	0.14
6/17/10	BIS	Hose	2.90	354	Platt	0.26
6/17/10	BIS	Niskin	2.02	815	Platt	0.26
6/17/10	RIS	Hose	0.64	50.03	Platt	0.18
6/17/10	RIS	Niskin	0.93	202.16	Platt	0.18
7/1/10	BIS	Hose	1.56	663	Platt	0.22
7/1/10	BIS	Niskin	1.20	1131	Platt	0.22
7/1/10	RIS	Hose	0.89	467.80	Platt	0.18
7/1/10	RIS	Niskin	0.75	785.22	Platt	0.18
7/23/10	BIS	Hose	1.53	295	Platt	0.23
7/23/10	BIS	Niskin	0.85	556	Platt	0.23
7/23/10	RIS	Hose	1.40	270.64	Platt	0.22

Date	Station	Sampling Method	Chlorophyll (mg m ⁻³)	¹⁴ C Primary Production (mg C m ⁻² d ⁻¹)	Model	Extinction Coefficient (m ⁻¹)
7/23/10	RIS	Niskin	1.14	288.76	Platt	0.22
8/17/10	BIS	Hose	4.73	1472	Platt	0.21
8/17/10	BIS	Niskin	4.62	2848	Platt	0.21
8/17/10	RIS	Hose	2.15	571.71	Platt	0.21
8/17/10	RIS	Niskin	3.12	2119.66	Platt	0.21
9/14/10	BIS	Hose	2.47	1138	Platt	0.25
9/14/10	BIS	Niskin	1.27	799	Platt	0.25
9/14/10	RIS	Hose	1.71	796.66	Platt	0.23
9/14/10	RIS	Niskin	1.30	735.93	Platt	0.23
10/13/10	BIS	Hose	5.24	2095	Platt	0.34
10/13/10	BIS	Niskin	5.79	2921	Platt	0.34
10/13/10	RIS	Hose	5.00	1894.25	Platt	0.31
10/13/10	RIS	Niskin	3.93	2082.70	Platt	0.31
11/29/10	BIS	Hose	2.45	274	Platt	0.32
11/29/10	BIS	Niskin	1.96	239	Webb	0.32
11/29/10	RIS	Hose	3.98	733.06	Platt	0.28
11/29/10	RIS	Niskin	2.52	430.61	Platt	0.28
12/30/10	BIS	Hose	2.50	344	Platt	0.33
12/30/10	BIS	Niskin	2.73	308	Platt	0.34
12/30/10	RIS	Hose	2.74	442.43	Platt	0.29
12/30/10	RIS	Niskin	3.80	420.36	Webb	0.29

Table C-2. Additional parameters from ^{14}C incubations.

Date	Station	Sampling Method	Euphotic Depth (m)	P_{max} or P_b	α	β
1/19/10	BIS	Hose	16.80	13.21	0.16	0.008
1/19/10	BIS	Niskin	16.80	29.59	0.10	0.023
				24600000		426447.
1/19/10	RIS	Hose	15.69	0.00	0.08	700
1/19/10	RIS	Niskin	15.69	14.83	0.15	0.002
2/5/10	BIS	Hose	13.78	18.51	0.24	0.004
2/5/10	BIS	Niskin	13.78	14.51	0.10	0.007
2/5/10	RIS	Hose	16.64	203457.40	0.02	278.447
2/5/10	RIS	Niskin	16.64	12.20	0.07	0.001
3/10/10	BIS	Niskin	24.35	3.82	0.01	0.003
3/10/10	RIS	Niskin	24.21	2.56	0.02	n/a
4/14/10	BIS	Hose	22.19	9.60	0.02	0.014
4/14/10	BIS	Niskin	22.19	5.58	0.02	n/a
4/14/10	RIS	Hose	24.75	2.11	0.02	0.001
4/14/10	RIS	Niskin	24.75	2.73	0.02	0.000
4/30/10	BIS	Hose	21.38	9.88	0.03	0.003
4/30/10	BIS	Niskin	21.38	22.54	0.04	0.016
4/30/10	RIS	Hose	20.96	3.61	0.02	0.002
4/30/10	RIS	Niskin	20.96	2.86	0.03	0.000
5/12/10	BIS	Hose	24.24	2.66	0.01	0.002
5/12/10	BIS	Niskin	24.24	3.76	0.02	0.002
5/12/10	RIS	Hose	32.48	2.04	0.02	0.001
5/12/10	RIS	Niskin	32.48	3.26	0.02	0.001
6/17/10	BIS	Hose	17.65	4.25	0.02	0.002
6/17/10	BIS	Niskin	17.65	8.16	0.05	0.001
6/17/10	RIS	Hose	25.00	0.61	0.00	0.001
6/17/10	RIS	Niskin	25.00	1.59	0.01	0.001
7/1/10	BIS	Hose	20.83	6.14	0.04	0.003
7/1/10	BIS	Niskin	20.83	9.22	0.05	0.001
7/1/10	RIS	Hose	26.27	2.64	0.02	0.001
7/1/10	RIS	Niskin	26.27	4.97	0.03	0.000
7/23/10	BIS	Hose	20.45	5.09	0.03	0.003
7/23/10	BIS	Niskin	20.45	10.34	0.04	0.002
7/23/10	RIS	Hose	21.00	3.19	0.03	0.002
7/23/10	RIS	Niskin	21.00	5.33	0.02	0.001
8/17/10	BIS	Hose	22.14	21.09	0.09	0.013
8/17/10	BIS	Niskin	22.14	46.57	0.13	0.014
8/17/10	RIS	Hose	22.36	6.64	0.04	0.004
8/17/10	RIS	Niskin	22.36	24.35	0.12	0.007
9/14/10	BIS	Hose	18.58	20.05	0.07	0.011
9/14/10	BIS	Niskin	18.58	11.29	0.04	0.002
9/14/10	RIS	Hose	19.84	8.10	0.05	0.001
9/14/10	RIS	Niskin	19.84	8.88	0.04	0.001
10/13/10	BIS	Hose	13.47	40.50	0.21	0.016
10/13/10	BIS	Niskin	13.47	91.69	0.23	0.052

Date	Station	Sampling Method	Euphotic Depth (m)	$P_{\max}$ or P_b	α	β
10/13/10	RIS	Hose	14.90	28.14	0.16	0.002
10/13/10	RIS	Niskin	14.90	29.91	0.18	0.001
11/29/10	BIS	Hose	14.46	5.63	0.04	0.001
11/29/10	BIS	Niskin	14.46	8.34	0.02	n/a
11/29/10	RIS	Hose	16.70	15.78	0.08	0.006
11/29/10	RIS	Niskin	16.70	9.25	0.04	0.002
12/30/10	BIS	Hose	13.80	8.68	0.05	0.003
12/30/10	BIS	Niskin	13.61	16.83	0.04	0.013
12/30/10	RIS	Hose	16.13	8.13	0.06	0.000
12/30/10	RIS	Niskin	16.13	9.36	0.04	n/a

Table C-3. Measurements of surface chlorophyll *a* concentrations collected throughout the Southern New England inner continental shelf from Dec 2008 to Sep 2010.

Date	Time	Latitude	Longitude	Surface chlorophyll <i>a</i> ($\mu\text{g L}^{-1}$)
12/18/2008	10:15	41.18	-71.76	1.74
12/18/2008	10:36	41.22	-71.78	2.50
12/18/2008	11:17	41.28	-71.80	3.74
12/18/2008	11:49	41.25	-71.70	3.90
12/18/2008	12:12	41.23	-71.63	3.46
12/18/2008	13:20	41.28	-71.63	2.95
12/18/2008	13:0	41.31	-71.64	6.53
12/18/2008	14:0	41.30	-71.52	27.36
12/18/2008	14:45	41.36	-71.43	5.25
1/22/2009	9:08	41.36	-71.24	2.95
2/26/2009	14:00	41.05	-71.62	2.29
2/26/2009		41.05	-71.57	2.83
2/26/2009	11:05	41.14	-71.53	2.97
2/26/2009	10:22	41.18	-71.40	2.35
2/26/2009		41.27	-71.38	3.50
2/26/2009	7:41	41.18	-71.31	4.70
2/26/2009	6:30	41.31	-71.39	1.30
3/26/2009	11:50	41.18	-71.31	0.53
3/26/2009	11:20	41.27	-71.33	0.65
3/26/2009	10:40	41.18	-71.35	0.79
3/26/2009	10:00	41.27	-71.38	0.58
3/26/2009	9:14	41.16	-71.46	0.59
3/26/2009	8:10	41.05	-71.58	0.56
3/26/2009	6:48	41.05	-71.62	0.89
4/23/2009	15:10	41.31	-71.80	0.84
4/23/2009	12:45	41.27	-71.73	0.54
4/23/2009	12:00	41.22	-71.73	0.80
4/23/2009	11:30	41.22	-71.69	0.58
4/23/2009	10:25	41.24	-71.60	0.74
4/23/2009	8:45	41.24	-71.50	0.50
4/23/2009	6:45	41.24	-71.54	0.49
4/26/2009	15:30	41.35	-71.52	0.49
4/26/2009	15:10	41.31	-71.52	0.55
4/26/2009	14:15	41.19	-71.55	0.52
4/26/2009	12:25	41.16	-71.52	0.55
4/26/2009	11:35	41.20	-71.51	0.53
4/26/2009	10:25	41.25	-71.52	0.64
4/26/2009	9:45	41.25	-71.55	0.83
4/26/2009	8:55	41.23	-71.52	0.78
4/30/2009	15:45	41.34	-71.54	1.14
4/30/2009	15:15	41.30	-71.58	1.25
4/30/2009	12:30	41.22	-71.73	1.00
4/30/2009	9:05	41.08	-71.59	1.13

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
4/30/2009	8:05	41.11	-71.64	1.16
4/30/2009	7:35	41.14	-71.69	1.23
4/30/2009	6:50	41.18	-71.69	1.16
4/30/2009	6:00	41.21	-71.65	0.98
5/7/2009	12:40	41.33	-71.54	0.88
5/7/2009	12:25	41.31	-71.56	1.22
5/7/2009	12:15	41.28	-71.57	0.93
5/7/2009	11:30	41.20	-71.63	0.74
5/7/2009	11:05	41.15	-71.67	0.71
5/7/2009	10:15	41.06	-71.69	1.19
5/7/2009	8:10	41.03	-71.66	0.56
5/11/2009	10:45	41.36	-71.52	0.44
5/11/2009	10:35	41.35	-71.55	0.68
5/11/2009	10:20	41.34	-71.58	0.76
5/11/2009	10:5	41.33	-71.62	0.59
5/11/2009	9:35	41.33	-71.66	0.77
5/11/2009	7:55	41.31	-71.76	0.77
5/11/2009	7:10	41.32	-71.71	1.11
5/13/2009	9:10	41.36	-71.51	0.62
5/13/2009	9:00	41.35	-71.53	0.53
5/13/2009	9:15	41.34	-71.56	0.41
5/13/2009	8:30	41.33	-71.59	0.40
5/13/2009	8:15	41.33	-71.63	0.45
5/13/2009	7:50	41.32	-71.67	1.11
5/13/2009	7:30	41.32	-71.70	0.73
5/13/2009	6:55	41.32	-71.73	0.56
5/15/2009	10:30	41.36	-71.53	1.30
5/15/2009	10:15	41.35	-71.57	0.79
5/15/2009	10:00	41.34	-71.60	0.61
5/15/2009	9:40	41.33	-71.64	0.78
5/15/2009	9:15	41.33	-71.66	0.91
5/15/2009	8:30	41.32	-71.69	0.83
5/15/2009	8:00	41.32	-71.72	0.69
5/15/2009	6:55	41.31	-71.69	0.85
5/18/2009	9:20	41.33	-71.63	0.63
5/18/2009	8:55	41.32	-71.66	0.62
5/18/2009	8:30	41.32	-71.68	0.91
5/18/2009	8:05	41.32	-71.71	1.52
5/18/2009	7:15	41.31	-71.74	1.22
5/18/2009	6:45	41.31	-71.77	1.21
6/11/2009	14:25	41.37	-71.51	2.83
6/11/2009	14:10	41.35	-71.54	3.17
6/11/2009	13:55	41.34	-71.60	2.58
6/11/2009	13:35	41.33	-71.65	2.28
6/11/2009	13:25	41.32	-71.68	2.47
6/11/2009	6:35	41.32	-71.71	2.23

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
6/11/2009	5:55	41.31	-71.74	1.80
6/11/2009	5:15	41.30	-71.78	1.46
6/12/2009	10:40	41.35	-71.51	2.69
6/12/2009	10:32	41.34	-71.48	3.60
6/12/2009	10:20	41.33	-71.46	3.37
6/12/2009	10:00	41.30	-71.43	2.78
6/12/2009	9:45	41.28	-71.40	1.95
6/12/2009	9:30	41.26	-71.37	2.10
6/12/2009	6:30	41.12	-71.29	1.41
6/12/2009	5:30	41.16	-71.28	1.32
6/15/2009	9:25	41.33	-71.46	2.85
6/15/2009	9:00	41.28	-71.41	1.20
6/15/2009	8:45	41.26	-71.38	1.05
6/15/2009	8:30	41.23	-71.35	1.12
6/15/2009	8:00	41.19	-71.29	1.30
6/15/2009	6:00	41.11	-71.30	1.10
6/15/2009	5:35	41.13	-71.29	1.16
6/15/2009	4:50	41.17	-71.28	1.12
6/25/2009	12:35	41.28	-71.43	1.35
6/25/2009	11:00	41.27	-71.53	1.20
6/25/2009	9:20	41.27	-71.44	2.40
6/25/2009	8:20	41.26	-71.48	2.10
6/25/2009	7:05	41.28	-71.52	2.15
6/25/2009	6:15	41.27	-71.47	2.98
6/25/2009	5:30	41.28	-71.43	1.52
6/25/2009	5:10	41.30	-71.40	1.13
6/30/2009	13:30	41.09	-71.56	0.81
6/30/2009	13:19	41.05	-71.57	0.99
6/30/2009	10:53	41.13	-71.57	1.31
6/30/2009	9:47	41.27	-71.34	0.72
6/30/2009	6:30	41.19	-71.32	0.62
6/30/2009	5:55	41.31	-71.49	1.92
7/1/2009	10:45	41.27	-71.43	1.46
7/1/2009	10:20	41.23	-71.40	0.74
7/1/2009	7:55	41.17	-71.28	0.76
7/1/2009	6:30	41.10	-71.29	0.82
7/1/2009	6:10	41.11	-71.29	0.95
7/1/2009	5:25	41.15	-71.29	0.88
7/1/2009	5:00	41.19	-71.29	0.71
7/2/2009	11:45	41.27	-71.49	1.62
7/2/2009	10:55	41.28	-71.52	0.90
7/2/2009	9:55	41.28	-71.60	1.74
7/2/2009	9:30	41.31	-71.65	1.73
7/2/2009	8:50	41.31	-71.69	1.53
7/2/2009	8:10	41.32	-71.73	1.49
7/2/2009	7:05	41.31	-71.70	1.90

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
7/2/2009	6:15	41.31	-71.74	2.03
7/6/2009	12:55	41.35	-71.55	1.88
7/6/2009	11:55	41.32	-71.64	1.31
7/6/2009	11:20	41.32	-71.68	1.94
7/6/2009	9:25	41.30	-71.67	1.66
7/6/2009	7:35	41.29	-71.76	2.57
7/6/2009	7:10	41.31	-71.78	2.65
7/6/2009	6:00	41.32	-71.71	2.16
7/6/2009	4:50	41.33	-71.61	1.92
7/7/2009	10:55	41.20	-71.61	1.68
7/7/2009	9:30	41.03	-71.62	1.15
7/7/2009	10:15	41.14	-71.64	1.22
7/7/2009	6:55	40.93	-71.58	0.88
7/7/2009	6:35	40.94	-71.59	0.85
7/7/2009	5:15	40.99	-71.61	0.86
7/7/2009	4:25	41.07	-71.60	1.43
7/7/2009	3:30	41.14	-71.55	1.35
7/13/2009	13:45	41.34	-71.49	1.51
7/13/2009	13:20	41.27	-71.44	1.22
7/13/2009	12:00	41.30	-71.53	1.61
7/13/2009	11:30	41.30	-71.60	2.07
7/13/2009	9:05	41.31	-71.75	2.29
7/13/2009	8:20	41.32	-71.71	2.59
7/13/2009	7:05	41.32	-71.65	2.84
7/14/2009	10:45	41.21	-71.37	0.72
7/14/2009	11:40	41.30	-71.46	0.95
7/14/2009	11:20	41.27	-71.43	0.81
7/14/2009	12:00	41.33	-71.49	1.37
7/14/2009	10:15	41.15	-71.32	0.65
7/14/2009	8:25	41.17	-71.28	0.80
7/14/2009	6:25	41.10	-71.29	0.79
7/14/2009	5:45	41.13	-71.30	0.82
7/15/2009	11:35	41.33	-71.49	1.30
7/15/2009	11:00	41.27	-71.43	0.76
7/15/2009	10:15	41.19	-71.36	0.66
7/15/2009	7:50	41.17	-71.26	0.57
7/15/2009	7:05	41.14	-71.29	0.59
7/15/2009	6:00	41.10	-71.30	0.84
7/22/2009	19:0	41.36	-71.44	2.50
7/22/2009	18:40	41.35	-71.39	3.48
7/22/2009	17:50	41.34	-71.25	1.36
7/22/2009	17:25	41.33	-71.17	0.91
7/22/2009	16:50	41.33	-71.07	0.94
7/22/2009	16:20	41.31	-70.97	1.15
7/29/2009	15:29	41.30	-71.37	1.19
7/29/2009	14:32	41.23	-71.23	1.03

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
7/29/2009	8:50	41.18	-71.31	0.87
7/30/2009	13:10	41.32	-71.52	1.74
7/30/2009	12:50	41.29	-71.52	2.14
7/30/2009	12:30	41.25	-71.52	2.43
7/30/2009	12:10	41.21	-71.53	1.97
7/30/2009	11:45	41.15	-71.54	1.28
7/30/2009	11:30	41.13	-71.56	2.02
8/3/2009	11:25	41.36	-71.53	3.63
8/3/2009	11:05	41.34	-71.57	3.05
8/3/2009	10:40	41.33	-71.62	2.36
8/3/2009	10:15	41.32	-71.66	2.10
8/3/2009	9:30	41.32	-71.70	1.66
8/3/2009	8:30	41.32	-71.74	1.40
8/3/2009	7:55	41.30	-71.80	2.57
8/12/2009	10:45	41.33	-71.53	2.16
8/12/2009	10:10	41.29	-71.53	2.35
8/12/2009	9:40	41.26	-71.52	2.96
8/12/2009	8:15	41.19	-71.53	1.85
8/12/2009	8:00	41.22	-71.54	2.43
8/12/2009	7:40	41.26	-71.55	2.60
8/12/2009	7:15	41.23	-71.61	2.34
8/12/2009	7:00	41.21	-71.64	3.02
8/18/2009	15:22	41.35	-71.48	2.86
8/18/2009	15:9	41.33	-71.46	1.69
8/18/2009	14:53	41.31	-71.43	1.54
8/18/2009	14:40	41.28	-71.41	1.05
8/18/2009	14:23	41.26	-71.37	0.91
8/18/2009	14:10	41.23	-71.35	1.00
8/18/2009	13:36	41.25	-71.32	0.88
8/18/2009	13:02	41.22	-71.33	0.97
8/20/2009	15:32	41.25	-71.39	1.59
8/20/2009	15:05	41.20	-71.34	1.00
8/20/2009	13:56	41.19	-71.30	0.67
8/20/2009	11:20	41.21	-71.28	0.63
8/20/2009	9:18	41.22	-71.24	0.75
8/20/2009	7:48	41.26	-71.26	0.63
8/20/2009	7:20	41.28	-71.33	0.77
8/20/2009	6:48	41.31	-71.41	2.00
8/21/2009	13:30	41.25	-71.25	1.15
8/21/2009	13:12	41.25	-71.26	1.09
8/21/2009	12:35	41.23	-71.32	1.08
8/21/2009	11:58	41.21	-71.26	0.92
8/21/2009	11:16	41.13	-71.29	0.98
8/21/2009	10:52	41.13	-71.23	0.83
8/21/2009	10:00	41.06	-71.26	0.68
8/21/2009	9:45	41.02	-71.35	0.70

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
9/2/2009		41.28	-71.71	2.69
9/2/2009		41.26	-71.75	4.32
9/2/2009		41.21	-71.80	2.24
9/2/2009		41.20	-71.69	3.89
9/2/2009	9:15	41.26	-71.63	3.03
9/2/2009	9:00	41.31	-71.61	2.64
9/3/2009	9:33	41.21	-71.47	1.35
9/3/2009	9:09	41.15	-71.47	0.97
9/3/2009	8:02	41.04	-71.44	0.48
9/3/2009	6:12	41.00	-71.42	0.58
9/3/2009	1:57	41.01	-71.42	0.57
9/3/2009	0:29	40.99	-71.41	0.44
9/2/2009	23:04	41.06	-71.45	0.89
9/2/2009	19:04	41.06	-71.38	0.48
9/3/2009		41.35	-71.49	6.26
9/3/2009		41.32	-71.46	1.03
9/3/2009		41.25	-71.39	1.06
9/3/2009		41.21	-71.35	1.25
9/3/2009		41.10	-71.30	0.83
9/3/2009		41.14	-71.29	1.09
9/3/2009		41.17	-71.28	1.35
9/4/2009	11:12	41.36	-71.42	1.66
9/4/2009	10:24	41.29	-71.30	0.63
9/4/2009	9:56	41.26	-71.34	1.64
9/4/2009	8:58	41.18	-71.42	1.09
9/8/2009	22:41	41.32	-71.49	3.36
9/8/2009	22:30	41.21	-71.49	3.58
9/8/2009	22:17	41.26	-71.48	2.85
9/8/2009	21:40	41.20	-71.48	1.84
9/8/2009	20:00	41.02	-71.43	0.23
9/8/2009	17:40	41.00	-71.42	0.23
9/8/2009	16:03	41.00	-71.41	0.19
9/8/2009	14:25	40.98	-71.42	0.22
9/13/2009	22:10	41.26	-71.47	3.09
9/13/2009	21:42	41.21	-71.46	1.72
9/13/2009	20:45	41.11	-71.44	1.75
9/13/2009	19:9	41.00	-71.42	0.69
9/13/2009	16:11	40.99	-71.42	0.45
9/13/2009	12:17	41.01	-71.43	0.75
9/13/2009	8:15	40.98	-71.42	0.82
9/13/2009	7:00	41.00	-71.42	1.78
9/15/2009	11:45	41.32	-71.50	7.10
9/15/2009	11:10	41.27	-71.48	5.85
9/15/2009	10:50	41.23	-71.48	3.76
9/15/2009	8:55	41.21	-71.52	3.41
9/15/2009	7:55	41.25	-71.55	4.40

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
9/15/2009	7:35	41.26	-71.59	4.48
9/15/2009	7:15	41.27	-71.63	3.44
9/15/2009	6:55	41.29	-71.68	2.40
9/16/2009	10:40	41.35	-71.52	6.18
9/16/2009	10:25	41.31	-71.54	3.32
9/16/2009	9:50	41.27	-71.57	4.49
9/16/2009	9:30	41.23	-71.60	3.94
9/16/2009	8:55	41.19	-71.62	4.01
9/16/2009	8:25	41.17	-71.63	3.23
9/16/2009	8:00	41.17	-71.67	2.40
9/16/2009	7:35	41.19	-71.72	2.50
9/21/2009	14:51	41.33	-71.42	2.17
9/21/2009	14:46	41.32	-71.41	2.10
9/21/2009	13:57	41.27	-71.28	1.14
9/21/2009	13:31	41.26	-71.21	1.25
9/21/2009	11:59	41.27	-71.23	1.62
9/21/2009	10:45	41.27	-71.24	1.72
9/22/2009	14:40	41.21	-71.15	0.51
9/22/2009	14:13	41.24	-71.04	0.85
9/22/2009	13:19	41.11	-71.12	0.54
9/22/2009	11:30	40.98	-71.31	0.75
9/22/2009	10:00	41.05	-70.99	0.47
9/22/2009	9:03	41.17	-70.91	0.64
9/22/2009	8:08	41.35	-71.03	3.00
9/22/2009	6:56	41.38	-71.26	2.91
9/23/2009	12:55	41.24	-71.49	4.42
9/23/2009	12:09	41.15	-71.47	0.41
9/23/2009	11:07	41.05	-71.45	0.41
9/23/2009	10:48	41.16	-71.36	0.48
9/23/2009	10:12	41.18	-71.26	0.67
9/23/2009	9:50	41.28	-71.29	0.94
9/24/2009	12:30	41.21	-71.68	6.51
9/24/2009	12:07	41.21	-71.81	4.69
9/24/2009	11:42	41.20	-71.78	3.33
9/24/2009	11:16	41.12	-71.77	4.03
9/24/2009	10:15	41.04	-71.66	4.66
9/24/2009	9:30	40.97	-71.76	7.20
9/24/2009	8:52	40.97	-71.65	5.54
9/24/2009	8:00	41.05	-71.56	2.40
10/20/2009	15:26	41.22	-71.38	6.39
10/20/2009	14:42	41.18	-71.34	8.22
10/20/2009	13:52	41.17	-71.32	8.17
10/20/2009	12:39	41.19	-71.31	8.36
10/20/2009	10:07	41.20	-71.27	7.88
10/20/2009	7:12	41.26	-71.32	4.68
10/21/2009	15:46	41.32	-71.43	5.51

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
10/21/2009	15:20	41.29	-71.37	5.11
10/21/2009	14:30	41.27	-71.25	5.58
10/21/2009	12:58	41.26	-71.21	7.16
10/21/2009	11:38	41.27	-71.24	9.15
10/21/2009	10:27	41.28	-71.27	6.29
10/21/2009	8:21	41.29	-71.30	5.31
10/22/2009	14:40	41.31	-71.43	6.76
10/22/2009	14:22	41.29	-71.40	6.56
10/22/2009	9:57	41.24	-71.33	6.55
10/22/2009	12:49	41.24	-71.36	5.20
10/22/2009	8:04	41.26	-71.34	5.14
10/22/2009	6:48	41.29	-71.38	5.83
10/22/2009	12:30	41.33	-71.50	8.58
10/22/2009	12:10	41.29	-71.48	4.12
10/22/2009	11:50	41.25	-71.47	4.79
10/22/2009	11:25	41.19	-71.45	9.76
10/22/2009	10:40	41.09	-71.41	7.96
10/22/2009	10:20	41.05	-71.40	7.19
10/22/2009	9:55	41.00	-71.38	7.05
10/22/2009	8:55	40.97	-71.33	6.92
10/27/2009	16:39	41.30	-71.45	7.82
10/27/2009	16:21	41.27	-71.42	7.17
10/27/2009	15:53	41.21	-71.37	8.34
10/27/2009	15:38	41.18	-71.34	8.77
10/27/2009	13:34	41.18	-71.30	8.46
10/27/2009	12:36	41.20	-71.30	7.89
10/27/2009	9:07	41.22	-71.23	7.57
10/27/2009	7:21	41.29	-71.36	7.11
11/3/2009	13:57	41.31	-71.43	5.28
11/3/2009	13:39	41.29	-71.40	6.09
11/3/2009	12:34	41.24	-71.36	7.83
11/3/2009	10:25	41.25	-71.33	7.50
11/3/2009	8:15	41.28	-71.36	7.17
11/3/2009	6:50	41.29	-71.38	5.87
11/4/2009	15:05	41.31	-71.47	6.16
11/4/2009	11:40	41.09	-71.37	7.91
11/4/2009	10:45	41.03	-71.33	7.72
11/4/2009	10:15	41.14	-71.37	7.90
11/4/2009	9:10	41.19	-71.42	8.88
11/4/2009	8:25	41.24	-71.41	4.93
11/4/2009	7:40	41.27	-71.42	4.65
11/4/2009	7:00	41.27	-71.47	4.05
11/5/2009	15:30	41.29	-71.43	5.89
11/5/2009	14:49	41.21	-71.37	9.19
11/5/2009	14:3	41.17	-71.32	8.69
11/5/2009	11:54	41.19	-71.30	7.33

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
11/5/2009	9:56	41.21	-71.25	8.03
11/5/2009	7:51	41.23	-71.23	8.01
11/5/2009	6:59	41.29	-71.36	5.19
11/5/2009	13:45	41.34	-71.57	6.13
11/5/2009	13:15	41.31	-71.64	3.49
11/5/2009	12:50	41.29	-71.70	2.93
11/5/2009	9:30	41.26	-71.71	5.34
11/5/2009	8:35	41.28	-71.68	3.81
11/5/2009	7:00	41.25	-71.62	4.19
11/5/2009	6:20	41.28	-71.63	3.48
11/9/2009	14:12	41.32	-71.42	4.57
11/9/2009	13:58	41.31	-71.38	5.59
11/9/2009	13:15	41.23	-71.35	6.56
11/9/2009	10:33	41.25	-71.33	6.64
11/9/2009	8:42	41.28	-71.36	6.50
11/9/2009	6:55	41.29	-71.39	5.61
11/9/2009	14:00	41.31	-71.53	3.97
11/9/2009	12:50	41.28	-71.59	2.74
11/9/2009	11:55	41.27	-71.63	2.72
11/9/2009	10:55	41.22	-71.65	2.71
11/9/2009	10:05	41.15	-71.69	3.86
11/9/2009	9:00	41.19	-71.68	2.76
11/9/2009	8:15	41.23	-71.69	2.79
11/9/2009	7:40	41.26	-71.72	2.71
11/10/2009	23:44	41.26	-71.03	6.74
11/11/2009	13:16	41.39	-71.08	5.24
11/11/2009	0:01	41.43	-71.41	3.12
11/11/2009	22:52	41.35	-71.38	5.56
11/11/2009	21:33	41.26	-71.36	6.97
11/11/2009	20:32	41.21	-71.35	6.78
11/11/2009	18:53	41.12	-71.33	7.52
11/11/2009	17:45	41.21	-71.22	7.56
11/11/2009	16:35	41.26	-71.20	4.28
11/11/2009	15:41	41.35	-71.18	4.27
11/11/2009	13:56	41.42	-71.18	5.58
11/11/2009	11:57	41.34	-70.92	7.47
11/17/2009	14:47	41.31	-71.42	3.07
11/17/2009	14:26	41.28	-71.37	4.20
11/17/2009	13:43	41.23	-71.34	3.74
11/17/2009	12:16	41.25	-71.33	3.64
11/17/2009	10:20	41.26	-71.35	3.57
11/17/2009	7:46	41.30	-71.37	3.60
11/17/2009	7:09	41.32	-71.41	2.69
11/17/2009	13:06	41.23	-71.52	2.67
11/17/2009	11:45	41.11	-71.53	4.41
11/17/2009	10:05	41.05	-71.56	4.37

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
11/17/2009	8:20	41.22	-71.68	2.16
11/17/2009	6:33	41.27	-71.64	1.80
11/19/2009	12:19	41.06	-71.32	3.72
11/19/2009	11:14	41.02	-71.29	3.79
11/19/2009	9:40	40.97	-71.31	3.42
11/19/2009	9:06	41.05	-71.17	3.17
11/19/2009	8:01	41.08	-71.15	3.86
11/19/2009	6:27	41.13	-71.15	3.36
12/1/2009	14:14	41.32	-71.43	3.02
12/1/2009	13:55	41.29	-71.39	2.87
12/1/2009	11:27	41.26	-71.34	3.51
12/1/2009	10:07	41.26	-71.33	3.37
12/1/2009	8:08	41.29	-71.38	2.64
12/1/2009	7:05	41.32	-71.39	2.28
12/2/2009	16:25	41.30	-71.45	3.69
12/2/2009	15:27	41.26	-71.41	3.05
12/2/2009	14:38	41.18	-71.33	3.80
12/2/2009	14:00	41.14	-71.28	3.80
12/2/2009	8:52	41.14	-71.22	3.57
12/2/2009	6:06	41.27	-71.38	2.61
12/2/2009	12:46	41.35	-71.13	3.40
12/2/2009	11:44	41.32	-71.14	3.36
12/2/2009	10:15	41.27	-71.12	3.78
12/2/2009	9:47	41.27	-71.02	4.17
12/2/2009	7:04	41.35	-70.99	3.90
12/2/2009	11:55	41.33	-71.51	3.30
12/2/2009	11:40	41.30	-71.52	3.44
12/2/2009	11:20	41.26	-71.52	2.08
12/2/2009	11:00	41.21	-71.53	2.07
12/2/2009	10:35	41.15	-71.54	1.38
12/2/2009	10:25	41.13	-71.58	2.24
12/2/2009	9:50	41.07	-71.58	2.76
12/2/2009	9:20	41.02	-71.57	2.79
12/7/2009	15:05	41.28	-71.29	3.19
12/7/2009		41.16	-71.36	4.25
12/7/2009		40.98	-71.31	2.35
12/7/2009	12:13	41.09	-71.22	2.94
12/7/2009	10:58	41.21	-71.14	3.24
12/7/2009	10:00	41.15	-71.01	3.30
12/7/2009	9:27	41.27	-70.96	3.34
12/7/2009	8:29	41.33	-71.10	3.99
12/7/2009	12:15	41.35	-71.52	2.90
12/7/2009	11:55	41.30	-71.52	1.83
12/7/2009	11:35	41.26	-71.53	1.62
12/7/2009	11:20	41.21	-71.53	2.84
12/7/2009	11:00	41.17	-71.54	2.66

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
12/7/2009	10:45	41.13	-71.55	2.39
12/7/2009	10:30	41.10	-71.56	2.24
12/8/2009	14:46	41.20	-71.78	1.12
12/8/2009	1:00	41.12	-71.77	2.02
12/8/2009	13:30	41.05	-71.76	2.11
12/8/2009	12:37	41.04	-71.66	1.93
12/8/2009	12:07	41.13	-71.66	1.45
12/8/2009	10:24	40.96	-71.55	3.03
12/8/2009	10:00	41.05	-71.45	2.37
12/8/2009	8:50	41.24	-71.48	1.63
12/8/2009	18:54	41.28	-71.48	2.24
12/8/2009	18:21	41.21	-71.48	2.74
12/8/2009	16:42	41.05	-71.45	2.69
12/8/2009	15:20	40.99	-71.59	2.56
12/8/2009	13:06	41.01	-71.42	2.90
12/8/2009	11:41	40.99	-71.42	2.78
12/8/2009	10:42	41.03	-71.43	2.77
12/8/2009	9:32	41.04	-71.44	2.48
12/8/2009	12:11	41.36	-71.51	2.40
12/8/2009	10:53	41.31	-71.52	2.00
12/8/2009	9:45	41.27	-71.41	1.65
12/8/2009	9:00	41.26	-71.28	3.11
12/8/2009	8:04	41.23	-71.37	3.22
12/8/2009	6:33	41.18	-71.33	3.45
12/8/2009	12:40	41.32	-71.52	2.17
12/8/2009	12:25	41.29	-71.52	1.69
12/8/2009	12:05	41.24	-71.53	1.45
12/8/2009	11:45	41.20	-71.53	1.86
12/8/2009	11:15	41.14	-71.56	2.34
12/8/2009	11:00	41.12	-71.60	2.11
12/8/2009	10:35	41.08	-71.61	1.42
12/8/2009	10:20	41.05	-71.61	1.89
12/15/2009	18:34	41.30	-71.50	1.87
12/15/2009	18:06	41.25	-71.50	1.58
12/15/2009	17:18	41.16	-71.52	1.88
12/15/2009	14:27	41.05	-71.45	2.29
12/15/2009	12:53	41.01	-71.42	2.17
12/15/2009	12:19	40.98	-71.42	2.25
12/15/2009	7:39	41.01	-71.42	1.81
12/15/2009	6:47	41.13	-71.46	1.63
12/28/2009	11:12	41.26	-71.33	2.25
12/28/2009	9:38	41.24	-71.33	2.39
12/28/2009	8:40	41.28	-71.37	1.96
12/28/2009	7:46	41.31	-71.42	1.58
12/31/2009	12:44	40.98	-71.31	1.23
12/31/2009	11:34	41.00	-71.28	1.81

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
12/31/2009	10:07	41.05	-71.31	1.66
12/31/2009	9:36	41.05	-71.17	1.31
12/31/2009	8:30	41.08	-71.15	1.38
12/31/2009	6:43	41.14	-71.18	1.81
1/12/2010	13:00	41.37	-71.51	3.31
1/12/2010	12:50	41.33	-71.51	3.77
1/12/2010	12:40	41.30	-71.52	3.55
1/12/2010	12:25	41.28	-71.52	3.11
1/12/2010	12:05	41.23	-71.52	2.43
1/12/2010	11:50	41.20	-71.52	2.33
1/12/2010	11:30	41.16	-71.52	2.46
1/14/2010	16:17	41.31	-71.43	3.11
1/14/2010	14:17	41.26	-71.16	2.61
1/14/2010	12:56	41.17	-71.32	3.27
1/14/2010	9:36	41.20	-71.27	3.08
1/14/2010	7:44	41.24	-71.28	3.59
1/14/2010	6:57	41.30	-71.39	2.98
1/19/2010	15:31	41.32	-71.40	4.38
1/19/2010	15:04	41.30	-71.32	4.87
1/19/2010	14:00	41.26	-71.22	3.61
1/19/2010	12:55	41.27	-71.24	3.65
1/19/2010	11:37	41.26	-71.26	3.57
1/19/2010	10:27	41.29	-71.28	3.92
1/19/2010	13:53	41.27	-71.39	4.55
1/19/2010	7:16	41.26	-71.37	4.80
1/19/2010	12:00	41.29	-71.30	4.44
1/19/2010	6:42	41.31	-71.44	3.22
1/19/2010	9:20	41.22	-71.66	4.16
1/21/2010	12:34	41.27	-71.64	4.90
1/21/2010	11:10	41.23	-71.65	2.96
1/21/2010	9:52	41.18	-71.65	2.98
1/21/2010	9:31	41.13	-71.58	3.90
1/21/2010	8:04	41.09	-71.54	3.89
1/21/2010	6:52	41.44	-71.44	3.83
2/2/2010	15:58	41.30	-71.40	3.51
2/2/2010	15:33	41.26	-71.35	3.78
2/2/2010	13:08	41.17	-71.32	3.07
2/2/2010	12:19	41.18	-71.31	3.92
2/2/2010	10:38	41.19	-71.29	3.76
2/2/2010	8:31	41.21	-71.23	3.04
2/2/2010	7:24	41.27	-71.32	3.92
2/2/2010	7:00	41.30	-71.41	3.14
2/3/2010	15:25	41.32	-71.41	2.80
2/3/2010	15:8	41.31	-71.37	2.59
2/3/2010	9:47	41.05	-71.17	1.96
2/3/2010	14:42	41.28	-71.30	2.84

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
2/3/2010	12:49	41.26	-71.22	2.59
2/3/2010	12:22	41.14	-71.16	4.42
2/3/2010	11:10	41.26	-71.25	2.38
2/3/2010	8:51	41.03	-71.33	2.51
2/3/2010	9:26	41.05	-71.27	2.08
2/3/2010	9:35	41.29	-71.29	2.92
2/3/2010	10:42	41.08	-71.19	3.49
2/3/2010	8:22	41.26	-71.36	2.89
2/3/2010	11:44	41.11	-71.17	2.57
2/3/2010	7:02	41.31	-71.42	2.64
2/5/2010	16:02	41.57	-71.41	8.45
2/5/2010	11:09	41.07	-71.30	4.01
2/5/2010	10:31	41.16	-71.27	4.58
2/5/2010	10:50	41.10	-71.28	3.21
2/5/2010	11:33	41.12	-71.35	4.13
2/5/2010	10:01	41.27	-71.32	3.18
2/5/2010	12:20	41.20	-71.40	4.04
2/5/2010	12:00	41.15	-71.47	3.66
2/5/2010	13:05	41.10	-71.56	4.89
2/5/2010	13:34	41.15	-71.67	6.09
2/5/2010	13:50	41.21	-71.68	5.02
2/5/2010	14:14	41.28	-71.71	4.64
2/5/2010	12:52	41.33	-71.46	3.05
2/5/2010	14:28	41.30	-71.64	4.25
2/5/2010	12:24	41.27	-71.35	6.57
2/5/2010	14:48	41.30	-71.52	3.66
2/5/2010	9:57	41.19	-71.35	4.46
2/5/2010	15:08	41.31	-71.44	3.11
2/5/2010	9:19	41.27	-71.52	3.85
2/5/2010	9:40	41.33	-71.33	3.09
2/5/2010	7:44	41.32	-71.53	5.62
2/5/2010	9:15	41.42	-71.39	6.33
2/5/2010	6:41	41.35	-71.51	3.93
2/9/2010	15:20	41.35	-71.52	5.34
2/9/2010	15:10	41.34	-71.51	3.55
2/9/2010	14:55	41.32	-71.51	3.34
2/9/2010	14:30	41.29	-71.51	3.31
2/9/2010	14:10	41.27	-71.50	3.46
2/9/2010	13:45	41.25	-71.48	3.54
2/9/2010	13:15	41.23	-71.50	3.64
2/9/2010	12:35	41.20	-71.51	3.40
2/15/2010	13:55	41.35	-71.51	6.51
2/15/2010	13:40	41.33	-71.52	2.70
2/15/2010	13:25	41.30	-71.52	2.58
2/15/2010	13:15	41.27	-71.52	3.05
2/15/2010	12:50	41.23	-71.52	2.31

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
2/15/2010	12:30	41.18	-71.52	2.61
2/15/2010	12:00	41.14	-71.47	3.31
2/15/2010	11:40	41.11	-71.44	4.61
2/22/2010	16:37	41.30	-71.43	1.38
2/22/2010	15:40	41.32	-71.53	1.96
2/22/2010	15:14	41.26	-71.36	1.21
2/22/2010	15:30	41.32	-71.56	1.81
2/22/2010	14:07	41.26	-71.32	0.87
2/22/2010	15:15	41.28	-71.59	1.82
2/22/2010	11:37	41.18	-71.31	1.91
2/22/2010	15:0	41.25	-71.62	1.67
2/22/2010	10:5	41.20	-71.27	1.46
2/22/2010	14:20	41.19	-71.65	1.40
2/22/2010	8:34	41.22	-71.23	1.63
2/22/2010	13:45	41.10	-71.62	1.19
2/22/2010	7:53	41.27	-71.33	1.44
2/22/2010	13:05	41.04	-71.60	0.66
2/22/2010	7:18	41.32	-71.43	0.77
2/22/2010	12:45	41.03	-71.59	1.43
2/28/2010	14:8	41.32	-71.41	1.09
2/28/2010	13:46	41.30	-71.36	1.07
2/28/2010	13:31	41.29	-71.32	0.94
2/28/2010	12:36	41.27	-71.23	0.97
2/28/2010	10:40	41.28	-71.28	1.10
2/28/2010	8:44	41.25	-71.40	0.83
2/28/2010	7:25	41.24	-71.50	0.91
3/2/2010	13:4	41.29	-71.30	0.71
3/2/2010	12:23	41.27	-71.39	0.60
3/2/2010	10:13	41.22	-71.66	0.95
3/9/2010	16:25	41.28	-71.29	1.41
3/9/2010	14:15	40.99	-71.21	0.59
3/9/2010	13:13	41.11	-71.12	1.81
3/9/2010	11:24	41.24	-71.04	0.78
3/9/2010	10:27	41.05	-70.99	1.35
3/9/2010	9:28	41.17	-70.91	0.76
3/9/2010	8:10	41.43	-71.10	1.56
3/9/2010	7:25	41.38	-71.26	0.72
3/10/2010	15:07	41.21	-71.68	1.12
3/10/2010	12:58	41.10	-71.57	0.85
3/10/2010	14:20	41.13	-71.66	0.47
3/10/2010	13:32	41.05	-71.55	0.72
3/10/2010	12:14	41.11	-71.45	0.74
3/10/2010	12:45	41.05	-71.76	1.67
3/10/2010	11:38	41.11	-71.33	0.47
3/10/2010	11:51	40.97	-71.65	0.50
3/10/2010	10:46	41.12	-71.16	1.38

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
3/10/2010	8:55	41.12	-71.03	0.69
3/10/2010	11:00	40.97	-71.43	0.38
3/10/2010	10:03	41.15	-71.47	1.43
3/10/2010	9:09	41.26	-71.39	1.31
3/11/2010	12:17	41.14	-71.18	1.30
3/11/2010		41.33	-71.51	2.35
3/11/2010	11:27	41.11	-71.13	1.20
3/11/2010		41.31	-71.60	2.04
3/11/2010	9:42	41.04	-71.17	1.15
3/11/2010		41.29	-71.70	0.53
3/11/2010	9:14	41.05	-71.31	0.35
3/11/2010		41.27	-71.81	0.42
3/11/2010	7:51	41.02	-71.30	0.37
3/11/2010		41.20	-71.78	1.26
3/11/2010	6:16	40.97	-71.31	0.54
3/17/2010	17:04	41.31	-71.42	3.39
3/17/2010	16:26	41.26	-71.35	1.32
3/17/2010	14:55	41.24	-71.31	0.88
3/17/2010	13:02	41.18	-71.31	1.69
3/17/2010	12:09	41.18	-71.30	2.78
3/17/2010	10:16	41.20	-71.28	1.81
3/17/2010	8:12	41.22	-71.24	2.69
3/17/2010	7:08	41.30	-71.40	2.21
3/22/2010	14:50	41.32	-71.42	0.76
3/22/2010	14:40	41.31	-71.40	0.96
3/22/2010	14:21	41.30	-71.34	0.77
3/22/2010	13:30	41.26	-71.27	0.48
3/22/2010	12:08	41.28	-71.28	0.42
3/22/2010	11:12	41.31	-71.32	0.41
3/22/2010	10:47	41.32	-71.39	0.70
3/28/2010		41.28	-71.30	0.64
3/28/2010		41.27	-71.39	1.22
3/28/2010		41.22	-71.66	0.77
4/3/2010	16:15	41.31	-71.43	3.01
4/3/2010	15:12	41.24	-71.29	0.47
4/3/2010	13:30	41.17	-71.33	0.52
4/3/2010	11:06	41.19	-71.29	0.47
4/3/2010	9:46	41.21	-71.25	0.44
4/3/2010	8:40	41.23	-71.26	0.62
4/3/2010	8:14	41.26	-71.34	0.71
4/3/2010	7:45	41.29	-71.39	4.19
4/12/2010	5:24	41.24	-71.46	0.75
4/12/2010	11:25	41.35	-71.52	3.52
4/12/2010	6:10	41.20	-71.44	1.20
4/12/2010	11:11	41.33	-71.54	4.49
4/12/2010	6:55	41.07	-71.41	0.63

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
4/12/2010	8:30	41.04	-71.42	1.03
4/12/2010	10:50	41.28	-71.57	0.54
4/12/2010	10:25	41.23	-71.60	0.55
4/12/2010	11:55	41.08	-71.45	0.83
4/12/2010	9:55	41.17	-71.63	0.78
4/12/2010	19:11	41.17	-71.47	0.81
4/12/2010	9:35	41.13	-71.61	0.48
4/12/2010	19:32	41.29	-71.48	0.76
4/14/2010	18:57	41.28	-71.47	1.06
4/14/2010	18:34	41.23	-71.46	1.24
4/14/2010	17:50	41.15	-71.44	0.89
4/14/2010	17:18	41.09	-71.42	1.22
4/14/2010	7:58	41.08	-71.41	1.24
4/14/2010	6:34	41.13	-71.43	1.92
4/14/2010	6:13	41.18	-71.45	0.81
4/14/2010	5:45	41.26	-71.47	0.82
4/15/2010		41.03	-71.45	0.41
4/15/2010		41.03	-71.45	0.33
4/15/2010		41.03	-71.45	0.39
4/15/2010		41.03	-71.45	1.11
4/15/2010		41.03	-71.46	1.15
4/15/2010		41.03	-71.46	1.07
4/20/2010	16:10	41.09	-71.40	0.65
4/20/2010	12:43	41.09	-71.40	0.72
4/20/2010	6:59	41.09	-71.42	0.59
4/20/2010	6:25	41.17	-71.45	0.62
4/20/2010	5:35	41.29	-71.49	0.54
4/21/2010	12:55	41.31	-71.44	2.24
4/21/2010	12:35	41.28	-71.40	2.54
4/21/2010	12:01	41.23	-71.32	0.79
4/21/2010	11:36	41.20	-71.26	1.39
4/21/2010	9:48	41.23	-71.24	0.54
4/21/2010	9:16	41.27	-71.31	0.62
4/21/2010	8:40	41.31	-71.40	0.53
4/22/2010	10:40	41.27	-71.52	0.58
4/22/2010	10:25	41.23	-71.53	0.49
4/22/2010	10:00	41.18	-71.53	0.60
4/22/2010	9:35	41.13	-71.57	0.45
4/22/2010	9:05	41.09	-71.59	0.57
5/4/2010	20:38	41.24	-71.47	1.24
5/4/2010	12:37	41.07	-71.41	0.58
5/4/2010	17:50	41.06	-71.37	1.27
5/4/2010	20:38	41.02	-71.31	0.50
5/4/2010	19:14	41.07	-71.33	0.84
5/4/2010	18:27	41.17	-71.39	0.63
5/4/2010	17:47	41.25	-71.44	0.87

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
5/4/2010	17:21	41.30	-71.47	0.91
5/13/2010	16:36	41.29	-71.51	0.62
5/13/2010	13:40	41.11	-71.47	0.17
5/13/2010	12:52	41.10	-71.33	0.55
5/13/2010	12:59	41.48	-71.56	1.42
5/13/2010	12:23	41.10	-71.24	0.75
5/13/2010	12:45	41.34	-71.60	0.69
5/13/2010	10:11	41.12	-71.03	0.66
5/13/2010	12:25	41.33	-71.64	0.27
5/13/2010	9:11	41.18	-71.18	1.29
5/13/2010	11:05	41.32	-71.68	0.28
5/13/2010	8:12	41.26	-71.32	0.94
5/13/2010	10:15	41.32	-71.71	0.89
5/13/2010	7:27	41.32	-71.43	0.98
5/24/2010	20:16	41.30	-70.55	0.67
5/24/2010	18:27	41.12	-70.72	0.62
5/24/2010	14:2	41.09	-70.73	0.25
5/24/2010	8:55	41.09	-70.73	0.42
5/24/2010	7:10	41.15	-70.70	0.41
5/24/2010	6:26	41.22	-70.63	0.51
5/24/2010	5:41	41.30	-70.55	0.61
6/8/2010	11:55	41.35	-71.49	2.18
6/8/2010	11:40	41.33	-71.46	2.05
6/8/2010	11:20	41.30	-71.43	0.76
6/8/2010	10:45	41.25	-71.36	0.44
6/8/2010	10:25	41.21	-71.32	0.44
6/8/2010	8:25	41.13	-71.30	0.50
6/8/2010	7:10	41.17	-71.28	0.56
6/9/2010	12:37	41.31	-71.45	0.88
6/9/2010	12:37	41.31	-71.45	0.96
6/9/2010	12:11	41.27	-71.40	0.78
6/9/2010	11:50	41.25	-71.37	0.73
6/9/2010	10:18	41.26	-71.35	0.55
6/9/2010	8:47	41.26	-71.32	0.80
6/9/2010	7:33	41.23	-71.35	0.78
6/9/2010	7:01	41.28	-71.42	0.78
6/16/2010	16:54	41.15	-71.36	0.32
6/16/2010	13:52	40.95	-71.21	0.26
6/16/2010	12:28	41.21	-71.15	0.59
6/16/2010	10:44	41.13	-71.01	0.46
6/16/2010	9:49	41.06	-70.88	0.36
6/16/2010	8:52	41.27	-70.96	0.64
6/16/2010	7:58	41.46	-71.10	2.16
6/16/2010	7:16	41.41	-71.26	0.58
6/18/2010	12:51	41.32	-71.60	1.39
6/18/2010	12:5	41.28	-71.81	2.16

Date	Time	Latitude	Longitude	Surface chlorophyll a ($\mu\text{g L}^{-1}$)
6/18/2010	11:20	41.10	-71.77	3.36
6/18/2010	10:03	40.93	-71.76	1.77
6/18/2010	9:08	40.91	-71.55	0.75
6/18/2010	8:24	41.11	-71.57	2.38
6/18/2010	7:36	41.21	-71.68	2.53
6/18/2010	6:22	41.26	-71.39	0.51
6/30/2010	16:26	41.32	-71.45	1.11
6/30/2010	16:12	41.30	-71.42	0.71
6/30/2010	15:51	41.26	-71.39	0.57
6/30/2010	15:00	41.17	-71.33	0.50
6/30/2010	12:08	41.19	-71.29	0.47
6/30/2010	8:29	41.23	-71.24	0.57
6/30/2010	7:54	41.24	-71.32	0.64
6/30/2010	7:09	41.30	-71.43	1.41
9/21/2010	11:50	41.36	-71.51	3.06
9/21/2010	11:35	41.28	-71.81	2.51
9/21/2010	11:10	41.27	-71.52	1.17
9/21/2010	10:55	41.23	-71.53	3.51
9/21/2010	10:35	41.20	-71.53	2.82
9/21/2010	10:20	41.17	-71.53	1.45
9/21/2010	10:00	41.13	-71.55	2.57
9/21/2010	9:40	41.10	-71.57	0.81

Table C-4. Extinction coefficients calculated using either Secchi disk depths (1.7/Secchi depth; Holms 1970) or CTD light profiles (Beer's law; Valiela 1992) throughout the Southern New England inner continental shelf from Jun 2009 to Mar 2010.

Date	Time	Latitude	Longitude	Extinction coefficient (m ⁻¹)	Method of measurement
6/25/2009	12:35	41.28	-71.43	0.28	secchi
6/25/2009	11:00	41.27	-71.53	0.34	secchi
6/25/2009	9:20	41.27	-71.44	0.34	secchi
6/25/2009	7:05	41.28	-71.52	0.34	secchi
7/1/2009	6:30	41.10	-71.29	0.28	secchi
7/1/2009	7:55	41.17	-71.28	0.31	secchi
7/2/2009	11:45	41.27	-71.49	0.35	secchi
7/2/2009	7:05	41.31	-71.70	0.43	secchi
7/6/2009	9:25	41.30	-71.67	0.31	secchi
7/6/2009	12:55	41.35	-71.55	0.34	secchi
7/6/2009	11:55	41.32	-71.64	0.34	secchi
7/6/2009	7:10	41.31	-71.78	0.43	secchi
7/7/2009	6:55	40.93	-71.58	0.34	secchi
7/7/2009	9:30	41.03	-71.62	0.38	secchi
7/13/2009	9:05	41.31	-71.75	0.34	secchi
7/13/2009	7:05	41.32	-71.65	0.34	secchi
7/13/2009	13:20	41.27	-71.44	0.43	secchi
7/14/2009	8:25	41.17	-71.28	0.34	secchi
7/14/2009	6:25	41.10	-71.29	0.43	secchi
7/15/2009	6:00	41.10	-71.30	0.26	secchi
7/15/2009	7:50	41.17	-71.26	0.31	secchi
8/3/2009	10:15	41.32	-71.66	0.34	secchi
8/3/2009	7:55	41.30	-71.80	0.34	secchi
8/12/2009	10:10	41.29	-71.53	0.34	secchi
8/21/2009	9:45	41.02	-71.35	0.21	secchi
8/21/2009	10:00	41.06	-71.26	0.23	secchi
8/21/2009	10:52	41.13	-71.23	0.24	secchi
8/21/2009	13:12	41.25	-71.26	0.28	secchi
8/21/2009	11:16	41.13	-71.29	0.28	secchi
8/21/2009	12:35	41.23	-71.32	0.31	secchi
8/21/2009	11:58	41.21	-71.26	0.31	secchi
9/3/2009		41.10	-71.30	0.23	secchi
9/3/2009		41.17	-71.28	0.24	secchi
10/21/2009	14:30	41.27	-71.25	0.28	secchi
10/21/2009	12:58	41.26	-71.21	0.31	secchi
10/21/2009	11:38	41.27	-71.24	0.31	secchi
10/22/2009	8:55	40.97	-71.33	0.24	secchi
10/22/2009	14:22	41.29	-71.40	0.34	secchi
11/3/2009	12:34	41.24	-71.36	0.34	secchi
11/3/2009	8:15	41.28	-71.36	0.38	secchi
11/4/2009	11:40	41.09	-71.37	0.26	secchi
11/4/2009	7:40	41.27	-71.42	0.34	secchi

Date	Time	Latitude	Longitude	Extinction coefficient (m^{-1})	Method of measurement
11/5/2009	9:56	41.21	-71.25	0.19	secchi
11/5/2009	14:03	41.17	-71.32	0.26	secchi
11/5/2009	9:30	41.26	-71.71	0.34	secchi
11/9/2009	10:33	41.25	-71.33	0.23	secchi
11/9/2009	7:40	41.26	-71.72	0.31	secchi
11/9/2009	10:05	41.15	-71.69	0.34	secchi
11/9/2009	14:12	41.32	-71.42	0.38	secchi
11/17/2009	10:20	41.26	-71.35	0.68	secchi
11/17/2009	13:43	41.23	-71.34	0.85	secchi
12/2/2009	9:20	41.02	-71.57	0.28	secchi
12/2/2009	16:25	41.30	-71.45	0.38	secchi
12/8/2009	15:20	40.99	-71.59	0.26	secchi
12/15/2009	12:53	41.01	-71.42	0.38	secchi
1/14/2010	12:56	41.17	-71.32	0.20	secchi
1/14/2010	9:36	41.20	-71.27	0.26	secchi
1/19/2010	10:27	41.29	-71.28	0.49	secchi
2/2/2010	13:08	41.17	-71.32	0.34	secchi
2/2/2010	15:58	41.30	-71.40	0.43	secchi
2/2/2010	10:38	41.19	-71.29	0.49	secchi
2/3/2010	12:49	41.26	-71.22	0.24	secchi
2/3/2010	11:10	41.26	-71.25	0.28	secchi
2/3/2010	15:25	41.32	-71.41	0.38	secchi
2/9/2010	14:30	41.29	-71.51	0.34	secchi
2/22/2010	14:07	41.26	-71.32	0.15	secchi
2/22/2010	10:05	41.20	-71.27	0.15	secchi
2/22/2010	15:15	41.28	-71.59	0.28	secchi
2/28/2010	8:44	41.25	-71.40	0.31	secchi
2/28/2010	10:40	41.28	-71.28	0.34	secchi
3/10/2010	8:55	41.12	-71.03	0.18	secchi
3/10/2010	12:58	41.10	-71.57	0.21	secchi
3/17/2010	13:02	41.18	-71.31	0.38	secchi
3/17/2010	12:09	41.18	-71.30	0.38	secchi
3/17/2010	16:26	41.26	-71.35	0.57	secchi
3/22/2010	12:08	41.28	-71.28	0.19	secchi
3/22/2010	14:40	41.31	-71.40	0.28	secchi
4/12/2010	8:30	41.04	-71.42	0.24	secchi
4/14/2010	17:18	41.09	-71.42	0.24	secchi
4/14/2010	7:58	41.08	-71.41	0.34	secchi
4/20/2010	12:43	41.09	-71.40	0.19	secchi
4/20/2010	16:10	41.09	-71.40	0.34	secchi
4/21/2010	9:48	41.23	-71.24	0.19	secchi
4/22/2010	9:05	41.09	-71.59	0.21	secchi
5/4/2010	20:38	41.24	-71.47	0.24	secchi
5/13/2010	10:11	41.12	-71.03	0.20	secchi
5/13/2010	13:40	41.11	-71.47	0.24	secchi
5/13/2010	12:25	41.33	-71.64	0.28	secchi

Date	Time	Latitude	Longitude	Extinction coefficient (m^{-1})	Method of measurement
5/24/2010	18:27	41.12	-70.72	0.21	secchi
5/24/2010	8:55	41.09	-70.73	0.24	secchi
6/9/2010	12:11	41.27	-71.40	0.28	secchi
6/9/2010	11:50	41.25	-71.37	0.28	secchi
6/9/2010	10:18	41.26	-71.35	0.34	secchi
6/30/2010	15:00	41.17	-71.33	0.26	secchi
6/30/2010	8:29	41.23	-71.24	0.26	secchi
2/5/2010	9:40	41.33	-71.33	0.25	CTD
2/5/2010	11:09	41.07	-71.30	0.23	CTD
2/5/2010	12:20	41.20	-71.40	0.31	CTD
2/5/2010	13:05	41.10	-71.56	0.31	CTD
2/5/2010	13:50	41.21	-71.68	0.35	CTD
6/10/2010	8:30	41.54	-71.40	0.22	CTD
6/10/2010	9:00	41.43	-71.42	0.23	CTD
6/10/2010	10:40	41.22	-71.66	0.41	secchi
6/10/2010	11:40	41.27	-71.47	0.17	CTD
6/10/2010	12:48	41.28	-71.30	0.18	CTD
8/28/2010	10:01	41.22	-71.67	0.25	CTD
8/28/2010	11:11	41.27	-71.40	0.24	secchi
8/28/2010	12:07	41.28	-71.31	0.21	secchi
12/18/2008	10:36	41.22	-71.78	0.22	CTD
12/18/2008	12:47	41.31	-71.64	0.23	CTD
12/18/2008	13:11	41.28	-71.63	0.23	CTD
12/18/2008	14:35	41.36	-71.43	0.23	CTD
9/4/2009	8:58	41.18	-71.42	0.21	CTD
9/4/2009	9:56	41.26	-71.34	0.19	CTD
9/4/2009	10:24	41.29	-71.30	0.22	CTD
7/2/2009	12:15	41.28	-71.30	0.16	CTD
7/2/2009	10:05	41.22	-71.66	0.24	CTD
8/17/2010	13:14	41.22	-71.66	0.21	CTD
8/17/2010	10:49	41.27	-71.40	0.21	CTD
8/17/2010	8:57	41.29	-71.30	0.20	CTD
10/9/2010	9:48	41.22	-71.67	0.11	secchi
10/9/2010	10:41	41.28	-71.54	0.09	secchi
10/9/2010	11:22	41.40	-71.41	0.13	secchi
1/6/2011	13:12	41.22	-71.66	0.17	CTD
10/19/2010	15:33	41.22	-71.66	0.22	CTD
10/19/2010	11:33	41.29	-71.30	0.22	CTD
1/19/2010		41.22	-71.61	0.27	CTD
2/5/2010		41.22	-71.61	0.33	CTD
3/10/2010		41.22	-71.61	0.19	CTD
4/14/2010		41.22	-71.61	0.21	CTD
4/30/2010		41.22	-71.61	0.22	CTD
5/12/2010		41.22	-71.61	0.19	CTD
6/17/2010		41.22	-71.61	0.26	CTD
7/1/2010		41.22	-71.61	0.22	CTD

Date	Time	Latitude	Longitude	Extinction coefficient (m ⁻¹)	Method of measurement
7/23/2010		41.22	-71.61	0.23	CTD
8/17/2010		41.22	-71.61	0.21	CTD
9/14/2010		41.22	-71.61	0.25	CTD
10/13/2010		41.22	-71.61	0.34	CTD
11/29/2010		41.22	-71.61	0.32	CTD
12/30/2010		41.22	-71.61	0.33	CTD
1/19/2010		41.27	-71.40	0.29	CTD
2/5/2010		41.27	-71.40	0.28	CTD
3/10/2010		41.27	-71.40	0.19	CTD
4/14/2010		41.27	-71.40	0.19	CTD
4/30/2010		41.27	-71.40	0.22	CTD
5/12/2010		41.27	-71.40	0.14	CTD
6/17/2010		41.27	-71.40	0.18	CTD
7/1/2010		41.27	-71.40	0.18	CTD
7/23/2010		41.27	-71.40	0.22	CTD
8/17/2010		41.27	-71.40	0.21	CTD
9/14/2010		41.27	-71.40	0.23	CTD
10/13/2010		41.27	-71.40	0.31	CTD
11/29/2010		41.27	-71.40	0.28	CTD
12/30/2010		41.27	-71.40	0.29	CTD
9/23/2010		41.27	-71.81	0.25	CTD
9/23/2010		41.29	-71.70	0.24	CTD
9/23/2010		41.31	-71.60	0.27	CTD
9/23/2010		41.33	-71.51	0.32	CTD
9/23/2010		41.20	-71.78	0.28	CTD
9/23/2010		41.21	-71.68	0.26	CTD
9/23/2010		41.25	-71.56	0.26	CTD
9/23/2010		41.24	-71.49	0.19	CTD
9/23/2010		41.12	-71.77	0.33	CTD
9/23/2010		41.13	-71.66	0.24	CTD
9/23/2010		41.13	-71.57	0.20	CTD
9/23/2010		41.15	-71.47	0.12	CTD
9/23/2010		41.34	-71.42	0.16	CTD
9/23/2010		41.36	-71.33	0.17	CTD
9/23/2010		41.38	-71.26	0.21	CTD
9/23/2010		41.26	-71.39	0.19	CTD
9/23/2010		41.28	-71.29	0.15	CTD
9/23/2010		41.30	-71.19	0.20	CTD
9/23/2010		41.16	-71.36	0.16	CTD
9/23/2010		41.18	-71.26	0.16	CTD
9/23/2010		41.07	-71.34	0.14	CTD
9/23/2010		41.09	-71.22	0.23	CTD
12/8/2010		41.34	-71.42	0.35	CTD
12/8/2010		41.36	-71.33	0.29	CTD
12/8/2010		41.38	-71.26	0.42	CTD
12/8/2010		41.26	-71.39	0.30	CTD

Date	Time	Latitude	Longitude	Extinction coefficient (m ⁻¹)	Method of measurement
12/8/2010		41.28	-71.29	0.31	CTD
12/8/2010		41.30	-71.19	0.39	CTD
12/8/2010		41.16	-71.36	0.24	CTD
12/8/2010		41.18	-71.26	0.25	CTD
12/8/2010		41.07	-71.34	0.20	CTD
12/8/2010		41.09	-71.22	0.18	CTD
12/8/2010		41.29	-71.70	0.32	CTD
12/8/2010		41.31	-71.60	0.31	CTD
12/8/2010		41.20	-71.78	0.32	CTD
12/8/2010		41.21	-71.68	0.33	CTD
12/8/2010		41.25	-71.56	0.34	CTD
12/8/2010		41.24	-71.49	0.30	CTD
12/8/2010		41.12	-71.77	0.40	CTD
12/8/2010		41.13	-71.66	0.30	CTD
12/8/2010		41.13	-71.57	0.26	CTD
12/8/2010		41.15	-71.47	0.27	CTD
6/16/2010		41.27	-71.81	0.24	CTD
6/16/2010		41.29	-71.70	0.22	CTD
6/16/2010		41.31	-71.60	0.22	CTD
6/16/2010		41.33	-71.51	0.22	CTD
6/16/2010		41.34	-71.42	0.21	CTD
6/16/2010		41.36	-71.33	0.22	CTD
6/16/2010		41.38	-71.26	0.20	CTD
6/16/2010		41.20	-71.78	0.23	CTD
6/16/2010		41.21	-71.68	0.27	CTD
6/16/2010		41.25	-71.56	0.27	CTD
6/16/2010		41.24	-71.49	0.22	CTD
6/16/2010		41.26	-71.39	0.18	CTD
6/16/2010		41.28	-71.29	0.16	CTD
6/16/2010		41.30	-71.19	0.15	CTD
6/16/2010		41.12	-71.77	0.34	CTD
6/16/2010		41.13	-71.66	0.25	CTD
6/16/2010		41.13	-71.57	0.20	CTD
6/16/2010		41.15	-71.47	0.18	CTD
6/16/2010		41.16	-71.36	0.16	CTD
6/16/2010		41.18	-71.26	0.16	CTD
6/16/2010		41.07	-71.34	0.17	CTD
6/16/2010		41.09	-71.22	0.18	CTD
3/10/2010		41.27	-71.81	0.18	CTD
3/10/2010		41.29	-71.70	0.17	CTD
3/10/2010		41.31	-71.60	0.18	CTD
3/10/2010		41.33	-71.51	0.20	CTD
3/10/2010		41.34	-71.42	0.19	CTD
3/10/2010		41.36	-71.33	0.20	CTD
3/10/2010		41.38	-71.26	0.21	CTD
3/10/2010		41.20	-71.78	0.20	CTD

Date	Time	Latitude	Longitude	Extinction coefficient (m^{-1})	Method of measurement
3/10/2010		41.21	-71.68	0.19	CTD
3/10/2010		41.25	-71.56	0.21	CTD
3/10/2010		41.24	-71.49	0.20	CTD
3/10/2010		41.26	-71.39	0.20	CTD
3/10/2010		41.28	-71.29	0.20	CTD
3/10/2010		41.30	-71.19	0.17	CTD
3/10/2010		41.12	-71.77	0.20	CTD
3/10/2010		41.13	-71.66	0.19	CTD
3/10/2010		41.13	-71.57	0.20	CTD
3/10/2010		41.15	-71.47	0.17	CTD
3/10/2010		41.16	-71.36	0.17	CTD
3/10/2010		41.18	-71.26	0.18	CTD
3/10/2010		41.07	-71.34	0.18	CTD
3/10/2010		41.09	-71.22	0.18	CTD

Table C-5. Phytoplankton cell counts measured in surface water samples collected on the same day (Feb 6, 2010) in Narragansett Bay, Rhode Island Sound, and Block Island Sound. Annual mean cell counts from Block Island Sound collected in 1949 by Riley (1952) shown for comparison. Cell counts done by J. Graff.

Species	Narragansett Bay	Rhode Island Sound	Block Island Sound	Block Island Sound, 1949
<i>Skeletonema spp.</i>	5967	87	488	270.5
<i>Leptocylindrus minimus</i>	1286	2138	287	
<i>Chaetoceros spp.</i>	78	5	73	19.7
<i>Asterionellopsis glacialis</i>	29	18	214	
<i>Thalassiosira nordenskiöldii</i>	21	5		
<i>Leptocylindrus danicus</i>	13		3	
<i>Leptocylindrus species</i>				6.9
<i>Thalassionema nitzschioides</i>	9	20	33	5.4
<i>Rhizosolenia spp.</i>	2	14	7	1.5
<i>Dinfolagellates unknown</i>	2	1	3	
<i>Ditylum brightwellii</i>	2		7	
<i>Guinardia delicatula</i>	1	5	2	
<i>Ceratium sp.</i>	1			
<i>pennate unknown</i>	1			
<i>Pseudo-nitzschia spp.</i>		11		
<i>Thalassiosira rotula</i>			15	
<i>Detonula/Lauderia sp.</i>			7	
<i>Dictyocha speculum</i>			2	
<i>Cylindrotheca closterium</i>				
<i>ciliate unknown</i>			1	
<i>Thalassiosira sp.</i>			39	5.8
<i>Ceratium cf. furca</i>		1		
<i>Nitzschia species</i>				5.3
<i>Asterionella japonica</i>				1.7
<i>Guinardia flaccida</i>				1
Total cells/ml	7412	2305	1181	

Table C-6. Daily modeled primary production based on sub-surface water samples in Block Island Sound. Daily interpolated biomass (B), euphotic depth (Z), and photosynthetically active radiation (I) were used as inputs for our BZI models of primary production (see chapter 2). Also shown is daily modeled primary production using the Webb/Platt models.

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
1/1/10	2.52	5.95	18.42	41.42	446.43
1/2/10	2.56	6.29	18.42	58.35	457.09
1/3/10	2.61	8.03	18.42	130.18	580.00
1/4/10	2.65	19.34	18.42	583.92	979.82
1/5/10	2.70	9.17	18.42	186.81	620.24
1/6/10	2.74	19.76	18.42	626.03	1002.29
1/7/10	2.78	19.44	18.42	625.68	988.45
1/8/10	2.83	9.44	18.42	215.94	600.55
1/9/10	2.87	20.44	18.42	693.99	1016.18
1/10/10	2.91	19.62	18.42	671.41	974.72
1/11/10	2.96	18.67	18.42	642.42	961.60
1/12/10	3.00	18.27	18.42	636.34	936.01
1/13/10	3.19	18.10	18.42	681.52	892.87
1/14/10	3.39	15.60	18.42	607.04	839.01
1/15/10	3.58	11.17	18.42	415.23	723.08
1/16/10	3.77	21.28	18.42	1018.14	1044.83
1/17/10	3.97	6.44	18.42	199.46	476.70
1/18/10	4.16	9.38	18.42	401.13	649.65
1/19/10	4.36	1.35	18.42	0.00	130.29
1/20/10	4.02	11.79	18.42	525.15	771.29
1/21/10	3.68	22.34	18.42	1045.76	1018.24
1/22/10	3.74	14.60	18.42	634.63	796.83
1/23/10	3.81	23.24	18.42	1140.70	999.62
1/24/10	3.87	11.67	18.42	492.82	605.85
1/25/10	3.94	0.88	18.42	0.00	78.78
1/26/10	4.00	21.87	18.42	1125.87	875.64
1/27/10	4.07	23.70	18.42	1258.59	913.11
1/28/10	4.13	7.73	18.42	294.97	498.14
1/29/10	4.20	25.13	18.42	1393.91	885.52
1/30/10	4.26	14.26	18.42	726.11	631.44
1/31/10	4.33	25.05	18.42	1437.66	827.56
2/1/10	4.39	25.40	18.42	1484.56	814.55
2/2/10	4.46	12.29	18.42	636.24	578.28
2/3/10	4.52	17.18	18.42	978.18	578.32
2/4/10	4.59	26.63	18.42	1642.37	750.44
2/5/10	4.65	21.91	18.42	1340.60	659.70
2/6/10	4.41	5.07	18.42	151.75	280.12
2/7/10	4.18	27.54	18.42	1536.00	704.70
2/8/10	3.94	28.17	18.42	1475.21	704.14
2/9/10	3.70	27.27	18.42	1325.04	671.59
2/10/10	3.63	2.94	18.42	0.00	168.89
2/11/10	3.57	24.06	18.42	1099.76	611.63

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
2/12/10	3.50	30.08	18.42	1390.63	652.30
2/13/10	3.43	19.96	18.42	841.35	511.34
2/14/10	3.37	28.57	18.42	1254.81	582.24
2/15/10	3.30	28.75	18.42	1235.23	597.61
2/16/10	3.08	6.86	18.42	132.80	270.80
2/17/10	2.85	15.68	18.42	485.57	402.77
2/18/10	2.63	25.13	18.42	803.90	500.40
2/19/10	2.40	23.30	18.42	654.03	493.46
2/20/10	2.18	31.60	18.42	846.24	541.58
2/21/10	1.95	29.21	18.42	670.62	503.07
2/22/10	1.73	30.35	18.42	602.17	479.30
2/23/10	1.59	6.42	18.42	0.00	199.23
2/24/10	1.46	3.13	18.42	0.00	108.11
2/25/10	1.32	5.18	18.42	0.00	149.19
2/26/10	1.18	10.66	18.42	5.95	252.35
2/27/10	1.05	14.28	18.42	40.68	277.99
2/28/10	0.91	16.19	18.42	37.53	283.31
3/1/10	0.93	16.47	18.42	46.36	280.28
3/2/10	0.95	27.75	18.42	211.34	332.57
3/3/10	0.96	7.85	18.42	0.00	151.81
3/4/10	0.96	10.83	18.42	0.00	186.02
3/5/10	0.97	23.68	18.42	159.91	267.43
3/6/10	0.97	37.50	18.42	363.24	314.47
3/7/10	0.98	37.36	18.42	364.60	298.27
3/8/10	0.99	37.36	18.42	367.91	278.17
3/9/10	0.99	37.57	18.42	374.35	262.59
3/10/10	1.00	35.80	18.42	351.33	231.49
3/11/10	1.32	8.15	18.42	0.00	99.83
3/12/10	1.33	14.23	18.42	100.76	145.10
3/13/10	1.35	1.06	18.42	0.00	16.96
3/14/10	1.36	5.29	18.42	0.00	76.37
3/15/10	1.37	4.76	18.42	0.00	69.14
3/16/10	1.38	37.98	18.42	603.06	294.70
3/17/10	1.40	41.86	18.42	691.34	320.54
3/18/10	1.41	41.76	18.42	697.27	329.50
3/19/10	1.42	40.80	18.42	684.80	334.27
3/20/10	1.44	40.87	18.42	694.16	343.46
3/21/10	1.45	39.89	18.42	680.69	344.56
3/22/10	1.46	7.21	18.42	0.00	118.26
3/23/10	1.47	5.35	18.42	0.00	86.73
3/24/10	1.49	38.62	18.42	675.44	366.74
3/25/10	1.50	33.83	18.42	575.37	356.22
3/26/10	1.51	20.75	18.42	286.22	256.89
3/27/10	1.53	43.79	18.42	815.38	419.44
3/28/10	1.54	23.68	18.42	361.65	302.52
3/29/10	1.55	2.97	18.42	0.00	65.12
3/30/10	1.56	2.19	18.42	0.00	47.28

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
3/31/10	1.58	15.40	18.42	180.07	246.63
4/1/10	1.59	35.81	18.42	667.72	399.41
4/2/10	1.60	46.16	18.42	922.40	498.75
4/3/10	1.61	46.13	18.42	930.47	500.72
4/4/10	1.63	40.91	18.42	812.42	466.05
4/5/10	1.64	45.70	18.42	937.60	524.43
4/6/10	1.65	27.75	18.42	503.03	409.64
4/7/10	1.67	46.27	18.42	969.37	545.42
4/8/10	1.68	43.59	18.42	910.88	549.45
4/9/10	1.69	4.98	18.42	0.00	120.68
4/10/10	1.70	44.03	18.42	938.91	553.55
4/11/10	1.72	42.86	18.42	917.36	557.68
4/12/10	1.73	49.81	18.42	1105.07	627.80
4/13/10	1.59	37.87	18.42	717.03	567.37
4/14/10	1.45	52.38	18.42	951.65	666.72
4/15/10	1.30	49.89	18.42	784.87	671.46
4/16/10	1.15	20.29	18.42	164.93	417.69
4/17/10	0.99	11.89	18.42	0.00	307.24
4/18/10	0.84	27.23	18.42	160.49	513.25
4/19/10	0.69	47.13	18.42	304.43	759.41
4/20/10	0.54	35.88	18.42	106.94	699.48
4/21/10	0.54	43.93	18.42	168.66	801.04
4/22/10	0.53	48.59	18.42	202.23	848.05
4/23/10	0.74	35.56	18.42	209.90	745.06
4/24/10	0.95	54.40	18.42	587.28	975.42
4/25/10	1.16	15.26	18.42	80.96	469.82
4/26/10	1.36	19.43	18.42	213.55	547.62
4/27/10	1.57	8.16	18.42	9.20	318.70
4/28/10	1.78	24.06	18.42	457.89	757.55
4/29/10	1.99	53.11	18.42	1396.42	1119.35
4/30/10	2.20	54.73	18.42	1615.32	1139.52
5/1/10	2.08	53.09	18.42	1467.90	1068.84
5/2/10	1.96	39.33	18.42	970.88	883.74
5/3/10	1.84	24.06	18.42	480.67	600.44
5/4/10	1.73	45.39	18.42	988.78	790.98
5/5/10	1.61	57.04	18.42	1188.87	873.86
5/6/10	1.49	34.92	18.42	595.51	606.48
5/7/10	1.37	57.07	18.42	988.51	747.00
5/8/10	1.26	17.50	18.42	145.69	347.26
5/9/10	1.14	56.72	18.42	781.60	622.97
5/10/10	1.02	59.81	18.42	728.76	576.48
5/11/10	0.90	50.67	18.42	500.25	469.35
5/12/10	0.78	16.38	18.42	9.34	239.24
5/13/10	0.55	58.05	18.42	294.51	453.62
5/14/10	0.61	25.68	18.42	52.55	299.78
5/15/10	0.68	58.12	18.42	404.01	489.15
5/16/10	0.74	54.04	18.42	413.44	497.25

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
5/17/10	0.80	50.15	18.42	417.57	485.56
5/18/10	0.86	11.80	18.42	0.00	238.15
5/19/10	0.93	15.42	18.42	30.76	276.84
5/20/10	0.99	58.08	18.42	675.77	556.47
5/21/10	1.05	57.55	18.42	721.83	575.57
5/22/10	1.11	45.92	18.42	582.02	525.67
5/23/10	1.18	36.56	18.42	460.52	471.02
5/24/10	1.24	57.54	18.42	883.33	612.66
5/25/10	1.30	58.78	18.42	961.48	639.75
5/26/10	1.37	55.03	18.42	940.07	628.76
5/27/10	1.43	49.20	18.42	867.19	616.77
5/28/10	1.49	57.63	18.42	1101.02	668.95
5/29/10	1.55	41.84	18.42	788.58	580.78
5/30/10	1.62	52.61	18.42	1087.77	679.59
5/31/10	1.68	57.40	18.42	1257.15	722.09
6/1/10	1.74	43.15	18.42	940.19	564.96
6/2/10	1.80	54.57	18.42	1288.40	680.65
6/3/10	1.87	31.81	18.42	704.83	575.10
6/4/10	1.93	55.43	18.42	1415.59	746.52
6/5/10	1.99	33.81	18.42	823.74	561.52
6/6/10	2.05	36.22	18.42	929.67	639.44
6/7/10	2.12	59.47	18.42	1699.29	841.37
6/8/10	2.18	51.19	18.42	1485.17	825.46
6/9/10	2.26	22.51	18.42	577.95	536.57
6/10/10	2.34	21.43	18.42	567.27	506.94
6/11/10	2.42	25.80	18.42	751.16	616.14
6/12/10	2.50	25.73	18.42	779.73	580.90
6/13/10	2.58	14.90	18.42	392.36	459.91
6/14/10	2.66	34.17	18.42	1177.50	750.87
6/15/10	2.74	57.65	18.42	2181.59	943.88
6/16/10	2.82	36.96	18.42	1377.41	763.40
6/17/10	2.91	41.40	18.42	1614.68	814.80
6/18/10	2.36	60.09	18.42	1936.85	1004.91
6/19/10	2.30	63.31	18.42	1992.08	1040.59
6/20/10	2.24	44.82	18.42	1315.36	874.58
6/21/10	2.17	58.57	18.42	1721.14	1052.04
6/22/10	2.11	44.78	18.42	1231.55	863.45
6/23/10	2.05	48.36	18.42	1300.01	962.47
6/24/10	1.99	48.89	18.42	1271.31	1003.19
6/25/10	1.93	60.86	18.42	1571.11	1122.03
6/26/10	1.87	45.92	18.42	1098.30	967.77
6/27/10	1.80	42.55	18.42	964.91	962.83
6/28/10	1.74	46.72	18.42	1034.40	950.21
6/29/10	1.68	40.59	18.42	837.24	1004.60
6/30/10	1.62	61.63	18.42	1309.25	1215.40
7/1/10	1.56	51.37	18.42	1013.45	1130.92
7/2/10	1.56	60.98	18.42	1235.86	1218.91

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
7/3/10	1.56	57.86	18.42	1161.99	1181.03
7/4/10	1.55	53.60	18.42	1061.94	1140.41
7/5/10	1.55	60.21	18.42	1213.99	1198.11
7/6/10	1.55	52.81	18.42	1041.19	1107.27
7/7/10	1.55	50.31	18.42	982.33	1101.28
7/8/10	1.55	54.75	18.42	1083.80	1086.12
7/9/10	1.55	43.03	18.42	811.76	1045.03
7/10/10	1.54	35.43	18.42	635.39	911.89
7/11/10	1.54	49.56	18.42	960.56	1098.71
7/12/10	1.54	53.58	18.42	1052.12	1103.06
7/13/10	1.54	33.57	18.42	590.38	786.31
7/14/10	1.54	14.96	18.42	161.48	539.20
7/15/10	1.54	23.65	18.42	360.79	727.77
7/16/10	1.54	39.48	18.42	723.71	935.15
7/17/10	1.53	54.76	18.42	1073.46	1096.64
7/18/10	1.53	50.79	18.42	981.26	1064.01
7/19/10	1.53	32.15	18.42	553.45	825.76
7/20/10	1.53	44.27	18.42	829.78	1009.57
7/21/10	1.53	40.10	18.42	733.57	806.00
7/22/10	1.53	51.70	18.42	997.46	1077.54
7/23/10	1.53	15.82	18.42	178.25	556.09
7/24/10	1.65	36.27	18.42	713.97	931.33
7/25/10	1.78	42.71	18.42	955.18	1070.37
7/26/10	1.91	57.97	18.42	1472.74	1482.02
7/27/10	2.04	56.74	18.42	1546.35	1592.97
7/28/10	2.17	55.26	18.42	1607.46	1676.39
7/29/10	2.30	32.21	18.42	922.58	1354.05
7/30/10	2.42	52.83	18.42	1731.33	1872.21
7/31/10	2.55	47.57	18.42	1631.79	1894.89
8/1/10	2.68	56.60	18.42	2084.83	2159.51
8/2/10	2.81	53.29	18.42	2054.43	2201.44
8/3/10	2.94	49.59	18.42	1994.21	2248.75
8/4/10	3.07	30.44	18.42	1212.08	1758.12
8/5/10	3.19	28.67	18.42	1185.97	1710.81
8/6/10	3.32	38.98	18.42	1752.39	2251.80
8/7/10	3.45	50.64	18.42	2428.74	2674.92
8/8/10	3.58	49.87	18.42	2484.64	2800.93
8/9/10	3.71	45.93	18.42	2361.57	2647.79
8/10/10	3.84	47.32	18.42	2529.23	2906.13
8/11/10	3.96	52.39	18.42	2920.51	3203.01
8/12/10	4.09	43.55	18.42	2480.23	2935.21
8/13/10	4.22	50.46	18.42	2999.65	3274.51
8/14/10	4.35	52.52	18.42	3230.06	3567.30
8/15/10	4.48	32.95	18.42	2021.88	2857.30
8/16/10	4.60	15.76	18.42	901.96	1768.43
8/17/10	4.73	34.04	18.42	2225.02	2847.64
8/18/10	4.65	26.59	18.42	1666.32	2615.19

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
8/19/10	4.57	50.56	18.42	3271.11	3599.20
8/20/10	4.49	43.18	18.42	2714.81	3126.07
8/21/10	4.41	41.07	18.42	2523.58	2955.17
8/22/10	4.33	3.48	18.42	42.68	459.13
8/23/10	4.25	2.95	18.42	4.33	383.63
8/24/10	4.17	9.68	18.42	420.03	1016.82
8/25/10	4.09	20.24	18.42	1053.07	1634.84
8/26/10	4.00	37.64	18.42	2070.02	2316.89
8/27/10	3.92	50.68	18.42	2788.68	2768.21
8/28/10	3.84	49.55	18.42	2662.61	2635.17
8/29/10	3.76	48.48	18.42	2542.48	2498.55
8/30/10	3.68	49.39	18.42	2534.26	2424.23
8/31/10	3.60	45.96	18.42	2289.86	2229.36
9/1/10	3.52	45.14	18.42	2191.05	2113.72
9/2/10	3.44	44.15	18.42	2085.48	1993.07
9/3/10	3.36	8.89	18.42	263.27	636.00
9/4/10	3.28	46.69	18.42	2103.02	1836.96
9/5/10	3.19	46.96	18.42	2059.24	1780.23
9/6/10	3.11	47.33	18.42	2019.67	1682.44
9/7/10	3.03	42.76	18.42	1755.50	1485.50
9/8/10	2.95	33.01	18.42	1273.75	1186.56
9/9/10	2.87	37.71	18.42	1435.13	1211.86
9/10/10	2.79	27.01	18.42	943.35	928.88
9/11/10	2.71	42.69	18.42	1545.54	1142.41
9/12/10	2.63	18.34	18.42	537.73	665.29
9/13/10	2.55	15.68	18.42	414.06	549.55
9/14/10	2.47	38.65	18.42	1241.82	798.74
9/15/10	2.46	44.58	18.42	1457.90	972.69
9/16/10	2.46	34.09	18.42	1070.12	871.21
9/17/10	2.45	17.90	18.42	474.19	605.76
9/18/10	2.45	24.38	18.42	710.56	868.99
9/19/10	2.45	33.57	18.42	1045.40	1115.05
9/20/10	2.44	40.29	18.42	1288.77	1333.74
9/21/10	2.44	39.40	18.42	1254.07	1412.71
9/22/10	2.57	35.90	18.42	1194.66	1408.93
9/23/10	2.69	36.29	18.42	1278.59	1462.00
9/24/10	2.82	15.98	18.42	491.20	974.08
9/25/10	2.95	34.95	18.42	1357.54	1629.68
9/26/10	3.08	23.33	18.42	889.55	1340.58
9/27/10	3.20	7.35	18.42	169.32	643.74
9/28/10	3.33	13.68	18.42	497.87	1080.31
9/29/10	3.46	28.70	18.42	1300.06	1686.73
9/30/10	3.58	13.15	18.42	521.71	1117.96
10/1/10	3.71	10.88	18.42	420.52	927.90
10/2/10	3.84	38.90	18.42	2048.86	2266.92
10/3/10	3.97	14.95	18.42	703.14	1399.53
10/4/10	4.09	19.00	18.42	979.33	1606.57

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
10/5/10	4.22	6.10	18.42	201.78	735.94
10/6/10	4.35	5.07	18.42	146.69	616.68
10/7/10	4.47	20.29	18.42	1173.58	1843.11
10/8/10	4.60	35.56	18.42	2262.40	2625.28
10/9/10	4.73	36.03	18.42	2363.08	2699.75
10/10/10	4.85	35.66	18.42	2404.68	2768.62
10/11/10	4.98	33.58	18.42	2317.32	2765.10
10/12/10	5.11	19.66	18.42	1318.42	1938.02
10/13/10	5.24	34.06	18.42	2482.87	2921.10
10/14/10	5.18	22.02	18.42	1521.20	2176.66
10/15/10	5.12	18.08	18.42	1200.14	1885.84
10/16/10	5.06	28.87	18.42	1999.24	2439.56
10/17/10	5.00	29.97	18.42	2055.81	2502.87
10/18/10	4.94	30.57	18.42	2073.67	2424.33
10/19/10	4.88	26.08	18.42	1719.28	2040.78
10/20/10	4.82	21.36	18.42	1356.06	1870.35
10/21/10	4.76	15.36	18.42	910.32	1602.44
10/22/10	4.70	25.81	18.42	1631.18	2023.56
10/23/10	4.64	23.82	18.42	1470.03	1946.57
10/24/10	4.58	8.24	18.42	382.08	909.05
10/25/10	4.52	12.46	18.42	659.44	1215.24
10/26/10	4.46	14.75	18.42	801.50	1195.85
10/27/10	4.40	2.89	18.42	7.64	346.73
10/28/10	4.35	21.56	18.42	1217.77	1593.31
10/29/10	4.29	17.18	18.42	917.96	1357.75
10/30/10	4.23	24.53	18.42	1366.62	1591.29
10/31/10	4.17	23.79	18.42	1299.05	1534.07
11/1/10	4.11	27.63	18.42	1513.39	1636.10
11/2/10	4.05	18.21	18.42	919.01	1223.70
11/3/10	3.99	23.16	18.42	1197.91	1339.60
11/4/10	3.93	3.68	18.42	33.75	338.90
11/5/10	3.87	6.90	18.42	216.49	553.18
11/6/10	3.81	10.91	18.42	438.65	691.58
11/7/10	3.75	8.81	18.42	311.29	630.17
11/8/10	3.69	4.85	18.42	84.73	374.91
11/9/10	3.63	10.92	18.42	410.47	672.83
11/10/10	3.57	6.24	18.42	150.66	429.58
11/11/10	3.51	22.37	18.42	992.33	981.65
11/12/10	3.45	24.05	18.42	1058.76	1017.24
11/13/10	3.40	23.80	18.42	1025.19	967.64
11/14/10	3.34	20.36	18.42	832.34	841.71
11/15/10	3.28	6.80	18.42	150.47	369.47
11/16/10	3.22	8.99	18.42	249.38	422.43
11/17/10	3.16	13.01	18.42	431.21	504.48
11/18/10	3.10	15.75	18.42	546.49	576.53
11/19/10	3.04	19.92	18.42	722.18	641.61
11/20/10	2.98	9.55	18.42	242.78	355.47

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
11/21/10	2.92	21.98	18.42	776.53	584.55
11/22/10	2.86	7.76	18.42	149.21	238.84
11/23/10	2.80	11.91	18.42	315.86	312.86
11/24/10	2.74	21.79	18.42	710.36	458.76
11/25/10	2.68	8.85	18.42	171.98	218.64
11/26/10	2.62	3.98	18.42	0.00	96.84
11/27/10	2.56	19.93	18.42	581.10	315.25
11/28/10	2.50	20.81	18.42	596.24	285.17
11/29/10	2.45	20.15	18.42	553.76	239.05
11/30/10	2.45	8.96	18.42	145.01	131.25
12/1/10	2.45	2.10	18.42	0.00	35.71
12/2/10	2.45	19.91	18.42	546.43	245.64
12/3/10	2.45	7.20	18.42	81.22	111.57
12/4/10	2.45	19.41	18.42	529.31	246.68
12/5/10	2.46	16.83	18.42	435.08	225.43
12/6/10	2.46	14.16	18.42	337.41	203.19
12/7/10	2.46	18.37	18.42	492.78	244.00
12/8/10	2.46	18.44	18.42	495.93	249.76
12/9/10	2.46	19.31	18.42	528.34	259.40
12/10/10	2.47	11.57	18.42	243.67	173.02
12/11/10	2.47	15.61	18.42	393.03	225.06
12/12/10	2.47	1.06	18.42	0.00	22.72
12/13/10	2.47	1.33	18.42	0.00	28.78
12/14/10	2.47	15.68	18.42	396.83	225.78
12/15/10	2.47	17.96	18.42	481.63	262.29
12/16/10	2.48	16.61	18.42	432.30	249.27
12/17/10	2.48	17.95	18.42	482.15	267.27
12/18/10	2.48	15.89	18.42	406.29	241.76
12/19/10	2.48	7.36	18.42	90.30	143.14
12/20/10	2.48	4.31	18.42	0.00	91.93
12/21/10	2.49	15.58	18.42	396.08	246.51
12/22/10	2.49	14.85	18.42	369.39	250.23
12/23/10	2.49	6.80	18.42	70.38	143.12
12/24/10	2.49	18.75	18.42	515.74	296.65
12/25/10	2.49	10.17	18.42	196.51	200.40
12/26/10	2.50	1.85	18.42	0.00	47.61
12/27/10	2.50	8.76	18.42	144.19	174.69
12/28/10	2.50	19.63	18.42	550.66	315.78
12/29/10	2.50	16.50	18.42	434.09	282.16
12/30/10	2.50	18.43	18.42	506.73	308.26

Table C-7. Daily modeled primary production based on sub-surface water samples in Rhode Island Sound. Daily interpolated biomass (B), euphotic depth (Z), and photosynthetically active radiation (I) were used as inputs for our BZI models of primary production (see chapter 2). Also shown is daily modeled primary production using the Webb/Platt models.

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
1/1/10	1.69	5.95	16.48	0.00	475.27
1/2/10	1.80	6.29	16.55	0.00	480.38
1/3/10	1.92	8.03	16.62	0.00	604.99
1/4/10	2.04	19.34	16.69	295.36	938.16
1/5/10	2.16	9.17	16.76	1.34	634.39
1/6/10	2.27	19.76	16.83	383.24	961.29
1/7/10	2.39	19.44	16.90	409.76	949.11
1/8/10	2.51	9.44	16.97	64.52	610.47
1/9/10	2.62	20.44	17.04	525.90	973.03
1/10/10	2.74	19.62	17.11	531.41	935.47
1/11/10	2.86	18.67	17.18	528.61	927.11
1/12/10	2.98	18.27	17.26	547.20	902.51
1/13/10	3.09	18.10	17.33	576.28	855.29
1/14/10	3.21	15.60	17.40	487.11	819.83
1/15/10	3.42	11.17	17.47	304.47	728.37
1/16/10	3.64	21.28	17.54	925.51	999.04
1/17/10	3.85	6.44	17.61	96.47	503.69
1/18/10	4.07	9.38	17.69	310.41	665.68
1/19/10	4.28	1.35	17.76	0.00	161.67
1/20/10	4.23	11.79	17.83	502.26	782.53
1/21/10	4.17	22.34	17.90	1204.01	979.60
1/22/10	4.12	14.60	17.97	675.53	787.44
1/23/10	4.06	23.24	18.04	1236.61	971.63
1/24/10	4.01	11.67	18.12	465.51	606.84
1/25/10	3.95	0.88	18.19	0.00	91.00
1/26/10	3.90	21.87	18.26	1104.59	864.80
1/27/10	3.85	23.70	18.33	1206.92	907.63
1/28/10	3.79	7.73	18.40	188.63	510.89
1/29/10	3.74	25.13	18.48	1264.51	894.16
1/30/10	3.68	14.26	18.55	579.99	635.99
1/31/10	3.63	25.05	18.62	1226.34	848.99
2/1/10	3.57	25.40	18.69	1230.08	843.07
2/2/10	3.52	12.29	18.76	433.79	579.26
2/3/10	2.62	17.18	18.83	465.93	600.49
2/4/10	3.27	26.63	18.90	1183.02	802.93
2/5/10	3.91	21.91	18.98	1167.84	700.89
2/6/10	3.92	5.07	19.05	43.66	266.98
2/7/10	3.92	27.54	19.12	1562.11	769.91
2/8/10	3.93	28.17	19.19	1613.92	772.40
2/9/10	3.93	27.27	19.26	1561.51	737.68
2/10/10	3.94	2.94	19.33	0.00	161.52
2/11/10	3.94	24.06	19.40	1358.83	668.60

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
2/12/10	3.95	30.08	19.47	1783.02	731.86
2/13/10	3.95	19.96	19.54	1089.74	558.79
2/14/10	3.96	28.57	19.61	1697.62	660.17
2/15/10	3.96	28.75	19.68	1719.72	675.96
2/16/10	3.58	6.86	19.75	140.34	281.83
2/17/10	3.21	15.68	19.82	600.62	443.59
2/18/10	2.83	25.13	19.89	977.35	571.57
2/19/10	2.46	23.30	19.96	731.51	560.92
2/20/10	2.08	31.60	20.03	888.77	634.29
2/21/10	1.71	29.21	20.10	604.47	590.30
2/22/10	1.33	30.35	20.17	435.86	570.25
2/23/10	1.28	6.42	20.24	0.00	225.15
2/24/10	1.22	3.13	20.30	0.00	123.63
2/25/10	1.17	5.18	20.37	0.00	174.00
2/26/10	1.11	10.66	20.44	0.00	299.63
2/27/10	1.06	14.28	20.51	0.00	337.37
2/28/10	1.00	16.19	20.57	2.87	349.60
3/1/10	0.83	16.47	20.64	0.00	350.76
3/2/10	0.66	27.75	20.71	44.43	427.52
3/3/10	0.70	7.85	20.77	0.00	199.58
3/4/10	0.73	10.83	20.84	0.00	249.12
3/5/10	0.77	23.68	20.91	44.86	360.45
3/6/10	0.80	37.50	20.97	271.31	433.87
3/7/10	0.84	37.36	21.04	296.24	419.15
3/8/10	0.87	37.36	21.10	323.36	399.55
3/9/10	0.91	37.57	21.16	354.27	386.07
3/10/10	0.94	35.80	21.23	345.29	354.26
3/11/10	0.42	8.15	21.29	0.00	168.13
3/12/10	0.70	14.23	21.35	0.00	219.86
3/13/10	0.98	1.06	21.42	0.00	31.41
3/14/10	1.26	5.29	21.48	0.00	123.70
3/15/10	1.54	4.76	21.54	0.00	107.94
3/16/10	1.82	37.98	21.60	1046.91	368.70
3/17/10	2.10	41.86	21.66	1416.83	387.03
3/18/10	1.81	41.76	21.72	1179.13	386.70
3/19/10	1.52	40.80	21.78	915.54	381.79
3/20/10	1.22	40.87	21.84	686.42	382.27
3/21/10	0.93	39.89	21.90	435.78	373.33
3/22/10	0.64	7.21	21.96	0.00	148.12
3/23/10	0.70	5.35	22.01	0.00	105.00
3/24/10	0.75	38.62	22.07	278.48	370.74
3/25/10	0.81	33.83	22.13	245.37	354.62
3/26/10	0.86	20.75	22.18	59.30	260.06
3/27/10	0.92	43.79	22.24	504.98	392.09
3/28/10	0.97	23.68	22.29	163.99	292.74
3/29/10	1.03	2.97	22.35	0.00	76.07
3/30/10	1.08	2.19	22.40	0.00	52.77

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
3/31/10	1.14	15.40	22.45	56.24	234.37
4/1/10	1.19	35.81	22.51	566.11	340.87
4/2/10	1.25	46.16	22.56	869.69	408.08
4/3/10	1.30	46.13	22.61	923.13	400.87
4/4/10	1.25	40.91	22.66	746.78	368.20
4/5/10	1.20	45.70	22.71	825.79	404.21
4/6/10	1.15	27.75	22.76	358.64	326.67
4/7/10	1.10	46.27	22.81	751.89	406.12
4/8/10	1.06	43.59	22.85	649.28	403.62
4/9/10	1.01	4.98	22.90	0.00	107.17
4/10/10	0.96	44.03	22.95	573.93	391.25
4/11/10	0.91	42.86	22.99	509.15	387.79
4/12/10	0.86	49.81	23.04	591.05	425.76
4/13/10	1.08	37.87	23.08	551.86	389.46
4/14/10	1.30	52.38	23.12	1117.84	434.73
4/15/10	0.74	49.89	23.16	472.82	422.10
4/16/10	0.72	20.29	23.21	8.26	275.90
4/17/10	0.70	11.89	23.25	0.00	208.94
4/18/10	0.68	27.23	23.29	91.23	299.00
4/19/10	0.66	47.13	23.33	356.08	407.50
4/20/10	0.64	35.88	23.36	185.95	374.79
4/21/10	1.23	43.93	23.40	841.19	403.41
4/22/10	1.21	48.59	23.44	943.05	408.04
4/23/10	1.19	35.56	23.47	597.01	359.77
4/24/10	1.17	54.40	23.51	1049.30	437.64
4/25/10	1.15	15.26	23.54	74.89	237.32
4/26/10	1.13	19.43	23.58	168.87	258.65
4/27/10	1.11	8.16	23.61	0.00	173.25
4/28/10	1.09	24.06	23.64	260.78	332.43
4/29/10	1.07	53.11	23.67	912.64	433.71
4/30/10	1.05	54.73	23.70	927.77	427.33
5/1/10	1.00	53.09	23.73	836.08	440.83
5/2/10	0.95	39.33	23.76	501.62	410.38
5/3/10	0.90	24.06	23.79	166.54	323.06
5/4/10	0.85	45.39	23.81	529.95	444.57
5/5/10	0.85	57.04	23.84	741.19	526.71
5/6/10	0.85	34.92	23.86	338.06	423.59
5/7/10	0.85	57.07	23.88	739.74	559.05
5/8/10	0.84	17.50	23.91	20.70	330.18
5/9/10	0.84	56.72	23.93	731.34	590.67
5/10/10	0.84	59.81	23.95	786.13	622.03
5/11/10	0.84	50.67	23.97	619.58	593.65
5/12/10	0.84	16.38	23.99	0.00	376.25
5/13/10	0.68	58.05	24.00	555.76	630.97
5/14/10	0.68	25.68	24.02	82.99	416.47
5/15/10	0.69	58.12	24.04	568.61	619.38
5/16/10	0.69	54.04	24.05	513.25	601.90

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
5/17/10	0.70	50.15	24.06	460.02	563.78
5/18/10	0.70	11.80	24.08	0.00	289.14
5/19/10	0.71	15.42	24.09	0.00	313.43
5/20/10	0.71	58.08	24.10	597.00	556.80
5/21/10	0.71	57.55	24.11	594.45	551.32
5/22/10	0.72	45.92	24.12	418.75	486.68
5/23/10	0.72	36.56	24.12	276.51	422.67
5/24/10	0.73	57.54	24.13	610.92	511.30
5/25/10	0.73	58.78	24.14	636.19	509.93
5/26/10	0.74	55.03	24.14	581.90	480.38
5/27/10	0.74	49.20	24.14	493.41	453.57
5/28/10	0.74	57.63	24.15	634.19	464.80
5/29/10	0.75	41.84	24.15	383.02	392.59
5/30/10	0.75	52.61	24.15	562.82	433.28
5/31/10	0.76	57.40	24.15	646.30	437.69
6/1/10	0.76	43.15	24.15	416.11	328.02
6/2/10	0.76	54.57	24.14	609.68	373.57
6/3/10	0.77	31.81	24.14	234.52	314.05
6/4/10	0.77	55.43	24.14	633.92	374.28
6/5/10	0.78	33.81	24.13	273.77	273.88
6/6/10	0.78	36.22	24.12	317.75	297.88
6/7/10	0.79	59.47	24.12	717.36	362.00
6/8/10	0.79	51.19	24.11	580.50	341.45
6/9/10	0.78	22.51	24.10	83.96	220.32
6/10/10	0.72	21.43	24.09	39.65	196.83
6/11/10	0.67	25.80	24.08	76.89	225.93
6/12/10	0.61	25.73	24.06	44.68	200.68
6/13/10	0.56	14.90	24.05	0.00	154.33
6/14/10	0.50	34.17	24.04	73.76	228.50
6/15/10	0.45	57.65	24.02	258.61	260.79
6/16/10	0.39	36.96	24.00	14.49	203.67
6/17/10	0.64	41.40	23.99	271.47	202.16
6/18/10	0.51	60.09	23.97	364.16	283.18
6/19/10	0.53	63.31	23.95	426.32	332.09
6/20/10	0.55	44.82	23.93	233.88	313.20
6/21/10	0.57	58.57	23.91	421.37	412.84
6/22/10	0.59	44.78	23.88	270.98	368.44
6/23/10	0.61	48.36	23.86	336.53	442.93
6/24/10	0.63	48.89	23.84	363.85	493.54
6/25/10	0.65	60.86	23.81	550.80	588.84
6/26/10	0.67	45.92	23.79	361.69	535.63
6/27/10	0.69	42.55	23.76	330.78	560.49
6/28/10	0.71	46.72	23.73	411.49	582.58
6/29/10	0.73	40.59	23.70	335.08	639.48
6/30/10	0.75	61.63	23.67	687.82	815.04
7/1/10	0.89	51.37	23.64	671.41	785.22
7/2/10	0.91	60.98	23.61	881.45	840.76

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
7/3/10	0.93	57.86	23.58	848.44	804.51
7/4/10	0.96	53.60	23.54	789.41	766.47
7/5/10	0.98	60.21	23.51	951.42	798.20
7/6/10	1.00	52.81	23.47	822.59	727.59
7/7/10	1.03	50.31	23.44	793.05	713.72
7/8/10	1.05	54.75	23.40	914.35	697.49
7/9/10	1.07	43.03	23.36	674.80	658.94
7/10/10	1.10	35.43	23.33	519.37	567.08
7/11/10	1.12	49.56	23.29	867.39	677.26
7/12/10	1.14	53.58	23.25	986.01	672.32
7/13/10	1.17	33.57	23.21	522.10	471.56
7/14/10	1.19	14.96	23.16	74.72	316.83
7/15/10	1.22	23.65	23.12	300.99	423.35
7/16/10	1.24	39.48	23.08	718.62	538.44
7/17/10	1.26	54.76	23.04	1135.82	623.74
7/18/10	1.29	50.79	22.99	1054.04	596.09
7/19/10	1.31	32.15	22.95	572.21	455.32
7/20/10	1.33	44.27	22.90	918.65	548.76
7/21/10	1.36	40.10	22.85	821.31	431.44
7/22/10	1.38	51.70	22.81	1166.68	567.80
7/23/10	1.40	15.82	22.76	157.78	288.76
7/24/10	1.43	36.27	22.71	764.94	510.56
7/25/10	1.46	42.71	22.66	976.82	609.62
7/26/10	1.49	57.97	22.61	1463.05	865.47
7/27/10	1.52	56.74	22.56	1456.06	955.29
7/28/10	1.55	55.26	22.51	1440.00	1028.68
7/29/10	1.58	32.21	22.45	732.58	874.75
7/30/10	1.61	52.83	22.40	1419.27	1191.78
7/31/10	1.64	47.57	22.35	1273.03	1230.59
8/1/10	1.67	56.60	22.29	1600.40	1403.05
8/2/10	1.70	53.29	22.24	1516.83	1452.08
8/3/10	1.73	49.59	22.18	1416.20	1508.67
8/4/10	1.76	30.44	22.13	770.16	1232.89
8/5/10	1.79	28.67	22.07	722.52	1211.17
8/6/10	1.82	38.98	22.01	1108.15	1574.07
8/7/10	1.85	50.64	21.96	1553.76	1838.82
8/8/10	1.88	49.87	21.90	1550.05	1942.91
8/9/10	1.91	45.93	21.84	1426.18	1854.31
8/10/10	1.94	47.32	21.78	1501.08	2037.06
8/11/10	1.97	52.39	21.72	1718.94	2246.22
8/12/10	2.00	43.55	21.66	1399.33	2094.37
8/13/10	2.03	50.46	21.60	1692.27	2302.88
8/14/10	2.06	52.52	21.54	1797.80	2532.33
8/15/10	2.09	32.95	21.48	1032.66	2126.29
8/16/10	2.12	15.76	21.42	346.23	1418.62
8/17/10	2.15	34.04	21.35	1107.45	2119.66
8/18/10	2.13	26.59	21.29	789.21	2018.80

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
8/19/10	2.12	50.56	21.23	1746.65	2597.59
8/20/10	2.10	43.18	21.16	1430.41	2293.96
8/21/10	2.08	41.07	21.10	1328.95	2187.17
8/22/10	2.07	3.48	21.04	0.00	420.31
8/23/10	2.05	2.95	20.97	0.00	354.59
8/24/10	2.04	9.68	20.91	74.29	863.32
8/25/10	2.02	20.24	20.84	470.91	1295.82
8/26/10	2.01	37.64	20.77	1115.62	1748.15
8/27/10	1.99	50.68	20.71	1583.97	2054.70
8/28/10	1.98	49.55	20.64	1521.92	1967.91
8/29/10	1.96	48.48	20.57	1462.92	1876.83
8/30/10	1.95	49.39	20.51	1476.21	1828.73
8/31/10	1.93	45.96	20.44	1334.45	1698.79
9/1/10	1.91	45.14	20.37	1287.13	1623.14
9/2/10	1.90	44.15	20.30	1234.64	1542.58
9/3/10	1.88	8.89	20.24	7.93	554.24
9/4/10	1.87	46.69	20.17	1285.54	1434.97
9/5/10	1.85	46.96	20.10	1275.96	1405.86
9/6/10	1.84	47.33	20.03	1269.68	1341.62
9/7/10	1.82	42.76	19.96	1101.76	1201.53
9/8/10	1.81	33.01	19.89	770.01	986.88
9/9/10	1.79	37.71	19.82	906.94	1013.02
9/10/10	1.77	27.01	19.75	554.82	798.62
9/11/10	1.76	42.69	19.68	1032.88	980.38
9/12/10	1.74	18.34	19.61	267.43	600.22
9/13/10	1.73	15.68	19.54	179.40	505.81
9/14/10	1.71	38.65	19.47	862.68	735.93
9/15/10	1.83	44.58	19.40	1123.99	869.56
9/16/10	1.94	34.09	19.33	853.06	762.46
9/17/10	2.05	17.90	19.26	339.93	526.46
9/18/10	2.17	24.38	19.19	614.94	739.19
9/19/10	2.28	33.57	19.12	1019.52	924.84
9/20/10	2.39	40.29	19.05	1355.21	1086.55
9/21/10	2.51	39.40	18.98	1388.94	1136.21
9/22/10	2.62	35.90	18.90	1302.69	1122.73
9/23/10	2.73	36.29	18.83	1383.73	1155.83
9/24/10	2.85	15.98	18.76	471.00	784.31
9/25/10	2.96	34.95	18.69	1442.84	1261.48
9/26/10	3.07	23.33	18.62	904.03	1040.77
9/27/10	3.19	7.35	18.55	94.15	534.77
9/28/10	3.30	13.68	18.48	453.27	858.84
9/29/10	3.41	28.70	18.40	1325.26	1273.14
9/30/10	3.53	13.15	18.33	468.07	880.68
10/1/10	3.64	10.88	18.26	353.53	725.90
10/2/10	3.75	38.90	18.19	2092.79	1676.75
10/3/10	3.87	14.95	18.12	645.28	1078.68
10/4/10	3.98	19.00	18.04	930.90	1205.35

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
10/5/10	4.09	6.10	17.97	106.68	600.12
10/6/10	4.21	5.07	17.90	46.66	497.89
10/7/10	4.32	20.29	17.83	1109.07	1375.97
10/8/10	4.43	35.56	17.76	2222.31	1898.07
10/9/10	4.55	36.03	17.69	2310.24	1945.66
10/10/10	4.66	35.66	17.61	2337.10	1989.29
10/11/10	4.77	33.58	17.54	2233.24	1984.05
10/12/10	4.89	19.66	17.47	1213.50	1412.08
10/13/10	5.00	34.06	17.40	2369.83	2082.70
10/14/10	4.98	22.02	17.33	1412.73	1572.58
10/15/10	4.96	18.08	17.26	1094.80	1397.99
10/16/10	4.93	28.87	17.18	1905.95	1769.98
10/17/10	4.91	29.97	17.11	1970.40	1824.03
10/18/10	4.89	30.57	17.04	1996.17	1766.79
10/19/10	4.87	26.08	16.97	1642.71	1499.01
10/20/10	4.85	21.36	16.90	1277.93	1390.24
10/21/10	4.83	15.36	16.83	825.88	1241.39
10/22/10	4.80	25.81	16.76	1573.52	1506.13
10/23/10	4.78	23.82	16.69	1414.09	1468.17
10/24/10	4.76	8.24	16.62	290.15	743.90
10/25/10	4.74	12.46	16.55	582.18	967.96
10/26/10	4.72	14.75	16.48	734.97	935.01
10/27/10	4.70	2.89	16.41	0.00	309.52
10/28/10	4.67	21.56	16.34	1184.93	1235.00
10/29/10	4.65	17.18	16.27	873.31	1086.90
10/30/10	4.63	24.53	16.20	1358.55	1243.84
10/31/10	4.61	23.79	16.13	1294.51	1208.20
11/1/10	4.59	27.63	16.06	1534.42	1292.52
11/2/10	4.57	18.21	15.99	899.18	1005.22
11/3/10	4.54	23.16	15.92	1210.50	1088.36
11/4/10	4.52	3.68	15.85	0.00	316.72
11/5/10	4.50	6.90	15.78	144.14	498.16
11/6/10	4.48	10.91	15.71	393.93	601.28
11/7/10	4.46	8.81	15.64	255.88	570.63
11/8/10	4.44	4.85	15.58	4.35	360.55
11/9/10	4.41	10.92	15.51	375.98	614.21
11/10/10	4.39	6.24	15.44	83.94	416.32
11/11/10	4.37	22.37	15.37	1055.60	868.63
11/12/10	4.35	24.05	15.30	1143.04	911.09
11/13/10	4.33	23.80	15.24	1115.24	881.06
11/14/10	4.30	20.36	15.17	899.53	789.86
11/15/10	4.28	6.80	15.10	99.10	388.18
11/16/10	4.26	8.99	15.03	221.22	436.76
11/17/10	4.24	13.01	14.97	445.99	510.94
11/18/10	4.22	15.75	14.90	593.83	601.23
11/19/10	4.20	19.92	14.84	819.27	672.86
11/20/10	4.17	9.55	14.77	233.22	410.63

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
11/21/10	4.15	21.98	14.70	910.85	644.01
11/22/10	4.13	7.76	14.64	125.51	294.28
11/23/10	4.11	11.91	14.57	344.80	389.38
11/24/10	4.09	21.79	14.51	866.07	570.75
11/25/10	4.07	8.85	14.44	170.55	315.98
11/26/10	4.04	3.98	14.38	0.00	157.48
11/27/10	4.02	19.93	14.31	735.86	473.90
11/28/10	4.00	20.81	14.25	770.68	463.39
11/29/10	3.98	20.15	14.18	726.72	430.61
11/30/10	3.94	8.96	14.12	151.60	264.20
12/1/10	3.90	2.10	14.06	0.00	78.13
12/2/10	3.86	19.91	13.99	670.51	429.64
12/3/10	3.82	7.20	13.93	47.77	215.81
12/4/10	3.78	19.41	13.87	618.46	423.57
12/5/10	3.74	16.83	13.81	484.74	389.77
12/6/10	3.70	14.16	13.74	350.67	354.95
12/7/10	3.66	18.37	13.68	530.64	408.62
12/8/10	3.62	18.44	13.62	521.06	414.26
12/9/10	3.58	19.31	13.56	546.17	423.64
12/10/10	3.54	11.57	13.50	200.31	289.87
12/11/10	3.50	15.61	13.43	363.41	365.04
12/12/10	3.46	1.06	13.37	0.00	41.98
12/13/10	3.42	1.33	13.31	0.00	52.20
12/14/10	3.38	15.68	13.25	334.80	353.52
12/15/10	3.34	17.96	13.19	414.87	406.67
12/16/10	3.30	16.61	13.13	350.66	384.34
12/17/10	3.26	17.95	13.07	390.99	406.67
12/18/10	3.22	15.89	13.01	301.81	365.20
12/19/10	3.18	7.36	12.95	0.00	222.87
12/20/10	3.14	4.31	12.89	0.00	144.40
12/21/10	3.10	15.58	12.83	260.51	362.46
12/22/10	3.06	14.85	12.78	225.15	366.10
12/23/10	3.02	6.80	12.72	0.00	213.62
12/24/10	2.98	18.75	12.66	339.45	424.09
12/25/10	2.94	10.17	12.60	42.13	288.71
12/26/10	2.90	1.85	12.54	0.00	71.29
12/27/10	2.86	8.76	12.49	0.00	247.00
12/28/10	2.82	19.63	12.43	322.02	437.48
12/29/10	2.78	16.50	12.37	213.51	388.02
12/30/10	2.74	18.43	12.32	262.42	420.36

Table C-8. Daily modeled primary production based on depth-integrated water samples in Block Island Sound. Daily interpolated biomass (B), euphotic depth (Z), and photosynthetically active radiation (I) were used as inputs for our BZI models of primary production (see chapter 2). Also shown is daily modeled primary production using the Webb/Platt models.

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
1/1/10	2.52	5.95	18.42	198.19	486.85
1/2/10	2.56	6.29	18.42	207.06	488.33
1/3/10	2.61	8.03	18.42	244.71	611.84
1/4/10	2.65	19.34	18.42	482.51	881.75
1/5/10	2.70	9.17	18.42	274.39	633.25
1/6/10	2.74	19.76	18.42	504.58	904.69
1/7/10	2.78	19.44	18.42	504.40	894.13
1/8/10	2.83	9.44	18.42	289.66	605.38
1/9/10	2.87	20.44	18.42	540.20	912.89
1/10/10	2.91	19.62	18.42	528.37	879.04
1/11/10	2.96	18.67	18.42	513.17	876.41
1/12/10	3.00	18.27	18.42	509.98	853.04
1/13/10	3.19	18.10	18.42	533.66	801.59
1/14/10	3.39	15.60	18.42	494.63	784.35
1/15/10	3.58	11.17	18.42	394.10	718.90
1/16/10	3.77	21.28	18.42	710.08	935.20
1/17/10	3.97	6.44	18.42	281.02	513.75
1/18/10	4.16	9.38	18.42	386.71	665.57
1/19/10	4.36	1.35	18.42	126.96	180.77
1/20/10	4.02	11.79	18.42	451.71	804.35
1/21/10	3.68	22.34	18.42	724.56	975.24
1/22/10	3.74	14.60	18.42	509.09	843.47
1/23/10	3.81	23.24	18.42	774.32	1033.56
1/24/10	3.87	11.67	18.42	434.77	703.42
1/25/10	3.94	0.88	18.42	108.04	131.30
1/26/10	4.00	21.87	18.42	766.55	1018.78
1/27/10	4.07	23.70	18.42	836.10	1104.76
1/28/10	4.13	7.73	18.42	331.07	738.31
1/29/10	4.20	25.13	18.42	907.02	1160.97
1/30/10	4.26	14.26	18.42	557.04	909.16
1/31/10	4.33	25.05	18.42	929.95	1180.25
2/1/10	4.39	25.40	18.42	954.53	1218.11
2/2/10	4.46	12.29	18.42	509.93	958.88
2/3/10	4.52	17.18	18.42	689.14	962.52
2/4/10	4.59	26.63	18.42	1037.24	1284.96
2/5/10	4.65	21.91	18.42	879.09	1195.79
2/6/10	4.41	5.07	18.42	256.02	566.01
2/7/10	4.18	27.54	18.42	981.50	1255.82
2/8/10	3.94	28.17	18.42	949.63	1247.77
2/9/10	3.70	27.27	18.42	870.93	1188.60
2/10/10	3.63	2.94	18.42	164.38	354.72
2/11/10	3.57	24.06	18.42	752.86	1077.89

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
2/12/10	3.50	30.08	18.42	905.31	1132.47
2/13/10	3.43	19.96	18.42	617.43	901.07
2/14/10	3.37	28.57	18.42	834.12	1000.40
2/15/10	3.30	28.75	18.42	823.86	1021.21
2/16/10	3.08	6.86	18.42	246.08	510.43
2/17/10	2.85	15.68	18.42	430.97	704.30
2/18/10	2.63	25.13	18.42	597.81	844.78
2/19/10	2.40	23.30	18.42	519.26	828.98
2/20/10	2.18	31.60	18.42	619.99	888.64
2/21/10	1.95	29.21	18.42	527.95	821.98
2/22/10	1.73	30.35	18.42	492.08	774.70
2/23/10	1.59	6.42	18.42	160.91	355.44
2/24/10	1.46	3.13	18.42	116.52	201.61
2/25/10	1.32	5.18	18.42	134.33	260.80
2/26/10	1.18	10.66	18.42	179.60	413.32
2/27/10	1.05	14.28	18.42	197.80	440.56
2/28/10	0.91	16.19	18.42	196.15	437.33
3/1/10	0.93	16.47	18.42	200.78	423.16
3/2/10	0.95	27.75	18.42	287.25	478.03
3/3/10	0.96	7.85	18.42	139.57	228.33
3/4/10	0.96	10.83	18.42	162.39	267.21
3/5/10	0.97	23.68	18.42	260.29	355.63
3/6/10	0.97	37.50	18.42	366.85	397.50
3/7/10	0.98	37.36	18.42	367.57	361.12
3/8/10	0.99	37.36	18.42	369.30	319.93
3/9/10	0.99	37.57	18.42	372.68	283.75
3/10/10	1.00	35.80	18.42	360.61	231.49
3/11/10	1.32	8.15	18.42	165.08	97.63
3/12/10	1.33	14.23	18.42	229.29	138.40
3/13/10	1.35	1.06	18.42	91.98	15.94
3/14/10	1.36	5.29	18.42	137.09	70.31
3/15/10	1.37	4.76	18.42	131.87	62.42
3/16/10	1.38	37.98	18.42	492.54	251.14
3/17/10	1.40	41.86	18.42	538.81	265.68
3/18/10	1.41	41.76	18.42	541.92	266.90
3/19/10	1.42	40.80	18.42	535.38	265.08
3/20/10	1.44	40.87	18.42	540.29	266.52
3/21/10	1.45	39.89	18.42	533.23	261.87
3/22/10	1.46	7.21	18.42	163.27	94.77
3/23/10	1.47	5.35	18.42	142.49	68.28
3/24/10	1.49	38.62	18.42	530.48	263.79
3/25/10	1.50	33.83	18.42	478.03	255.33
3/26/10	1.51	20.75	18.42	326.49	185.45
3/27/10	1.53	43.79	18.42	603.82	282.12
3/28/10	1.54	23.68	18.42	366.02	211.46
3/29/10	1.55	2.97	18.42	116.84	47.94
3/30/10	1.56	2.19	18.42	107.64	34.32

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
3/31/10	1.58	15.40	18.42	270.86	170.24
4/1/10	1.59	35.81	18.42	526.43	250.28
4/2/10	1.60	46.16	18.42	659.91	303.36
4/3/10	1.61	46.13	18.42	664.14	298.61
4/4/10	1.63	40.91	18.42	602.27	276.24
4/5/10	1.64	45.70	18.42	667.87	305.33
4/6/10	1.65	27.75	18.42	440.12	252.02
4/7/10	1.67	46.27	18.42	684.52	308.07
4/8/10	1.68	43.59	18.42	653.87	311.15
4/9/10	1.69	4.98	18.42	146.76	78.46
4/10/10	1.70	44.03	18.42	668.56	301.89
4/11/10	1.72	42.86	18.42	657.27	301.96
4/12/10	1.73	49.81	18.42	755.64	330.03
4/13/10	1.59	37.87	18.42	552.27	311.93
4/14/10	1.45	52.38	18.42	675.24	338.74
4/15/10	1.30	49.89	18.42	587.83	360.49
4/16/10	1.15	20.29	18.42	262.92	257.21
4/17/10	0.99	11.89	18.42	173.38	199.74
4/18/10	0.84	27.23	18.42	260.59	321.54
4/19/10	0.69	47.13	18.42	336.03	473.15
4/20/10	0.54	35.88	18.42	232.53	456.63
4/21/10	0.54	43.93	18.42	264.88	527.95
4/22/10	0.53	48.59	18.42	282.47	567.98
4/23/10	0.74	35.56	18.42	286.49	514.01
4/24/10	0.95	54.40	18.42	484.27	679.82
4/25/10	1.16	15.26	18.42	218.91	338.64
4/26/10	1.36	19.43	18.42	288.40	397.52
4/27/10	1.57	8.16	18.42	181.30	236.88
4/28/10	1.78	24.06	18.42	416.46	559.78
4/29/10	1.99	53.11	18.42	908.34	844.54
4/30/10	2.20	54.73	18.42	1023.07	872.88
5/1/10	2.08	53.09	18.42	945.81	807.94
5/2/10	1.96	39.33	18.42	685.32	652.45
5/3/10	1.84	24.06	18.42	428.40	433.94
5/4/10	1.73	45.39	18.42	694.70	569.63
5/5/10	1.61	57.04	18.42	799.57	617.76
5/6/10	1.49	34.92	18.42	488.59	413.80
5/7/10	1.37	57.07	18.42	694.56	500.24
5/8/10	1.26	17.50	18.42	252.84	219.04
5/9/10	1.14	56.72	18.42	586.12	384.52
5/10/10	1.02	59.81	18.42	558.42	336.07
5/11/10	0.90	50.67	18.42	438.66	252.39
5/12/10	0.78	16.38	18.42	181.38	114.83
5/13/10	0.55	58.05	18.42	330.83	217.76
5/14/10	0.61	25.68	18.42	204.02	143.04
5/15/10	0.68	58.12	18.42	388.22	231.79
5/16/10	0.74	54.04	18.42	393.16	235.10

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5/17/10	0.80	50.15	18.42	395.33	228.26
5/18/10	0.86	11.80	18.42	160.56	111.69
5/19/10	0.93	15.42	18.42	192.60	130.11
5/20/10	0.99	58.08	18.42	530.65	256.74
5/21/10	1.05	57.55	18.42	554.79	264.54
5/22/10	1.11	45.92	18.42	481.52	242.11
5/23/10	1.18	36.56	18.42	417.84	216.83
5/24/10	1.24	57.54	18.42	639.43	277.82
5/25/10	1.30	58.78	18.42	680.39	288.97
5/26/10	1.37	55.03	18.42	669.17	283.45
5/27/10	1.43	49.20	18.42	630.97	278.60
5/28/10	1.49	57.63	18.42	753.52	298.77
5/29/10	1.55	41.84	18.42	589.77	261.77
5/30/10	1.62	52.61	18.42	746.58	303.36
5/31/10	1.68	57.40	18.42	835.35	319.97
6/1/10	1.74	43.15	18.42	669.23	249.91
6/2/10	1.80	54.57	18.42	851.73	298.31
6/3/10	1.87	31.81	18.42	545.88	258.86
6/4/10	1.93	55.43	18.42	918.39	326.64
6/5/10	1.99	33.81	18.42	608.20	249.56
6/6/10	2.05	36.22	18.42	663.72	284.60
6/7/10	2.12	59.47	18.42	1067.07	365.37
6/8/10	2.18	51.19	18.42	954.85	362.03
6/9/10	2.26	22.51	18.42	479.38	242.03
6/10/10	2.34	21.43	18.42	473.78	228.00
6/11/10	2.42	25.80	18.42	570.16	276.77
6/12/10	2.50	25.73	18.42	585.14	258.88
6/13/10	2.58	14.90	18.42	382.12	208.97
6/14/10	2.66	34.17	18.42	793.61	332.41
6/15/10	2.74	57.65	18.42	1319.85	403.69
6/16/10	2.82	36.96	18.42	898.38	333.98
6/17/10	2.91	41.40	18.42	1022.73	353.64
6/18/10	2.36	60.09	18.42	1191.58	440.21
6/19/10	2.30	63.31	18.42	1220.52	466.98
6/20/10	2.24	44.82	18.42	865.86	412.05
6/21/10	2.17	58.57	18.42	1078.53	501.32
6/22/10	2.11	44.78	18.42	821.94	425.98
6/23/10	2.05	48.36	18.42	857.81	485.73
6/24/10	1.99	48.89	18.42	842.77	519.86
6/25/10	1.93	60.86	18.42	999.89	582.03
6/26/10	1.87	45.92	18.42	752.10	522.19
6/27/10	1.80	42.55	18.42	682.19	533.68
6/28/10	1.74	46.72	18.42	718.61	527.12
6/29/10	1.68	40.59	18.42	615.28	583.65
6/30/10	1.62	61.63	18.42	862.65	690.14
7/1/10	1.56	51.37	18.42	707.63	662.66
7/2/10	1.56	60.98	18.42	824.19	696.69

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7/3/10	1.56	57.86	18.42	785.47	672.41
7/4/10	1.55	53.60	18.42	733.04	649.26
7/5/10	1.55	60.21	18.42	812.73	667.43
7/6/10	1.55	52.81	18.42	722.17	616.33
7/7/10	1.55	50.31	18.42	691.32	613.85
7/8/10	1.55	54.75	18.42	744.50	590.54
7/9/10	1.55	43.03	18.42	601.92	582.72
7/10/10	1.54	35.43	18.42	509.49	509.44
7/11/10	1.54	49.56	18.42	679.91	591.69
7/12/10	1.54	53.58	18.42	727.89	580.05
7/13/10	1.54	33.57	18.42	485.90	421.50
7/14/10	1.54	14.96	18.42	261.11	311.94
7/15/10	1.54	23.65	18.42	365.57	401.98
7/16/10	1.54	39.48	18.42	555.77	488.39
7/17/10	1.53	54.76	18.42	739.08	547.09
7/18/10	1.53	50.79	18.42	690.76	531.53
7/19/10	1.53	32.15	18.42	466.54	425.11
7/20/10	1.53	44.27	18.42	611.37	501.72
7/21/10	1.53	40.10	18.42	560.95	386.03
7/22/10	1.53	51.70	18.42	699.25	513.14
7/23/10	1.53	15.82	18.42	269.90	295.31
7/24/10	1.65	36.27	18.42	550.67	454.67
7/25/10	1.78	42.71	18.42	677.09	515.00
7/26/10	1.91	57.97	18.42	948.34	699.85
7/27/10	2.04	56.74	18.42	986.92	757.15
7/28/10	2.17	55.26	18.42	1018.94	801.56
7/29/10	2.30	32.21	18.42	660.00	695.52
7/30/10	2.42	52.83	18.42	1083.87	904.85
7/31/10	2.55	47.57	18.42	1031.70	929.44
8/1/10	2.68	56.60	18.42	1269.13	1036.29
8/2/10	2.81	53.29	18.42	1253.20	1066.71
8/3/10	2.94	49.59	18.42	1221.64	1105.33
8/4/10	3.07	30.44	18.42	811.73	915.71
8/5/10	3.19	28.67	18.42	798.05	892.19
8/6/10	3.32	38.98	18.42	1094.91	1142.61
8/7/10	3.45	50.64	18.42	1449.38	1309.16
8/8/10	3.58	49.87	18.42	1478.68	1379.13
8/9/10	3.71	45.93	18.42	1414.17	1309.68
8/10/10	3.84	47.32	18.42	1502.04	1435.12
8/11/10	3.96	52.39	18.42	1707.11	1570.37
8/12/10	4.09	43.55	18.42	1476.36	1468.23
8/13/10	4.22	50.46	18.42	1748.59	1596.78
8/14/10	4.35	52.52	18.42	1869.35	1753.87
8/15/10	4.48	32.95	18.42	1236.14	1496.77
8/16/10	4.60	15.76	18.42	649.19	1010.27
8/17/10	4.73	34.04	18.42	1342.61	1472.19
8/18/10	4.65	26.59	18.42	1049.80	1442.95

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8/19/10	4.57	50.56	18.42	1890.86	1840.22
8/20/10	4.49	43.18	18.42	1599.31	1657.59
8/21/10	4.41	41.07	18.42	1499.08	1609.70
8/22/10	4.33	3.48	18.42	198.85	322.19
8/23/10	4.25	2.95	18.42	178.75	276.12
8/24/10	4.17	9.68	18.42	396.62	685.98
8/25/10	4.09	20.24	18.42	728.39	1040.76
8/26/10	4.00	37.64	18.42	1261.37	1408.99
8/27/10	3.92	50.68	18.42	1638.02	1679.79
8/28/10	3.84	49.55	18.42	1571.95	1645.11
8/29/10	3.76	48.48	18.42	1508.99	1605.47
8/30/10	3.68	49.39	18.42	1504.68	1600.22
8/31/10	3.60	45.96	18.42	1376.59	1527.21
9/1/10	3.52	45.14	18.42	1324.80	1498.16
9/2/10	3.44	44.15	18.42	1269.48	1463.84
9/3/10	3.36	8.89	18.42	314.46	552.30
9/4/10	3.28	46.69	18.42	1278.67	1438.79
9/5/10	3.19	46.96	18.42	1255.72	1456.66
9/6/10	3.11	47.33	18.42	1234.98	1436.01
9/7/10	3.03	42.76	18.42	1096.53	1336.58
9/8/10	2.95	33.01	18.42	844.05	1147.19
9/9/10	2.87	37.71	18.42	928.63	1222.86
9/10/10	2.79	27.01	18.42	670.89	1016.57
9/11/10	2.71	42.69	18.42	986.50	1290.35
9/12/10	2.63	18.34	18.42	458.30	852.00
9/13/10	2.55	15.68	18.42	393.49	759.95
9/14/10	2.47	38.65	18.42	827.32	1138.48
9/15/10	2.46	44.58	18.42	940.56	1293.79
9/16/10	2.46	34.09	18.42	737.33	1106.25
9/17/10	2.45	17.90	18.42	425.01	752.77
9/18/10	2.45	24.38	18.42	548.88	1029.00
9/19/10	2.45	33.57	18.42	724.37	1243.03
9/20/10	2.44	40.29	18.42	851.92	1418.84
9/21/10	2.44	39.40	18.42	833.73	1455.89
9/22/10	2.57	35.90	18.42	802.60	1415.09
9/23/10	2.69	36.29	18.42	846.59	1425.95
9/24/10	2.82	15.98	18.42	433.92	978.02
9/25/10	2.95	34.95	18.42	887.96	1514.22
9/26/10	3.08	23.33	18.42	642.69	1248.03
9/27/10	3.20	7.35	18.42	265.22	641.55
9/28/10	3.33	13.68	18.42	437.41	1015.42
9/29/10	3.46	28.70	18.42	857.84	1454.95
9/30/10	3.58	13.15	18.42	449.91	1016.69
10/1/10	3.71	10.88	18.42	396.87	827.23
10/2/10	3.84	38.90	18.42	1250.28	1830.78
10/3/10	3.97	14.95	18.42	544.99	1208.69
10/4/10	4.09	19.00	18.42	689.74	1327.02

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10/5/10	4.22	6.10	18.42	282.23	663.54
10/6/10	4.35	5.07	18.42	253.36	545.87
10/7/10	4.47	20.29	18.42	791.55	1473.40
10/8/10	4.60	35.56	18.42	1362.20	1973.53
10/9/10	4.73	36.03	18.42	1414.96	2004.70
10/10/10	4.85	35.66	18.42	1436.77	2036.54
10/11/10	4.98	33.58	18.42	1390.98	2024.20
10/12/10	5.11	19.66	18.42	867.46	1452.83
10/13/10	5.24	34.06	18.42	1477.75	2094.57
10/14/10	5.18	22.02	18.42	973.74	1603.74
10/15/10	5.12	18.08	18.42	805.47	1431.03
10/16/10	5.06	28.87	18.42	1224.28	1775.24
10/17/10	5.00	29.97	18.42	1253.93	1826.20
10/18/10	4.94	30.57	18.42	1263.29	1757.97
10/19/10	4.88	26.08	18.42	1077.55	1488.55
10/20/10	4.82	21.36	18.42	887.19	1395.24
10/21/10	4.76	15.36	18.42	653.58	1263.45
10/22/10	4.70	25.81	18.42	1031.38	1492.52
10/23/10	4.64	23.82	18.42	946.92	1459.66
10/24/10	4.58	8.24	18.42	376.73	756.54
10/25/10	4.52	12.46	18.42	522.09	974.86
10/26/10	4.46	14.75	18.42	596.55	925.85
10/27/10	4.40	2.89	18.42	180.49	314.45
10/28/10	4.35	21.56	18.42	814.71	1207.84
10/29/10	4.29	17.18	18.42	657.58	1069.04
10/30/10	4.23	24.53	18.42	892.72	1196.77
10/31/10	4.17	23.79	18.42	857.31	1159.71
11/1/10	4.11	27.63	18.42	969.65	1227.09
11/2/10	4.05	18.21	18.42	658.13	966.78
11/3/10	3.99	23.16	18.42	804.30	1027.87
11/4/10	3.93	3.68	18.42	194.17	312.10
11/5/10	3.87	6.90	18.42	289.94	484.05
11/6/10	3.81	10.91	18.42	406.38	570.32
11/7/10	3.75	8.81	18.42	339.63	545.97
11/8/10	3.69	4.85	18.42	220.89	347.24
11/9/10	3.63	10.92	18.42	391.61	576.09
11/10/10	3.57	6.24	18.42	255.44	394.27
11/11/10	3.51	22.37	18.42	696.56	777.38
11/12/10	3.45	24.05	18.42	731.37	808.17
11/13/10	3.40	23.80	18.42	713.78	774.66
11/14/10	3.34	20.36	18.42	612.71	693.68
11/15/10	3.28	6.80	18.42	255.34	353.05
11/16/10	3.22	8.99	18.42	307.18	387.48
11/17/10	3.16	13.01	18.42	402.48	438.56
11/18/10	3.10	15.75	18.42	462.89	510.32
11/19/10	3.04	19.92	18.42	554.97	556.35
11/20/10	2.98	9.55	18.42	303.72	347.13

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
11/21/10	2.92	21.98	18.42	583.46	511.11
11/22/10	2.86	7.76	18.42	254.68	240.05
11/23/10	2.80	11.91	18.42	342.02	305.86
11/24/10	2.74	21.79	18.42	548.78	425.92
11/25/10	2.68	8.85	18.42	266.62	243.87
11/26/10	2.62	3.98	18.42	162.54	122.58
11/27/10	2.56	19.93	18.42	481.03	326.20
11/28/10	2.50	20.81	18.42	488.97	306.76
11/29/10	2.45	20.15	18.42	466.70	273.74
11/30/10	2.45	8.96	18.42	252.48	181.84
12/1/10	2.45	2.10	18.42	121.10	58.56
12/2/10	2.45	19.91	18.42	462.87	281.25
12/3/10	2.45	7.20	18.42	219.05	153.71
12/4/10	2.45	19.41	18.42	453.89	282.69
12/5/10	2.46	16.83	18.42	404.50	265.72
12/6/10	2.46	14.16	18.42	353.31	247.98
12/7/10	2.46	18.37	18.42	434.74	281.36
12/8/10	2.46	18.44	18.42	436.40	287.63
12/9/10	2.46	19.31	18.42	453.39	295.23
12/10/10	2.47	11.57	18.42	304.19	211.19
12/11/10	2.47	15.61	18.42	382.47	262.13
12/12/10	2.47	1.06	18.42	101.31	35.48
12/13/10	2.47	1.33	18.42	106.53	44.35
12/14/10	2.47	15.68	18.42	384.46	258.38
12/15/10	2.47	17.96	18.42	428.90	299.34
12/16/10	2.48	16.61	18.42	403.05	286.76
12/17/10	2.48	17.95	18.42	429.17	303.89
12/18/10	2.48	15.89	18.42	389.41	275.97
12/19/10	2.48	7.36	18.42	223.80	182.11
12/20/10	2.48	4.31	18.42	164.72	122.82
12/21/10	2.49	15.58	18.42	384.07	280.55
12/22/10	2.49	14.85	18.42	370.08	289.29
12/23/10	2.49	6.80	18.42	213.37	181.82
12/24/10	2.49	18.75	18.42	446.78	332.71
12/25/10	2.49	10.17	18.42	279.47	242.39
12/26/10	2.50	1.85	18.42	116.84	66.67
12/27/10	2.50	8.76	18.42	252.05	210.75
12/28/10	2.50	19.63	18.42	465.08	351.53
12/29/10	2.50	16.50	18.42	403.99	318.70
12/30/10	2.50	18.43	18.42	442.06	344.33

Table C-9. Daily modeled primary production based on depth-integrated water samples in Rhode Island Sound. Daily interpolated biomass (B), euphotic depth (Z), and photosynthetically active radiation (I) were used as inputs for our BZI models of primary production (see chapter 2). Also shown is daily modeled primary production using the Webb/Platt models.

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
1/1/10	1.69	5.95	16.48	180.08	363.76
1/2/10	1.80	6.29	16.55	186.85	375.03
1/3/10	1.92	8.03	16.62	207.55	476.92
1/4/10	2.04	19.34	16.69	328.95	853.29
1/5/10	2.16	9.17	16.76	230.24	516.31
1/6/10	2.27	19.76	16.83	358.45	872.34
1/7/10	2.39	19.44	16.90	367.35	859.89
1/8/10	2.51	9.44	16.97	251.45	503.65
1/9/10	2.62	20.44	17.04	406.34	886.28
1/10/10	2.74	19.62	17.11	408.19	849.78
1/11/10	2.86	18.67	17.18	407.25	834.10
1/12/10	2.98	18.27	17.26	413.49	812.56
1/13/10	3.09	18.10	17.33	423.25	778.95
1/14/10	3.21	15.60	17.40	393.32	722.04
1/15/10	3.42	11.17	17.47	332.01	606.93
1/16/10	3.64	21.28	17.54	540.49	912.58
1/17/10	3.85	6.44	17.61	262.18	389.81
1/18/10	4.07	9.38	17.69	334.00	539.09
1/19/10	4.28	1.35	17.76	161.22	99.73
1/20/10	4.23	11.79	17.83	398.40	630.94
1/21/10	4.17	22.34	17.90	633.99	860.72
1/22/10	4.12	14.60	17.97	456.57	640.17
1/23/10	4.06	23.24	18.04	644.93	811.98
1/24/10	4.01	11.67	18.12	386.07	461.96
1/25/10	3.95	0.88	18.19	149.34	49.66
1/26/10	3.90	21.87	18.26	600.61	661.09
1/27/10	3.85	23.70	18.33	634.96	671.27
1/28/10	3.79	7.73	18.40	293.12	308.77
1/29/10	3.74	25.13	18.48	654.29	613.00
1/30/10	3.68	14.26	18.55	424.50	396.48
1/31/10	3.63	25.05	18.62	641.48	531.83
2/1/10	3.57	25.40	18.69	642.74	498.90
2/2/10	3.52	12.29	18.76	375.42	298.87
2/3/10	2.62	17.18	18.83	386.21	308.38
2/4/10	3.27	26.63	18.90	626.94	390.93
2/5/10	3.91	21.91	18.98	621.84	308.90
2/6/10	3.92	5.07	19.05	244.45	102.61
2/7/10	3.92	27.54	19.12	754.20	355.13
2/8/10	3.93	28.17	19.19	771.59	361.99
2/9/10	3.93	27.27	19.26	754.00	349.88
2/10/10	3.94	2.94	19.33	197.69	65.27
2/11/10	3.94	24.06	19.40	685.96	324.67

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
2/12/10	3.95	30.08	19.47	828.36	366.24
2/13/10	3.95	19.96	19.54	595.62	278.68
2/14/10	3.96	28.57	19.61	799.69	342.31
2/15/10	3.96	28.75	19.68	807.11	355.37
2/16/10	3.58	6.86	19.75	276.91	138.24
2/17/10	3.21	15.68	19.82	431.42	235.49
2/18/10	2.83	25.13	19.89	557.90	316.40
2/19/10	2.46	23.30	19.96	475.36	315.56
2/20/10	2.08	31.60	20.03	528.16	368.68
2/21/10	1.71	29.21	20.10	432.72	349.56
2/22/10	1.33	30.35	20.17	376.11	345.97
2/23/10	1.28	6.42	20.24	180.19	132.61
2/24/10	1.22	3.13	20.30	153.58	74.06
2/25/10	1.17	5.18	20.37	167.28	108.57
2/26/10	1.11	10.66	20.44	203.22	194.75
2/27/10	1.06	14.28	20.51	223.44	227.37
2/28/10	1.00	16.19	20.57	230.76	243.58
3/1/10	0.83	16.47	20.64	215.41	251.76
3/2/10	0.66	27.75	20.71	244.71	318.89
3/3/10	0.70	7.85	20.77	164.42	151.64
3/4/10	0.73	10.83	20.84	180.02	196.30
3/5/10	0.77	23.68	20.91	244.85	296.14
3/6/10	0.80	37.50	20.97	320.87	369.75
3/7/10	0.84	37.36	21.04	329.24	370.65
3/8/10	0.87	37.36	21.10	338.35	367.30
3/9/10	0.91	37.57	21.16	348.72	369.75
3/10/10	0.94	35.80	21.23	345.71	354.26
3/11/10	0.42	8.15	21.29	152.17	167.80
3/12/10	0.70	14.23	21.35	194.38	218.44
3/13/10	0.98	1.06	21.42	136.88	31.46
3/14/10	1.26	5.29	21.48	173.41	123.15
3/15/10	1.54	4.76	21.54	177.82	107.27
3/16/10	1.82	37.98	21.60	581.24	357.52
3/17/10	2.10	41.86	21.66	705.43	372.79
3/18/10	1.81	41.76	21.72	625.63	370.46
3/19/10	1.52	40.80	21.78	537.15	363.86
3/20/10	1.22	40.87	21.84	460.23	362.37
3/21/10	0.93	39.89	21.90	376.09	351.92
3/22/10	0.64	7.21	21.96	160.74	144.79
3/23/10	0.70	5.35	22.01	154.85	102.24
3/24/10	0.75	38.62	22.07	323.28	344.34
3/25/10	0.81	33.83	22.13	312.17	328.88
3/26/10	0.86	20.75	22.18	249.70	243.36
3/27/10	0.92	43.79	22.24	399.32	356.58
3/28/10	0.97	23.68	22.29	284.84	271.18
3/29/10	1.03	2.97	22.35	150.69	75.73
3/30/10	1.08	2.19	22.40	146.17	52.05

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
3/31/10	1.14	15.40	22.45	248.67	218.45
4/1/10	1.19	35.81	22.51	419.84	303.63
4/2/10	1.25	46.16	22.56	521.75	357.18
4/3/10	1.30	46.13	22.61	539.69	348.28
4/4/10	1.25	40.91	22.66	480.49	319.21
4/5/10	1.20	45.70	22.71	507.02	347.02
4/6/10	1.15	27.75	22.76	350.19	288.11
4/7/10	1.10	46.27	22.81	482.21	344.73
4/8/10	1.06	43.59	22.85	447.76	341.68
4/9/10	1.01	4.98	22.90	164.82	102.96
4/10/10	0.96	44.03	22.95	422.47	326.13
4/11/10	0.91	42.86	22.99	400.72	321.56
4/12/10	0.86	49.81	23.04	428.21	348.25
4/13/10	1.08	37.87	23.08	415.06	323.95
4/14/10	1.30	52.38	23.12	605.06	349.05
4/15/10	0.74	49.89	23.16	388.52	342.56
4/16/10	0.72	20.29	23.21	232.57	239.88
4/17/10	0.70	11.89	23.25	188.58	188.01
4/18/10	0.68	27.23	23.29	260.42	254.69
4/19/10	0.66	47.13	23.33	349.33	338.75
4/20/10	0.64	35.88	23.36	292.22	319.82
4/21/10	1.23	43.93	23.40	512.18	341.26
4/22/10	1.21	48.59	23.44	546.38	343.96
4/23/10	1.19	35.56	23.47	430.21	309.94
4/24/10	1.17	54.40	23.51	582.05	371.65
4/25/10	1.15	15.26	23.54	254.94	209.47
4/26/10	1.13	19.43	23.58	286.48	227.42
4/27/10	1.11	8.16	23.61	194.72	150.33
4/28/10	1.09	24.06	23.64	317.34	295.86
4/29/10	1.07	53.11	23.67	536.17	379.82
4/30/10	1.05	54.73	23.70	541.25	374.95
5/1/10	1.00	53.09	23.73	510.47	375.87
5/2/10	0.95	39.33	23.76	398.19	344.01
5/3/10	0.90	24.06	23.79	285.70	265.41
5/4/10	0.85	45.39	23.81	407.70	350.12
5/5/10	0.85	57.04	23.84	478.61	402.44
5/6/10	0.85	34.92	23.86	343.28	321.71
5/7/10	0.85	57.07	23.88	478.13	407.08
5/8/10	0.84	17.50	23.91	236.74	248.37
5/9/10	0.84	56.72	23.93	475.31	411.35
5/10/10	0.84	59.81	23.95	493.70	422.82
5/11/10	0.84	50.67	23.97	437.79	400.80
5/12/10	0.84	16.38	23.99	229.50	267.34
5/13/10	0.68	58.05	24.00	416.36	410.00
5/14/10	0.68	25.68	24.02	257.65	284.14
5/15/10	0.69	58.12	24.04	420.68	398.01
5/16/10	0.69	54.04	24.05	402.09	385.48

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
5/17/10	0.70	50.15	24.06	384.23	360.58
5/18/10	0.70	11.80	24.08	190.30	202.69
5/19/10	0.71	15.42	24.09	209.27	212.87
5/20/10	0.71	58.08	24.10	430.21	342.80
5/21/10	0.71	57.55	24.11	429.35	337.23
5/22/10	0.72	45.92	24.12	370.37	299.10
5/23/10	0.72	36.56	24.12	322.62	261.72
5/24/10	0.73	57.54	24.13	434.88	302.91
5/25/10	0.73	58.78	24.14	443.37	298.48
5/26/10	0.74	55.03	24.14	425.14	278.91
5/27/10	0.74	49.20	24.14	395.43	262.33
5/28/10	0.74	57.63	24.15	442.69	261.77
5/29/10	0.75	41.84	24.15	358.38	222.99
5/30/10	0.75	52.61	24.15	418.73	238.33
5/31/10	0.76	57.40	24.15	446.76	235.79
6/1/10	0.76	43.15	24.15	369.48	174.77
6/2/10	0.76	54.57	24.14	434.46	193.01
6/3/10	0.77	31.81	24.14	308.52	168.04
6/4/10	0.77	55.43	24.14	442.60	186.48
6/5/10	0.78	33.81	24.13	321.70	136.73
6/6/10	0.78	36.22	24.12	336.46	145.45
6/7/10	0.79	59.47	24.12	470.61	164.87
6/8/10	0.79	51.19	24.11	424.67	152.51
6/9/10	0.78	22.51	24.10	257.98	101.85
6/10/10	0.72	21.43	24.09	243.10	87.16
6/11/10	0.67	25.80	24.08	255.60	95.09
6/12/10	0.61	25.73	24.06	244.79	80.30
6/13/10	0.56	14.90	24.05	190.44	61.30
6/14/10	0.50	34.17	24.04	254.55	78.51
6/15/10	0.45	57.65	24.02	316.61	77.45
6/16/10	0.39	36.96	24.00	234.66	57.91
6/17/10	0.64	41.40	23.99	320.93	50.03
6/18/10	0.51	60.09	23.97	352.04	87.85
6/19/10	0.53	63.31	23.95	372.91	120.51
6/20/10	0.55	44.82	23.93	308.31	130.96
6/21/10	0.57	58.57	23.91	371.25	182.08
6/22/10	0.59	44.78	23.88	320.76	176.85
6/23/10	0.61	48.36	23.86	342.77	220.18
6/24/10	0.63	48.89	23.84	351.94	257.43
6/25/10	0.65	60.86	23.81	414.70	307.82
6/26/10	0.67	45.92	23.79	351.22	295.90
6/27/10	0.69	42.55	23.76	340.84	318.45
6/28/10	0.71	46.72	23.73	367.93	331.19
6/29/10	0.73	40.59	23.70	342.28	383.17
6/30/10	0.75	61.63	23.67	460.70	470.52
7/1/10	0.89	51.37	23.64	455.19	467.80
7/2/10	0.91	60.98	23.61	525.70	495.06

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
7/3/10	0.93	57.86	23.58	514.62	480.95
7/4/10	0.96	53.60	23.54	494.80	467.72
7/5/10	0.98	60.21	23.51	549.19	482.79
7/6/10	1.00	52.81	23.47	505.94	448.03
7/7/10	1.03	50.31	23.44	496.03	450.55
7/8/10	1.05	54.75	23.40	536.74	437.13
7/9/10	1.07	43.03	23.36	456.33	434.79
7/10/10	1.10	35.43	23.33	404.15	384.66
7/11/10	1.12	49.56	23.29	520.98	446.41
7/12/10	1.14	53.58	23.25	560.80	439.53
7/13/10	1.17	33.57	23.21	405.07	326.69
7/14/10	1.19	14.96	23.16	254.88	258.20
7/15/10	1.22	23.65	23.12	330.84	323.05
7/16/10	1.24	39.48	23.08	471.04	387.11
7/17/10	1.26	54.76	23.04	611.09	430.16
7/18/10	1.29	50.79	22.99	583.64	424.16
7/19/10	1.31	32.15	22.95	421.89	350.08
7/20/10	1.33	44.27	22.90	538.19	409.48
7/21/10	1.36	40.10	22.85	505.51	314.95
7/22/10	1.38	51.70	22.81	621.45	421.29
7/23/10	1.40	15.82	22.76	282.76	270.64
7/24/10	1.43	36.27	22.71	486.59	356.42
7/25/10	1.46	42.71	22.66	557.71	374.17
7/26/10	1.49	57.97	22.61	720.94	468.11
7/27/10	1.52	56.74	22.56	718.60	480.30
7/28/10	1.55	55.26	22.51	713.21	485.99
7/29/10	1.58	32.21	22.45	475.72	417.48
7/30/10	1.61	52.83	22.40	706.25	504.73
7/31/10	1.64	47.57	22.35	657.16	502.26
8/1/10	1.67	56.60	22.29	767.05	537.34
8/2/10	1.70	53.29	22.24	739.00	538.56
8/3/10	1.73	49.59	22.18	705.22	544.98
8/4/10	1.76	30.44	22.13	488.34	450.58
8/5/10	1.79	28.67	22.07	472.35	429.08
8/6/10	1.82	38.98	22.01	601.81	528.10
8/7/10	1.85	50.64	21.96	751.40	584.64
8/8/10	1.88	49.87	21.90	750.15	605.02
8/9/10	1.91	45.93	21.84	708.57	566.12
8/10/10	1.94	47.32	21.78	733.71	606.26
8/11/10	1.97	52.39	21.72	806.85	652.16
8/12/10	2.00	43.55	21.66	699.55	603.68
8/13/10	2.03	50.46	21.60	797.89	641.31
8/14/10	2.06	52.52	21.54	833.32	696.29
8/15/10	2.09	32.95	21.48	576.46	595.28
8/16/10	2.12	15.76	21.42	346.02	409.31
8/17/10	2.15	34.04	21.35	601.57	571.71
8/18/10	2.13	26.59	21.29	494.73	577.14

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
8/19/10	2.12	50.56	21.23	816.15	734.51
8/20/10	2.10	43.18	21.16	709.99	679.63
8/21/10	2.08	41.07	21.10	675.93	675.10
8/22/10	2.07	3.48	21.04	175.94	151.77
8/23/10	2.05	2.95	20.97	168.46	133.44
8/24/10	2.04	9.68	20.91	254.73	321.34
8/25/10	2.02	20.24	20.84	387.88	482.28
8/26/10	2.01	37.64	20.77	604.31	657.63
8/27/10	1.99	50.68	20.71	761.54	795.68
8/28/10	1.98	49.55	20.64	740.71	796.02
8/29/10	1.96	48.48	20.57	720.90	793.43
8/30/10	1.95	49.39	20.51	725.36	807.89
8/31/10	1.93	45.96	20.44	677.77	787.54
9/1/10	1.91	45.14	20.37	661.89	789.32
9/2/10	1.90	44.15	20.30	644.27	787.72
9/3/10	1.88	8.89	20.24	232.46	318.30
9/4/10	1.87	46.69	20.17	661.36	807.60
9/5/10	1.85	46.96	20.10	658.14	835.28
9/6/10	1.84	47.33	20.03	656.03	842.08
9/7/10	1.82	42.76	19.96	599.66	800.07
9/8/10	1.81	33.01	19.89	488.29	706.50
9/9/10	1.79	37.71	19.82	534.26	766.02
9/10/10	1.77	27.01	19.75	416.05	653.29
9/11/10	1.76	42.69	19.68	576.54	841.65
9/12/10	1.74	18.34	19.61	319.57	579.68
9/13/10	1.73	15.68	19.54	290.02	533.99
9/14/10	1.71	38.65	19.47	519.40	796.66
9/15/10	1.83	44.58	19.40	607.12	919.65
9/16/10	1.94	34.09	19.33	516.17	802.17
9/17/10	2.05	17.90	19.26	343.91	560.63
9/18/10	2.17	24.38	19.19	436.23	772.22
9/19/10	2.28	33.57	19.12	572.05	942.06
9/20/10	2.39	40.29	19.05	684.74	1090.10
9/21/10	2.51	39.40	18.98	696.06	1131.39
9/22/10	2.62	35.90	18.90	667.11	1111.99
9/23/10	2.73	36.29	18.83	694.32	1136.29
9/24/10	2.85	15.98	18.76	387.91	780.26
9/25/10	2.96	34.95	18.69	714.16	1224.78
9/26/10	3.07	23.33	18.62	533.28	1011.45
9/27/10	3.19	7.35	18.55	261.40	527.02
9/28/10	3.30	13.68	18.48	381.96	833.09
9/29/10	3.41	28.70	18.40	674.69	1212.46
9/30/10	3.53	13.15	18.33	386.93	843.71
10/1/10	3.64	10.88	18.26	348.47	691.06
10/2/10	3.75	38.90	18.19	932.35	1572.24
10/3/10	3.87	14.95	18.12	446.42	1016.41
10/4/10	3.98	19.00	18.04	542.30	1128.07

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
10/5/10	4.09	6.10	17.97	265.61	561.73
10/6/10	4.21	5.07	17.90	245.46	463.60
10/7/10	4.32	20.29	17.83	602.11	1273.18
10/8/10	4.43	35.56	17.76	975.83	1747.41
10/9/10	4.55	36.03	17.69	1005.35	1786.21
10/10/10	4.66	35.66	17.61	1014.37	1821.76
10/11/10	4.77	33.58	17.54	979.50	1812.87
10/12/10	4.89	19.66	17.47	637.17	1287.02
10/13/10	5.00	34.06	17.40	1025.36	1894.25
10/14/10	4.98	22.02	17.33	704.05	1438.28
10/15/10	4.96	18.08	17.26	597.32	1284.47
10/16/10	4.93	28.87	17.18	869.63	1635.83
10/17/10	4.91	29.97	17.11	891.27	1695.49
10/18/10	4.89	30.57	17.04	899.91	1651.73
10/19/10	4.87	26.08	16.97	781.26	1409.61
10/20/10	4.85	21.36	16.90	658.80	1316.98
10/21/10	4.83	15.36	16.83	507.04	1184.17
10/22/10	4.80	25.81	16.76	758.03	1444.96
10/23/10	4.78	23.82	16.69	704.51	1418.95
10/24/10	4.76	8.24	16.62	327.20	724.58
10/25/10	4.74	12.46	16.55	425.23	950.48
10/26/10	4.72	14.75	16.48	476.53	923.88
10/27/10	4.70	2.89	16.41	197.41	308.30
10/28/10	4.67	21.56	16.34	627.58	1239.74
10/29/10	4.65	17.18	16.27	522.97	1101.42
10/30/10	4.63	24.53	16.20	685.86	1267.51
10/31/10	4.61	23.79	16.13	664.37	1242.58
11/1/10	4.59	27.63	16.06	744.90	1339.30
11/2/10	4.57	18.21	15.99	531.65	1055.28
11/3/10	4.54	23.16	15.92	636.16	1150.23
11/4/10	4.52	3.68	15.85	209.91	341.38
11/5/10	4.50	6.90	15.78	278.18	542.54
11/6/10	4.48	10.91	15.71	362.04	659.22
11/7/10	4.46	8.81	15.64	315.69	635.61
11/8/10	4.44	4.85	15.58	231.25	407.60
11/9/10	4.41	10.92	15.51	356.01	699.89
11/10/10	4.39	6.24	15.44	257.97	482.98
11/11/10	4.37	22.37	15.37	584.16	1005.26
11/12/10	4.35	24.05	15.30	613.52	1068.80
11/13/10	4.33	23.80	15.24	604.18	1048.37
11/14/10	4.30	20.36	15.17	531.77	957.18
11/15/10	4.28	6.80	15.10	263.06	486.10
11/16/10	4.26	8.99	15.03	304.06	553.66
11/17/10	4.24	13.01	14.97	379.52	653.51
11/18/10	4.22	15.75	14.90	429.14	783.40
11/19/10	4.20	19.92	14.84	504.83	888.68
11/20/10	4.17	9.55	14.77	308.09	562.62

Date	B ($\mu\text{g L}^{-1}$)	I ($\text{E m}^{-2} \text{d}^{-1}$)	z (m)	BZI PP ($\text{mg C m}^{-2} \text{d}^{-1}$)	Webb/Platt PP ($\text{mg C m}^{-2} \text{d}^{-1}$)
11/21/10	4.15	21.98	14.70	535.57	881.50
11/22/10	4.13	7.76	14.64	271.93	420.64
11/23/10	4.11	11.91	14.57	345.54	565.45
11/24/10	4.09	21.79	14.51	520.54	837.06
11/25/10	4.07	8.85	14.44	287.05	490.04
11/26/10	4.04	3.98	14.38	200.04	255.07
11/27/10	4.02	19.93	14.31	476.83	756.89
11/28/10	4.00	20.81	14.25	488.51	762.30
11/29/10	3.98	20.15	14.18	473.76	733.06
11/30/10	3.94	8.96	14.12	280.69	460.96
12/1/10	3.90	2.10	14.06	164.96	139.16
12/2/10	3.86	19.91	13.99	454.89	703.73
12/3/10	3.82	7.20	13.93	245.83	363.77
12/4/10	3.78	19.41	13.87	437.41	675.97
12/5/10	3.74	16.83	13.81	392.52	618.28
12/6/10	3.70	14.16	13.74	347.52	560.88
12/7/10	3.66	18.37	13.68	407.93	627.36
12/8/10	3.62	18.44	13.62	404.71	627.25
12/9/10	3.58	19.31	13.56	413.14	630.33
12/10/10	3.54	11.57	13.50	297.04	434.78
12/11/10	3.50	15.61	13.43	351.79	532.19
12/12/10	3.46	1.06	13.37	144.98	66.50
12/13/10	3.42	1.33	13.31	148.43	81.52
12/14/10	3.38	15.68	13.25	342.19	490.52
12/15/10	3.34	17.96	13.19	369.07	555.41
12/16/10	3.30	16.61	13.13	347.51	518.82
12/17/10	3.26	17.95	13.07	361.05	538.07
12/18/10	3.22	15.89	13.01	331.11	476.71
12/19/10	3.18	7.36	12.95	221.63	301.20
12/20/10	3.14	4.31	12.89	182.88	197.00
12/21/10	3.10	15.58	12.83	317.25	450.80
12/22/10	3.06	14.85	12.78	305.38	451.95
12/23/10	3.02	6.80	12.72	208.98	273.12
12/24/10	2.98	18.75	12.66	343.75	497.92
12/25/10	2.94	10.17	12.60	243.94	348.82
12/26/10	2.90	1.85	12.54	150.40	92.72
12/27/10	2.86	8.76	12.49	224.55	288.84
12/28/10	2.82	19.63	12.43	337.90	476.40
12/29/10	2.78	16.50	12.37	301.47	419.41
12/30/10	2.74	18.43	12.32	317.89	442.43

C-2. SEDIMENT CHARACTERIZATION DATA

Table C-10. Sediment chlorophyll *a* and phaeopigment content in the top centimeter of sediment, and inventory of the top 5 centimeters of sediment.

Date	Station	Chl, 0-1 cm ($\mu\text{g cm}^{-2}$)	Phaeo, 0-1 cm ($\mu\text{g cm}^{-2}$)	Chl, 0-5 cm ($\mu\text{g cm}^{-2}$)	Phaeo, 0-5 cm ($\mu\text{g cm}^{-2}$)
10/1/09	BIS	7.7	12.0	38.9	72.7
1/1/10	BIS	10.1	30.2	55.9	114.2
5/1/10	BIS	1.1	24.5	12.6	142.5
7/1/10	BIS	9.6	11.3	33.2	50.5
8/1/10	BIS	7.2	15.6	47.9	76.2
10/1/10	BIS	8.0	9.5	36.7	42.5
1/1/11	BIS	4.2		34.8	58.7
5/1/11	BIS	7.0	36.2	40.9	183.6
7/1/11	BIS	8.0	8.9	41.1	30.9
9/1/11	BIS	2.8	10.6	25.1	44.3
8/1/12	BIS	3.2	10.6	29.2	43.6
5/17/10	MNB	15.0	288.4	92.0	1484.2
6/22/10	MNB	7.0	194.8	37.6	1218.9
8/2/10	MNB	42.9	321.2	309.7	959.5
10/11/10	MNB	18.8	257.4	106.6	1130.8
1/20/11	MNB	141.1	274.6	395.2	987.7
6/16/11	MNB	51.7	185.5	249.5	938.9
8/24/11	MNB	30.2	192.2	199.6	726.5
1/10/12	MNB	138.3	115.7	331.0	605.9
6/19/12	MNB	52.6	158.2	446.9	338.8
8/1/11	MP	5.8	4.4	22.3	55.0
8/1/12	MP*	3.29	3.10	14.7	30.9
7/1/10	MS1	6.8	6.0	24.4	43.3
5/17/10	PRE	88.7	577.6	371.4	3377.3
6/22/10	PRE	116.1	504.6	411.2	3211.0
8/2/10	PRE	52.4	539.3	204.1	2426.7
1/20/11	PRE	101.1	419.7	374.2	1301.1
6/16/11	PRE	58.8	727.2	203.5	2817.2
8/24/11	PRE	81.9	260.9	461.5	2313.1
1/10/12	PRE	141.8	373.4	618.5	1850.0
6/19/12	PRE	115.6	387.9	145.8	1907.4
10/1/09	RIS1	6.4	10.6	39.6	46.1
1/1/10	RIS1	13.5	36.3	44.7	91.2
5/1/10	RIS1	2.8	38.2	17.9	223.1
8/1/10	RIS1	6.4	15.7	54.0	51.2

*Values for this station include 1-5 cm only (no 1-0 cm sample)

Date	Station	Chl, 0-1 cm ($\mu\text{g cm}^{-2}$)	Phaeo, 0-1 cm ($\mu\text{g cm}^{-2}$)	Chl, 0-5 cm ($\mu\text{g cm}^{-2}$)	Phaeo, 0-5 cm ($\mu\text{g cm}^{-2}$)
10/1/09	RIS2	4.5	6.6	31.6	42.4
1/1/10	RIS2	8.5	20.8	27.5	62.4
5/1/10	RIS2	7.6	31.0	37.1	137.9
7/1/10	RIS2	2.5	3.0	7.8	12.7
8/1/10	RIS2	6.3	7.4	40.6	66.1
10/1/10	RIS2	1.0	14.5	24.6	73.3
1/1/11	RIS2	3.9	11.5	9.4	89.1
5/1/11	RIS2	2.7	28.1	11.0	118.0
7/1/11	RIS2	4.9	12.8	37.8	43.1
9/1/11	RIS2	4.4	14.8	9.7	77.8
8/1/12	RIS2	0.0	27.1	6.6	102.3
7/1/10	RIS3	7.3	52.5	62.1	128.8

Table C-11. Sediment molar C/N ratio and organic matter content in the top centimeter, and the average molar C/N for the top 5 centimeters of sediment.

Date	Station	C/N ratio, 0-1 cm	C/N ratio, 0-5 cm average	% organic matter, 0-1 cm
10/1/09	BIS	9.2	9.4	
1/1/10	BIS	9.4	9.7	
5/1/10	BIS	9.0	9.6	6.4
7/1/10	BIS	9.4	9.9	5.8
8/1/10	BIS	11.3	11.3	6.9
10/1/10	BIS	8.8	8.7	5.9
1/1/11	BIS	8.7	9.0	6.5
5/1/11	BIS	8.1	8.5	6.3
7/1/11	BIS			5.1
9/1/11	BIS			
8/1/12	BIS			
5/17/10	MNB	16.6	16.2	
6/22/10	MNB	15.9	15.8	
8/2/10	MNB	15.4	16.5	
10/11/10	MNB	12.9	13.3	
1/20/11	MNB	13.6	14.0	
6/16/11	MNB	16.1	16.7	
8/24/11	MNB			
1/10/12	MNB			
6/19/12	MNB			
8/1/11	MP			4.7
8/1/12	MP			
7/1/10	MS1	8.4	8.7	6.6
5/17/10	PRE	17.2	18.8	
6/22/10	PRE	18.3	19.3	
8/2/10	PRE	18.9	18.8	
10/11/10	PRE	18.6	35.6	
1/20/11	PRE	20.7	20.8	
6/16/11	PRE	16.5	17.6	
8/24/11	PRE			
1/10/12	PRE			
6/19/12	PRE			
10/1/09	RIS1	9.1	9.5	
1/1/10	RIS1	9.4	9.5	
5/1/10	RIS1	9.2	9.6	4.7
8/1/10	RIS1	6.6	7.7	3.0
10/1/09	RIS2	8.6	8.7	

Date	Station	C/N ratio, 0-1 cm	C/N ratio, 0-5 cm average	% organic matter, 0-1 cm
1/1/10	RIS2	16.4	11.3	
5/1/10	RIS2	9.3	9.4	8.2
7/1/10	RIS2	9.0	9.2	2.7
8/1/10	RIS2	6.6	7.3	3.3
10/1/10	RIS2	6.9	7.9	2.8
1/1/11	RIS2	8.6	7.7	3.2
5/1/11	RIS2	5.9	6.6	1.9
7/1/11	RIS2			2.3
9/1/11	RIS2			
8/1/12	RIS2			
7/1/10	RIS3	9.2	9.2	5.7

Table C-12. Visual observations of macrofauna in sediment cores collected in mid-Narragansett Bay and the Providence River Estuary.

Date	Station	Macrofauna
5/17/2010	MNB	1 dead mud anemone
5/17/2010	PRE	1 quahog
5/17/2010	PRE	1 quahog
6/22/10	MNB	2 polychaetes
6/22/10	MNB	burrows present
6/22/10	PRE	1 quahog
8/2/10	PRE	3 quahogs
10/11/10	MNB	burrows present
10/11/10	PRE	1 quahog
10/11/10	PRE	1 quahog
6/16/11	MNB	burrows present
6/16/11	MNB	burrows present
8/24/11	MNB	2 dead mud anemones
8/24/11	MNB	burrows present
8/24/11	MNB	1 mud anemone
8/24/11	PRE	1 quahog
8/24/11	PRE	1 quahog
1/10/12	PRE	burrows present
1/10/12	PRE	1 quahog (more?)
1/10/12	PRE	1 polychaete
1/10/12	MNB	1 mud anemone
1/10/12	MNB	1 mud anemone
6/19/12	PRE	burrows present
6/19/12	PRE	1 polychaete
6/19/12	MNB	1 polychaete
6/19/12	MNB	1 polychaete

Table C-13. Grain size of sediment collected from stations. Numbers in parentheses are standard error.

		% Clay	% Silt	% Coarse Silt	% Very fine sand (62.5- 125 μm)	% fine sand (125- 250 μm)	% medium sand (250-500 μm)	% coarse sand (500- 1000 μm)	% very coarse sand (1000- 2000 μm)
BIS	4-6 cm	3.6 (0.7)	35.4 (9.4)	12.3 (2.6)	21.7 (3.1)	18.3 (5.7)	5.2 (2.4)	2.2 (2)	1.3 (1.3)
	0-2 cm	3.6 (0.2)	38.5 (4.1)	14.4 (0.9)	21 (1.5)	15.3 (1.4)	4 (1)	2.1 (0.9)	1.2 (0.5)
RIS1	4-6 cm	3.4 (0.8)	28.4 (7.8)	8.8 (2.3)	17.9 (6.8)	15.4 (6.8)	13.2 (8.7)	11 (11)	1.8 (3)
	0-2 cm	2.9 (0.4)	29.2 (5.4)	10.8 (1.3)	21.3 (3.8)	17.8 (5)	9.7 (2.8)	6.8 (2.9)	1.5 (0.7)
RIS2	4-6 cm	4.9 (1)	50.2 (3.6)	15.2 (3.4)	15.8 (2.6)	10.2 (2.8)	2.8 (1.1)	0.6 (0.5)	0.3 (0.4)
	0-2 cm	3 (0.5)	39.6 (9.1)	13.7 (5.5)	15.8 (3.1)	13.4 (4.8)	9 (7.3)	4.8 (5.1)	0.7 (0.8)

C-3. BENTHIC FLUX DATA FROM SEDIMENT CORE INCUBATIONS

Table C-14. Sediment oxygen uptake (SOD) and dissolved inorganic phosphorus (DIP) fluxes measured in sediment cores from offshore (continental shelf) stations.

Date	Temperature, °C	Station	Core Rep	SOD, mg m ⁻² h ⁻¹	DIP flux, μmol m ⁻² h ⁻¹
10/2/09	17.4	BIS	A	48.50	0.80
10/2/09	17.4	BIS	B	69.16	6.43
10/2/09	17.4	BIS	C	64.86	-3.88
10/2/09	17.4	RIS1	A	55.57	-2.40
10/2/09	17.4	RIS1	B	51.32	1.52
10/2/09	17.4	RIS1	C	30.83	-2.98
10/2/09	17.4	RIS2	A	52.37	-1.30
10/2/09	17.4	RIS2	B	43.17	6.53
10/2/09	17.4	RIS2	C	29.65	0.25
1/19/10	4.2	BIS	A	2.79	1.56
1/19/10	4.2	BIS	B	0.00	-0.16
1/19/10	4.2	BIS	C	0.00	2.86
1/19/10	4.2	RIS1	A	29.31	4.58
1/19/10	4.2	RIS1	B	42.24	4.71
1/19/10	4.2	RIS1	C	26.91	2.78
1/19/10	4.2	RIS2	A	12.02	0.60
1/19/10	4.2	RIS2	B	8.28	0.45
1/19/10	4.2	RIS2	C	9.97	-0.51
5/2/10	7.7	BIS	A	37.61	0.86
5/2/10	7.7	BIS	B	35.66	3.12
5/2/10	7.7	BIS	C	56.89	3.29
5/2/10	7.7	RIS1	A	46.99	-10.91
5/2/10	7.7	RIS1	B	59.59	-10.68
5/2/10	7.7	RIS1	C	41.90	-8.10
5/2/10	7.7	RIS2	A	9.07	
5/2/10	7.7	RIS2	B	14.19	
5/2/10	7.7	RIS2	C	12.17	7.22
7/7/10	12.8	BIS	A	30.52	10.43
7/7/10	12.8	BIS	B	36.60	-1.90
7/7/10	12.8	BIS	C	19.68	-3.05
7/7/10	12.8	RIS2	A	22.43	-2.28
7/7/10	12.8	RIS2	B	16.95	9.32
7/7/10	12.8	RIS2	C	26.91	7.08
8/17/10	14.6	BIS	A	65.40	4.89
8/17/10	14.6	BIS	B	34.45	7.90
8/17/10	14.6	BIS	C	28.49	3.87

Date	Temperature, °C	Station	Core Rep	SOD, mg m ⁻² h ⁻¹	DIP flux, μmol m ⁻² h ⁻¹
8/17/10	14.6	RIS1	A	21.88	-3.09
8/17/10	14.6	RIS1	B	21.12	2.43
8/17/10	14.6	RIS1	C	8.32	0.68
8/17/10	14.6	RIS2	A	13.19	4.41
8/17/10	14.6	RIS2	B	18.05	0.19
8/17/10	14.6	RIS2	C	17.56	0.88
10/19/10	14	BIS	A	36.54	9.38
10/19/10	14	BIS	B	30.35	1.42
10/19/10	14	BIS	C	38.77	6.94
10/19/10	14	RIS2	A	24.06	1.75
10/19/10	14	RIS2	B	39.78	5.23
10/19/10	14	RIS2	C	27.27	-4.92
1/6/11	5.8	BIS	A	14.69	1.25
1/6/11	5.8	BIS	B	10.92	-0.62
1/6/11	5.8	BIS	C	12.21	0.81
1/6/11	5.8	RIS2	A	12.75	-0.08
1/6/11	5.8	RIS2	B	40.88	3.89
1/6/11	5.8	RIS2	C	22.54	2.03
5/31/11	12.1	BIS	A	46.92	7.18
5/31/11	12.1	BIS	B	35.65	8.60
5/31/11	12.1	BIS	C	33.90	4.00
5/31/11	12.1	BIS	D	45.79	8.67
5/31/11	12.1	RIS2	A	53.63	11.69
5/31/11	12.1	RIS2	B	54.82	6.18
5/31/11	12.1	RIS2	C	48.06	11.13
7/20/11	15.8	BIS	A	30.97	6.49
7/20/11	15.8	BIS	B	24.31	2.89
7/20/11	15.8	BIS	C	34.59	11.67
7/20/11	15.8	BIS	D	36.44	9.05
7/20/11	15.8	RIS2	A	30.60	3.43
7/20/11	15.8	RIS2	B	34.79	6.39
7/20/11	15.8	RIS2	C	54.26	7.12
7/20/11	15.8	RIS2	D	37.06	-7.52
9/27/11	16.6	BIS	A	23.37	26.35
9/27/11	16.6	BIS	B	19.91	24.31
9/27/11	16.6	BIS	C	21.23	32.33
9/27/11	16.6	BIS	D	6.88	0.00
9/27/11	16.6	RIS2	A	29.43	21.52
9/27/11	16.6	RIS2	B	24.41	13.40
9/27/11	16.6	RIS2	C	34.47	4.52
9/27/11	16.6	RIS2	D	14.77	7.34

Date	Temperature, °C	Station	Core Rep	SOD, mg m ⁻² h ⁻¹	DIP flux, μmol m ⁻² h ⁻¹
7/2/12	13.8	BIS	A	32.62	27.61
7/2/12	13.8	BIS	B	20.32	14.42
7/2/12	13.8	BIS	C	18.43	19.43
7/2/12	13.8	BIS	D	23.93	5.86
7/2/12	13.8	RIS2	A	14.23	-1.76
7/2/12	13.8	RIS2	B	17.33	1.36
7/2/12	13.8	RIS2	D	14.98	2.17

Table C-15. Ammonium (NH_4^+) and nitrate+nitrite (NO_x) fluxes measured in sediment cores from offshore (continental shelf) stations.

Date	Temperature, °C	Station	Core Rep	NH_4^+ flux, $\mu\text{mol m}^{-2} \text{h}^{-1}$	NO_x flux, $\mu\text{mol m}^{-2} \text{h}^{-1}$
10/2/09	17.4	BIS	A	-4.04	-17.74
10/2/09	17.4	BIS	B	45.60	20.73
10/2/09	17.4	BIS	C	-6.90	-15.81
10/2/09	17.4	RIS1	A	-29.04	-25.60
10/2/09	17.4	RIS1	B	1.42	-94.56
10/2/09	17.4	RIS1	C	-8.77	-92.14
10/2/09	17.4	RIS2	A	-24.77	-54.85
10/2/09	17.4	RIS2	B	-11.01	-39.65
10/2/09	17.4	RIS2	C	-14.04	-62.60
1/19/10	4.2	BIS	A	6.79	19.65
1/19/10	4.2	BIS	B	-3.12	12.38
1/19/10	4.2	BIS	C	8.08	9.92
1/19/10	4.2	RIS1	A	-1.45	41.89
1/19/10	4.2	RIS1	B	3.17	39.45
1/19/10	4.2	RIS1	C	-4.26	23.20
1/19/10	4.2	RIS2	A	1.26	6.49
1/19/10	4.2	RIS2	B	9.83	1.29
1/19/10	4.2	RIS2	C	-12.34	0.74
5/2/10	7.7	BIS	A	0.53	23.94
5/2/10	7.7	BIS	B	5.85	56.90
5/2/10	7.7	BIS	C	109.13	55.51
5/2/10	7.7	RIS1	A	33.27	59.54
5/2/10	7.7	RIS1	B	56.39	77.68
5/2/10	7.7	RIS1	C	36.93	75.21
5/2/10	7.7	RIS2	A	44.49	5.91
5/2/10	7.7	RIS2	B	63.05	-1.19
5/2/10	7.7	RIS2	C	59.63	5.37
7/7/10	12.8	BIS	A	74.47	13.51
7/7/10	12.8	BIS	B	52.20	-5.36
7/7/10	12.8	BIS	C	63.86	9.74
7/7/10	12.8	RIS2	A	62.79	8.16
7/7/10	12.8	RIS2	B	14.71	8.05
7/7/10	12.8	RIS2	C	49.85	22.28
8/17/10	14.6	BIS	A	183.22	4.89
8/17/10	14.6	BIS	B	99.72	7.90
8/17/10	14.6	BIS	C	76.62	3.87
8/17/10	14.6	RIS1	A	23.08	-3.09
8/17/10	14.6	RIS1	B	0.36	2.43

Date	Temperature, °C	Station	Core Rep	NH ₄ ⁺ flux, μmol m ⁻² h ⁻¹	NO _x flux, μmol m ⁻² h ⁻¹
8/17/10	14.6	RIS1	C	9.04	0.68
8/17/10	14.6	RIS2	A	86.96	4.41
8/17/10	14.6	RIS2	B	36.03	0.19
8/17/10	14.6	RIS2	C	48.11	0.88
10/19/10	14	BIS	A	33.65	20.03
10/19/10	14	BIS	B	8.34	21.55
10/19/10	14	BIS	C	8.66	21.13
10/19/10	14	RIS2	A	0.46	5.97
10/19/10	14	RIS2	B	15.26	7.90
10/19/10	14	RIS2	C	15.36	13.48
1/6/11	5.8	BIS	A	2.87	4.69
1/6/11	5.8	BIS	B	0.86	0.18
1/6/11	5.8	BIS	C	-2.21	1.91
1/6/11	5.8	RIS2	A	5.06	1.19
1/6/11	5.8	RIS2	B	10.37	19.61
1/6/11	5.8	RIS2	C	6.90	8.50
5/31/11	12.1	BIS	A	55.59	55.31
5/31/11	12.1	BIS	B	86.28	38.67
5/31/11	12.1	BIS	C	14.99	47.40
5/31/11	12.1	BIS	D	36.55	34.41
5/31/11	12.1	RIS2	A	47.30	77.36
5/31/11	12.1	RIS2	B	21.79	79.77
5/31/11	12.1	RIS2	C	41.81	60.91
7/20/11	15.8	BIS	A	50.21	24.37
7/20/11	15.8	BIS	B	93.15	23.47
7/20/11	15.8	BIS	C	19.74	43.93
7/20/11	15.8	BIS	D	31.92	39.17
7/20/11	15.8	RIS2	A	4.83	50.03
7/20/11	15.8	RIS2	B	7.36	34.02
7/20/11	15.8	RIS2	C	68.04	31.89
7/20/11	15.8	RIS2	D	36.95	8.95
9/27/11	16.6	BIS	A	-8.41	26.75
9/27/11	16.6	BIS	B	-14.45	33.62
9/27/11	16.6	BIS	C	-4.24	31.37
9/27/11	16.6	BIS	D	2.97	20.66
9/27/11	16.6	RIS2	A	83.29	18.48
9/27/11	16.6	RIS2	B	35.79	13.66
9/27/11	16.6	RIS2	C	100.38	16.40
9/27/11	16.6	RIS2	D	34.27	14.62
7/2/12	13.8	BIS	A	147.77	41.13
7/2/12	13.8	BIS	B	20.98	29.43

Date	Temperature, °C	Station	Core Rep	NH ₄ ⁺ flux, μmol m ⁻² h ⁻¹	NO _x flux, μmol m ⁻² h ⁻¹
7/2/12	13.8	BIS	C	-3.19	36.17
7/2/12	13.8	BIS	D	71.68	74.54
7/2/12	13.8	RIS2	A	24.02	4.74
7/2/12	13.8	RIS2	B	-6.66	18.12
7/2/12	13.8	RIS2	D	-17.33	26.79

Table C-16. Dissolved silica (Si) fluxes measured in sediment cores from offshore (continental shelf) stations.

Date	Temperature, °C	Station	Core Rep	Si flux, $\mu\text{mol m}^{-2} \text{h}^{-1}$
10/2/09	17.4	BIS	A	627.17
10/2/09	17.4	BIS	B	-299.96
10/2/09	17.4	BIS	C	1135.81
10/2/09	17.4	RIS1	A	402.00
10/2/09	17.4	RIS1	B	100.14
10/2/09	17.4	RIS1	C	374.16
10/2/09	17.4	RIS2	A	736.25
10/2/09	17.4	RIS2	B	1169.13
10/2/09	17.4	RIS2	C	266.50
1/19/10	4.2	BIS	A	307.16
1/19/10	4.2	BIS	B	166.55
1/19/10	4.2	BIS	C	489.64
1/19/10	4.2	RIS1	A	-90.34
1/19/10	4.2	RIS1	B	108.52
1/19/10	4.2	RIS1	C	92.85
1/19/10	4.2	RIS2	A	-11.79
1/19/10	4.2	RIS2	B	-8.55
1/19/10	4.2	RIS2	C	-16.28
5/2/10	7.7	BIS	A	272.99
5/2/10	7.7	BIS	B	311.63
5/2/10	7.7	BIS	C	493.22
5/2/10	7.7	RIS1	A	234.09
5/2/10	7.7	RIS1	B	254.06
5/2/10	7.7	RIS1	C	178.52
5/2/10	7.7	RIS2	A	133.21
5/2/10	7.7	RIS2	B	149.97
5/2/10	7.7	RIS2	C	105.95
7/7/10	12.8	BIS	A	431.27
7/7/10	12.8	BIS	B	430.95
7/7/10	12.8	BIS	C	203.57
7/7/10	12.8	RIS2	A	223.56
7/7/10	12.8	RIS2	B	158.84
7/7/10	12.8	RIS2	C	204.65
8/17/10	14.6	BIS	A	332.85
8/17/10	14.6	BIS	B	331.95
8/17/10	14.6	BIS	C	325.69
8/17/10	14.6	RIS1	A	126.20
8/17/10	14.6	RIS1	B	245.40
8/17/10	14.6	RIS1	C	124.64

Date	Temperature, °C	Station	Core Rep	Si flux, $\mu\text{mol m}^{-2} \text{h}^{-1}$
8/17/10	14.6	RIS2	A	221.25
8/17/10	14.6	RIS2	B	137.96
8/17/10	14.6	RIS2	C	191.23
10/19/10	14	BIS	A	257.22
10/19/10	14	BIS	B	145.17
10/19/10	14	BIS	C	260.96
10/19/10	14	RIS2	A	80.50
10/19/10	14	RIS2	B	242.87
10/19/10	14	RIS2	C	118.06
1/6/11	5.8	BIS	A	70.04
1/6/11	5.8	BIS	B	28.24
1/6/11	5.8	BIS	C	54.40
1/6/11	5.8	RIS2	A	33.58
1/6/11	5.8	RIS2	B	68.09
1/6/11	5.8	RIS2	C	51.47
5/31/11	12.1	BIS	A	396.89
5/31/11	12.1	BIS	B	254.27
5/31/11	12.1	BIS	C	235.93
5/31/11	12.1	BIS	D	272.98
5/31/11	12.1	RIS2	A	312.43
5/31/11	12.1	RIS2	B	323.52
5/31/11	12.1	RIS2	C	257.29
7/20/11	15.8	BIS	A	483.39
7/20/11	15.8	BIS	B	363.77
7/20/11	15.8	BIS	C	488.12
7/20/11	15.8	BIS	D	454.95
7/20/11	15.8	RIS2	A	292.25
7/20/11	15.8	RIS2	B	333.38
7/20/11	15.8	RIS2	C	358.62
7/20/11	15.8	RIS2	D	263.82
9/27/11	16.6	BIS	A	660.31
9/27/11	16.6	BIS	B	774.61
9/27/11	16.6	BIS	C	676.14
9/27/11	16.6	BIS	D	-180.89
9/27/11	16.6	RIS2	A	301.04
9/27/11	16.6	RIS2	B	102.84
9/27/11	16.6	RIS2	C	242.49
9/27/11	16.6	RIS2	D	516.74
7/2/12	13.8	BIS	A	284.66
7/2/12	13.8	BIS	B	147.32
7/2/12	13.8	BIS	C	256.07

Date	Temperature, °C	Station	Core Rep	Si flux, $\mu\text{mol m}^{-2} \text{h}^{-1}$
7/2/12	13.8	BIS	D	185.15
7/2/12	13.8	RIS2	A	41.68
7/2/12	13.8	RIS2	B	69.43
7/2/12	13.8	RIS2	D	70.25

Table C-17. Sediment oxygen uptake and phosphate fluxes measured in sediment cores from stations in Narragansett Bay.

Date	Temperature, °C	Station	Core Rep	SOD, mg m ⁻² h ⁻¹	DIP flux, μmol m ⁻² h ⁻¹
5/17/10	10.6	MNB	A	18.78	19.04
5/17/10	10.6	MNB	B	17.64	16.92
5/17/10	10.6	MNB	C	22.66	13.99
5/17/10	10.6	PRE	A	128.50	-22.80
5/17/10	10.6	PRE	B	76.92	-14.32
5/17/10	10.6	PRE	C	61.45	-32.08
6/22/10	17.4	MNB	A	35.71	-16.85
6/22/10	17.4	MNB	B	28.72	-21.59
6/22/10	17.4	MNB	C	23.12	-11.03
6/22/10	17.4	PRE	A	65.82	-37.90
6/22/10	17.4	PRE	B	82.88	-39.80
6/22/10	17.4	PRE	C	36.88	-13.08
8/2/10	23.6	MNB	A	38.57	10.27
8/2/10	23.6	MNB	B	42.62	37.16
8/2/10	23.6	MNB	C	46.02	27.66
8/2/10	23.6	PRE	A	156.64	-123.03
8/2/10	23.6	PRE	B	51.19	
8/2/10	23.6	PRE	C	38.46	-2.74
10/11/10	19.1	PRE	A	69.64	38.75
10/11/10	19.1	PRE	B	88.31	53.95
10/11/10	19.1	PRE	C	92.28	86.68
10/11/10	19.1	PRE	D	49.44	6.91
10/11/10	19.1	MNB	A	36.05	8.81
10/11/10	19.1	MNB	B	31.51	1.00
10/11/10	19.1	MNB	C	51.09	34.81
1/20/11	2.5	PRE	A	54.82	11.67
1/20/11	2.5	PRE	B	51.13	4.68
1/20/11	2.5	PRE	C	72.15	3.42
1/20/11	2.5	MNB	A	16.17	8.64
1/20/11	2.5	MNB	B	12.76	3.42
1/20/11	2.5	MNB	C	12.35	2.10
6/16/11	16	MNB	A	30.69	
6/16/11	16	MNB	B	30.85	
6/16/11	16	MNB	C	53.25	
6/16/11	16	PRE	A	41.62	10.35
6/16/11	16	PRE	B	162.03	20.34
6/16/11	16	PRE	C	102.24	52.76
8/24/11	21.7	MNB	A	28.42	-20.30
8/24/11	21.7	MNB	B	28.77	19.72

Date	Temperature, °C	Station	Core Rep	SOD, mg m ⁻² h ⁻¹	DIP flux, μmol m ⁻² h ⁻¹
8/24/11	21.7	MNB	C	21.64	4.32
8/24/11	21.7	MNB	D	21.08	19.41
8/24/11	21.7	MNB	E	33.12	30.09
8/24/11	21.7	PRE	A	85.87	2.75
8/24/11	21.7	PRE	B	102.58	0.94
8/24/11	21.7	PRE	C	367.28	-1.20
8/24/11	21.7	PRE	D	47.53	-12.53
1/10/12	7.8	MNB	A	9.17	-0.62
1/10/12	7.8	MNB	B	10.60	0.70
1/10/12	7.8	MNB	C	9.88	0.69
1/10/12	7.8	MNB	D	9.87	-0.14
1/10/12	7.8	MNB	E	8.79	-0.27
1/10/12	7.8	PRE	A	17.68	-3.91
1/10/12	7.8	PRE	B	19.41	-1.00
1/10/12	7.8	PRE	C	17.92	6.45
1/10/12	7.8	PRE	D	30.05	9.40
1/10/12	7.8	PRE	E	17.33	-3.37
6/19/12	17.5	PRE	A	42.40	29.22
6/19/12	17.5	PRE	B	41.07	18.00
6/19/12	17.5	PRE	H	33.39	26.35
6/19/12	17.5	MNB	A	18.82	
6/19/12	17.5	MNB	C	22.75	
6/19/12	17.5	MNB	F	17.93	
6/19/12	17.5	PRE	F	49.13	17.61
6/19/12	17.5	MNB	D	39.71	13.85
6/19/12	17.5	MNB	E	26.65	5.14
6/19/12	17.5	PRE	C	45.64	
6/19/12	17.5	PRE	G	61.97	
6/19/12	17.5	MNB	G	34.88	
6/19/12	17.5	MNB	H	31.08	

Table C-18. Ammonium and nitrate+nitrite fluxes measured in sediment cores from stations in Narragansett Bay.

Date	Temperature, °C	Station	Core Rep	NH ₄ ⁺ flux, μmol m ⁻² h ⁻¹	NO _x flux, μmol m ⁻² h ⁻¹
5/17/10	10.6	MNB	A	40.14	5.54
5/17/10	10.6	MNB	B	50.39	-1.18
5/17/10	10.6	MNB	C	46.95	7.94
5/17/10	10.6	PRE	A	189.68	-34.50
5/17/10	10.6	PRE	B	-30.59	44.25
5/17/10	10.6	PRE	C	-43.80	20.24
6/22/10	17.4	MNB	A	246.93	28.48
6/22/10	17.4	MNB	B	79.48	25.91
6/22/10	17.4	MNB	C	101.51	20.72
6/22/10	17.4	PRE	A	232.61	-186.53
6/22/10	17.4	PRE	B	285.17	36.50
6/22/10	17.4	PRE	C	89.07	34.54
8/2/10	23.6	MNB	A	226.04	5.01
8/2/10	23.6	MNB	B	510.82	2.84
8/2/10	23.6	MNB	C	430.15	3.19
8/2/10	23.6	PRE	A	441.15	-332.59
8/2/10	23.6	PRE	B	31.29	221.86
8/2/10	23.6	PRE	C	73.24	61.52
10/11/10	19.1	MNB	A	496.86	6.99
10/11/10	19.1	MNB	B	196.09	22.98
10/11/10	19.1	MNB	C	1304.89	-2.21
10/11/10	19.1	PRE	A	370.01	-10.70
10/11/10	19.1	PRE	B	860.38	-6.50
10/11/10	19.1	PRE	C	829.58	18.13
10/11/10	19.1	PRE	D	30.86	34.80
1/20/11	2.5	MNB	A	1.06	1.13
1/20/11	2.5	MNB	B	7.53	2.18
1/20/11	2.5	MNB	C	-1.32	0.86
1/20/11	2.5	PRE	A	-4.54	-6.91
1/20/11	2.5	PRE	B	-0.15	9.30
1/20/11	2.5	PRE	C	55.21	-16.29
6/16/11	16	MNB	A	56.96	
6/16/11	16	MNB	B	97.68	
6/16/11	16	MNB	C	248.71	
6/16/11	16	PRE	A	-44.29	-237.99
6/16/11	16	PRE	B	285.45	98.69
6/16/11	16	PRE	C	108.62	171.49
8/24/11	21.7	MNB	A	110.29	-34.45
8/24/11	21.7	MNB	B	117.89	91.60

Date	Temperature, °C	Station	Core Rep	NH ₄ ⁺ flux, μmol m ⁻² h ⁻¹	NO _x flux, μmol m ⁻² h ⁻¹
8/24/11	21.7	MNB	C	-13.68	-251.63
8/24/11	21.7	MNB	D	-120.26	76.13
8/24/11	21.7	MNB	E	153.77	-274.94
8/24/11	21.7	PRE	A	149.52	-444.13
8/24/11	21.7	PRE	B	143.86	-6.31
8/24/11	21.7	PRE	C	809.12	-257.44
8/24/11	21.7	PRE	D	-12.30	164.73
1/10/12	7.8	MNB	A	-4.08	0.42
1/10/12	7.8	MNB	B	-2.25	7.32
1/10/12	7.8	MNB	C	29.87	2.94
1/10/12	7.8	MNB	D	2.85	-1.73
1/10/12	7.8	MNB	E	4.86	3.19
1/10/12	7.8	PRE	A	53.33	-70.41
1/10/12	7.8	PRE	B	104.95	-38.29
1/10/12	7.8	PRE	C	75.85	43.89
1/10/12	7.8	PRE	D	45.27	88.78
1/10/12	7.8	PRE	E	141.38	-37.97
6/19/12	17.5	MNB	A	-31.70	
6/19/12	17.5	MNB	C	-10.56	
6/19/12	17.5	MNB	D	163.71	30.59
6/19/12	17.5	MNB	E	43.48	-47.48
6/19/12	17.5	MNB	F	79.99	
6/19/12	17.5	MNB	G		
6/19/12	17.5	MNB	H		
6/19/12	17.5	PRE	A	81.38	85.44
6/19/12	17.5	PRE	B	-41.51	-36.17
6/19/12	17.5	PRE	C		
6/19/12	17.5	PRE	F	14.39	24.25
6/19/12	17.5	PRE	G		
6/19/12	17.5	PRE	H	148.24	-38.23

APPENDIX D – BENTHIC FLUX DATA FROM PAST STUDIES

D-1. MID-NARRAGANSETT BAY DATA

Table D-1. Past measurements of benthic fluxes in mid-Narragansett Bay. Sediment oxygen demand (SOD) is in $\text{mg m}^{-2} \text{h}^{-1}$, and all nutrient fluxes are in $\mu\text{mol m}^{-2} \text{h}^{-1}$. Ref numbers refer to the corresponding reference number in Table D-2.

Date	Temp, °C	SOD	DIP Flux	NH_4^+ Flux	NO_x Flux	Si Flux	Type of Core	Ref
1973-74	1.2	28.1					in situ	7
1973-74	1.2	25.0					in situ	7
1973-74	1.2	21.8					in situ	7
1973-74	1.5	17.9					in situ	7
1973-74	1.6	6.5					in situ	7
1973-74	1.7	10.0					in situ	7
1973-74	1.9	6.2					in situ	7
1973-74	3.0	12.5					in situ	7
1973-74	3.0	9.4					in situ	7
1973-74	3.1	6.7					in situ	7
1973-74	3.1	0.0					in situ	7
1973-74	3.1	6.7					in situ	7
1973-74	3.2		-2.2				in situ	7
1973-74	3.2		0.0				in situ	7
1973-74	3.2		2.2				in situ	7
1973-74	3.5	19.8					in situ	7
1973-74	3.7	22.1					in situ	7
1973-74	4.4	6.7					in situ	7
1973-74	4.5	42.1					in situ	7
1973-74	4.5	25.0					in situ	7
1973-74	4.5	20.3					in situ	7
1973-74	4.7	1.3					in situ	7
1973-74	4.7	3.3					in situ	7
1973-74	4.8	9.1					in situ	7
1973-74	5.0		1.1				in situ	7
1973-74	8.1	36.7					in situ	7
1973-74	8.3	46.7					in situ	7
1973-74	8.6		8.9				in situ	7
1973-74	8.8	40.0					in situ	7
1973-74	9.0		4.4				in situ	7
1973-74	9.7		1.1				in situ	7
1973-74	9.7		5.6				in situ	7
1973-74	9.7		9.4				in situ	7
1973-74	10.2	40.0					in situ	7

Date	Temp, °C	SOD	DIP Flux	NH ₄ ⁺ Flux	NO _x Flux	Si Flux	Type of Core	Ref
1973-74	10.2	53.3					in situ	7
1973-74	10.3	36.7					in situ	7
1973-74	10.3	60.0					in situ	7
1973-74	10.3	73.3					in situ	7
1973-74	10.4		3.9				in situ	7
1973-74	10.4		5.0				in situ	7
1973-74	10.7		5.6				in situ	7
1973-74	10.7		7.8				in situ	7
1973-74	10.8		16.1				in situ	7
1973-74	13.4	140.0					in situ	7
1973-74	13.9		23.9				in situ	7
1973-74	16.9	66.7					in situ	7
1973-74	16.9	90.0					in situ	7
1973-74	18.9	100.0					in situ	7
1973-74	18.9	110.0					in situ	7
1973-74	19.4		18.9				in situ	7
1973-74	19.4		32.8				in situ	7
1973-74	20.9	123.3					in situ	7
1973-74	20.9	143.3					in situ	7
1973-74	20.9	160.0					in situ	7
6/9/75	16.5			39.0			in situ	8
6/9/75	16.5	32.4		46.0			in situ	8
6/9/75	16.5	53.5		122.0			in situ	8
6/9/75	16.8	51.5						8
6/9/75	16.8	43.7						8
6/9/75	17.0	45.6						8
6/9/75	17.2	42.7						8
6/23/75	17.5	48.0	32.0	116.0		315.0	in situ	8
6/23/75	17.5	47.0		57.0			in situ	8
6/23/75	17.5	50.0		114.0			in situ	8
6/25/75	17.5	39.0	26.0	84.0		353.0	in situ	8
6/25/75	17.5	42.0		93.0			in situ	8
6/25/75	17.5	38.0		94.0			in situ	8
6/25/75	17.5	40.6						8
6/25/75	17.6	62.7						8
6/25/75	17.6	45.6						8
6/30/75	18.0	58.0	35.0	153.0		546.0	in situ	8
6/30/75	18.0	71.0		162.0			in situ	8
6/30/75	18.0	67.0		169.0			in situ	8
6/30/75	18.0	82.1						8
6/30/75	18.1	69.3						8
6/30/75	18.3	49.7						8
6/30/75	18.4	64.8						8
7/6/75	18.5	62.0	37.0	129.0		409.0	in situ	8

Date	Temp, °C	SOD	DIP Flux	NH ₄ ⁺ Flux	NO _x Flux	Si Flux	Type of Core	Ref
7/6/75	18.5	25.0		61.0			in situ	8
7/6/75	18.5	35.0		74.0			in situ	8
7/6/75	18.9	59.4						8
7/6/75	18.9	57.8						8
7/6/75	19.3	91.6						8
7/6/75	19.5	78.5						8
7/6/75	19.5	58.6						8
7/6/75	19.6	78.0						8
7/6/75	19.8	74.7						8
7/6/75	19.8	58.0						8
7/21/75	20.0	27.0	55.0	230.0		342.0	in situ	8
7/21/75	20.0			132.0			in situ	8
7/21/75	20.0	40.0		218.0			in situ	8
7/21/75	20.0	61.9						8
7/21/75	20.0	57.4						8
7/21/75	20.0	53.8						8
7/21/75	20.0	38.0						8
7/21/75	20.1	61.9						8
7/21/75	20.1	55.3						8
7/21/75	20.3	55.6						8
7/21/75	20.4	65.1						8
7/21/75	20.5	56.7						8
7/21/75	20.8	78.3						8
7/21/75	20.9	78.3						8
7/28/75	21.0	35.0	34.0	144.0		416.0	in situ	8
7/28/75	21.0	38.0		79.0			in situ	8
7/28/75	21.0	35.0		120.0			in situ	8
7/28/75	21.0	184.4						8
7/28/75	21.0	160.9						8
7/28/75	21.0	58.9						8
7/28/75	21.1	93.0						8
7/28/75	21.2	40.2						8
12/30/75	5.0	4.8	1.2	-3.3				8
12/30/75	5.0	4.0	1.4	-1.1				8
12/30/75	8.0	16.8						8
12/30/75	8.1	18.9						8
12/30/75	8.2	25.4						8
12/30/75	8.4	35.9						8
12/30/75	8.4	32.8						8
12/30/75	8.7	45.3						8
12/30/75	9.9	67.2						8
3/29/76	5.0	24.0	2.7	12.0	-0.3	57.0	extracted	8
3/29/76	5.0	11.0		4.0	0.1	40.0	extracted	8
4/22/76	10.5	21.5	3.2	81.0	6.7	135.0	extracted	8
4/22/76	10.5	18.0	2.9	61.0	8.1	143.0	extracted	8
4/22/76	10.5	13.5	5.5	85.0	9.8	232.0	extracted	8
4/26/76	10.2	48.4						8

Date	Temp, °C	SOD	DIP Flux	NH ₄ ⁺ Flux	NO _x Flux	Si Flux	Type of Core	Ref
4/26/76	10.2	39.0						8
4/26/76	10.2	28.1						8
4/26/76	10.4	22.8						8
4/26/76	10.7	10.9						8
4/26/76	10.8	23.0						8
4/26/76	11.9	23.1						8
5/11/76	10.0		0.0			109.0	extracted	8
5/11/76	10.0		0.7			91.0	extracted	8
5/11/76	10.0		2.0			180.0	extracted	8
5/11/76	10.0	9.8	3.0	51.0	54.0	87.5	extracted	8
5/11/76	10.0	16.9	2.6	53.0	55.6	100.0	extracted	8
5/11/76	10.0	28.5	3.7	117.0	120.7	172.0	extracted	8
5/12/76	10.0		2.6					8
5/17/76	10.0		1.1					8
5/17/76	10.0		2.6					8
5/17/76	10.0		2.8					8
5/18/76	10.0	24.8	1.9	63.0				8
5/18/76	10.0	20.5	3.9	63.0				8
5/18/76	10.0	9.3	4.6	105.0				8
5/31/76	10.0		1.3					8
5/31/76	10.0		1.3					8
5/31/76	10.0		1.8					8
6/2/76	10.0	21.4	3.5	70.0				8
6/2/76	10.0	20.6	3.8	72.0				8
6/2/76	10.0	15.6	3.6	107.0				8
8/23/76	23.1	171.9		131.0			MERL	9
9/21/76	18.9	109.4	0.0	140.0	5.0	143.0	MERL	9
10/18/76	11.9	78.1	3.0	59.0	0.0	76.0	MERL	9
11/15/76	6.3	50.8		18.0	0.0	8.0	MERL	9
1/11/77	0.5	54.7	4.0	8.0	0.0	22.0	MERL	9
3/21/77	4.0	27.4	4.0	8.0	2.0	0.0	MERL	9
4/17/77	11.2	74.3	3.0	41.0	4.0	26.0	MERL	9
5/15/77	13.6	78.1	11.0	44.0	3.0	54.0	MERL	9
6/11/77	22.4	152.4	12.0	98.0	7.0	115.0	MERL	9
6/13/77	16.8	125.0	8.0	56.0	1.0	18.0	MERL	9
8/1/77	22.4	105.5	7.0	68.0	12.0	80.0	MERL	9
8/29/77	23.4	128.9	3.0	109.0	4.0	101.0	MERL	9
9/20/77	19.6	82.1	18.0	80.0	1.0		MERL	9
10/19/77	12.5	26.0		82.0	4.6		extracted	8
10/19/77	12.5	37.5		101.0	72.0		extracted	8
10/19/77	12.5	14.5		19.0			extracted	8
10/19/77	12.5	18.3		73.0			extracted	8
10/25/77	12.0		2.4					8
10/25/77	12.0		2.4					8
11/16/77	11.9	13.3	0.0	5.8		39.0	extracted	8
11/16/77	11.9	20.8	6.1	34.7		64.0	extracted	8

Date	Temp, °C	SOD	DIP Flux	NH ₄ ⁺ Flux	NO _x Flux	Si Flux	Type of Core	Ref
11/16/77	18.0	14.7	2.2	19.5		63.0	extracted	8
11/16/77	18.0	14.8	3.6	46.8		141.0	extracted	8
11/17/77	12.7	23.7						8
5/24/81	12.8	23.2	5.0	56.8	3.6	343.3	MERL	1-3
5/24/81	13.1	29.5	9.1	117.2	3.3	113.4	MERL	1-3
5/24/81	13.8	35.2	8.7	116.0	14.2	-54.8	MERL	1-3
6/27/81	19.4	58.0	23.2	80.5	10.1	202.5	MERL	1-3
6/27/81	19.5	58.6	13.8	141.3	6.9	364.7	MERL	1-3
6/27/81	19.8	50.8	10.8	117.8	-3.4	225.0	MERL	1-3
7/29/81	19.5	53.8	-1.8	131.6	9.0	-370.0	MERL	1-3
7/29/81	19.9	38.0		175.8	21.0	206.5	MERL	1-3
7/29/81	20.0	57.4		93.6	9.3	135.5	MERL	1-3
8/26/81	17.7			225.9	-18.3		MERL	1-3
8/26/81	17.9			119.3	-16.1		MERL	1-3
8/26/81	18.4		11.1	165.6	-0.5		MERL	1-3
9/23/81	17.6	62.7	7.8	140.2	20.7	184.9	MERL	1-3
9/23/81	17.8	42.7	7.5	92.7	34.0	12.8	MERL	1-3
9/23/81	18.1	49.7	7.7	82.9	17.0	115.7	MERL	1-3
11/7/81	10.3		3.2	31.3	9.3	50.7	MERL	1-3
11/7/81	10.8		7.1	34.3	9.9	203.5	MERL	1-3
11/7/81	11.0		1.9	40.7	-49.3	87.3	MERL	1-3
1/17/82	0.9	6.5	0.5	0.5	0.4	3.6	MERL	1-3
1/17/82	1.0	6.2	1.1	10.3	3.8	20.1	MERL	1-3
1/17/82	1.3	10.0	1.1	11.5	4.3	39.9	MERL	1-3
3/20/82	4.4	22.1	1.1	9.3	1.8	31.7	MERL	1-3
3/20/82	4.4	19.8	1.6	25.9	7.4	41.2	MERL	1-3
3/20/82	5.7	9.1	0.9	32.7	6.2	63.8	MERL	1-3
5/20/82	14.0	53.5	6.3	111.0	20.6	436.2	MERL	1-3
5/20/82	14.1	47.8	5.5	86.8	32.5	212.1	MERL	1-3
5/20/82	15.4	50.1	5.3	105.4	25.3	77.5	MERL	1-3
6/30/82	18.1	82.1		210.2	23.7		MERL	1-3
6/30/82	18.1	69.3		142.0	40.0	283.6	MERL	1-3
6/30/82	18.4	64.8	6.0	125.6	21.1	266.4	MERL	1-3
7/21/82	20.1	55.3	10.2	147.5	24.3	218.1	MERL	1-3
7/21/82	20.2	61.9	9.3	179.8	19.4		MERL	1-3
7/21/82	20.3	78.3	8.8	178.3	13.8		MERL	1-3
8/18/82	20.8	78.3	4.1	179.3	26.2	289.5	MERL	1-3
8/18/82	20.9	58.9	8.2	156.8	14.1		MERL	1-3
8/18/82	21.0	93.0	11.5	151.0	54.1		MERL	1-3
10/6/82	16.0	39.6	-4.5	99.4	29.4	185.2	MERL	1-3
10/6/82	16.0	57.9	5.4	78.6	37.8	273.1	MERL	1-3
10/6/82	16.0	36.8	10.0	96.9	20.4	174.3	MERL	1-3
12/1/82	8.2	25.4	0.7	12.0	14.5	83.6	MERL	1-3
12/1/82	8.3	18.9	0.9	12.4	22.3	64.0	MERL	1-3
12/1/82	8.3	16.8	3.3	28.6	4.8	69.9	MERL	1-3
2/16/83	1.2	17.9	0.7	8.0	11.5	25.8	MERL	1-3
2/16/83	1.6						MERL	1-3

Date	Temp, °C	SOD	DIP Flux	NH ₄ ⁺ Flux	NO _x Flux	Si Flux	Type of Core	Ref
2/16/83	1.8						MERL	1-3
5/11/83	12.3	45.8	4.9	72.4	27.1	170.7	MERL	1-3
5/11/83	12.4	41.7	3.7	73.4	30.0	91.8	MERL	1-3
5/11/83	13.1	47.4	8.3	62.0	9.0	246.2	MERL	1-3
6/29/83	18.5	91.6	13.0	180.6	22.1	337.3	MERL	1-3
6/29/83	19.0	74.7	15.1	190.6	64.0	91.8	MERL	1-3
6/29/83	19.5	65.1	18.0	183.4	17.0	248.2	MERL	1-3
7/31/83	21.8	78.0	11.6	154.6	75.6	236.4	MERL	1-3
7/31/83	21.8	78.5	13.8	183.2	51.9	354.3	MERL	1-3
7/31/83	22.6	55.6	16.0	165.5	25.2	339.5	MERL	1-3
9/21/83	19.9	56.7	14.6	160.6	33.0	269.4	MERL	1-3
9/21/83	19.9	60.9	33.1	241.0	4.7	45.7	MERL	1-3
9/21/83	21.2	40.2	11.2	154.4	11.5	151.4	MERL	1-3
6/20/84	22.0	56.9	7.8		163.3	16.0	MERL	4
6/20/84	22.1	49.6	8.0	82.0	1.7	270.9	MERL	4
6/20/84	22.5	59.0	12.8		8.8	267.2	MERL	4
8/3/84	19.8	58.6	13.2	206.2	22.5	203.9	MERL	4
8/3/84	20.3	59.4	12.0	204.8	13.2	800.2	MERL	4
8/3/84	20.9	42.1	9.7	133.1	22.5	315.7	MERL	4
8/31/84	20.0	49.3	12.9	186.1	96.7	291.7	MERL	4
8/31/84	20.5	58.6	12.2	218.1	29.2	208.2	MERL	4
8/31/84	20.6	52.1	17.5	189.8	21.9	285.8	MERL	4
9/16/84	17.2	41.6	7.6	126.0	65.4	289.4	MERL	4
9/16/84	18.8	41.6	9.1	110.2	17.8	197.7	MERL	4
6/1/85	18.6	38.1	11.2	29.5	8.6	131.0	MERL	9
6/1/85	18.6	77.8	27.8	65.7	12.1	284.0	MERL	9
7/1/85	20.3	42.8	2.0	31.8	11.0	165.0	MERL	9
7/1/85	20.3	46.5	13.0	31.2	15.3	552.0	MERL	9
8/1/85	20.5	197.0	8.6	182.0	14.3	125.0	MERL	9
8/1/85	20.5	157.0	12.3	143.0	15.7	63.0	MERL	9
9/1/85	17.0	98.0	3.4	78.4	19.1	141.0	MERL	9
9/1/85	17.0	75.3	9.6	73.2	2.1	144.0	MERL	9
10/1/85	10.9	32.4	-5.2	31.3	1.1	27.0	MERL	9
10/1/85	10.9	65.2	3.1	50.6	14.6	51.0	MERL	9
12/1/85	8.3	48.6	1.9	38.0	10.6	27.6	MERL	9
12/1/85	8.3	51.2	2.5	35.3	15.9	61.0	MERL	9
2/1/86	2.2	11.8	1.2	10.6	1.2	20.1	MERL	9
2/1/86	2.2	40.1	1.3	30.2	9.9	35.0	MERL	9
4/1/86	8.4	80.9	3.1	60.9	20.0	51.4	MERL	9
4/1/86	8.4	68.2	3.9	46.8	21.4	98.5	MERL	9
6/1/86	15.2	111.0	7.4	82.0	29.0	243.0	MERL	9
6/1/86	15.2	158.0	9.7	121.0	37.4	199.0	MERL	9
8/21/86	21.0	123.5	13.0	382.2	39.7	390.7	MERL	5
8/21/86	21.5	97.5	-4.4	144.3	177.4	283.1	MERL	5
8/22/86	21.1	67.6	3.9	92.3	134.6	215.8	MERL	5
9/17/86	16.0	88.8	12.2	181.3	7.6	274.9	MERL	5
9/17/86	17.2	58.5	-15.2	-142.1	185.5	150.9	MERL	5

Date	Temp, °C	SOD	DIP Flux	NH ₄ ⁺ Flux	NO _x Flux	Si Flux	Type of Core	Ref
10/23/86	11.9	62.4	48.4	180.7	58.8	152.4	MERL	5
10/23/86	12.9	47.1	15.0	75.4	70.2	120.3	MERL	5
11/13/86	9.0	47.3	-66.0	-56.0	-46.7	27.0	MERL	5
11/13/86	9.5	35.6	11.3	30.7	63.1	67.6	MERL	5
7/1/05	18.0	12.1	3.5	30.5	0.8	252.7	extracted	6
7/1/05	18.0	14.6	1.4	9.3	7.0	121.5	extracted	6
7/1/05	18.0	15.0	2.8	38.0	1.1	263.1	extracted	6
8/26/05	23.0	10.9	1.7	-7.2	-0.1	709.8	extracted	6
8/26/05	23.0	14.8	0.9	12.0	1.6		extracted	6
8/26/05	23.0	27.5	20.8	98.8	2.6	233.5	extracted	6
11/7/05	13.0	14.9	-4.2	6.6	-7.1		extracted	6
11/7/05	13.0	15.3	-2.5	-15.6	-7.7	212.2	extracted	6
11/7/05	13.0	16.4	-0.1	9.1	-0.4	231.1	extracted	6
5/3/06	6.0	3.4	1.4	-4.2	-5.9	108.9	extracted	6
5/3/06	6.0	8.6	1.9	21.2	-7.9	172.2	extracted	6
5/3/06	6.0	19.2	2.3	9.7	-8.7	557.1	extracted	6
7/19/06	18.0	30.8	2.9	83.7	5.8	776.2	extracted	6
7/19/06	18.0	32.4	1.6	64.0	4.2	560.4	extracted	6
7/19/06	18.0	36.3	0.4	165.1	18.7	496.0	extracted	6
8/14/06	21.0	24.0	-4.6	-10.3	18.3	357.8	extracted	6
8/14/06	21.0	28.8	0.3	8.2	14.4	749.9	extracted	6
8/14/06	21.0	31.6	7.0	164.7	1.8	617.8	extracted	6

Table D-2. Data sources for mid-Narragansett Bay benthic flux measurements in Table D-1.

Source	Reference
1	Frithsen, J.B., A.A. Keller, and M.E.Q. Pilson. 1985. Effects of inorganic nutrient additions in coastal areas: A mesocosm experiment data report. Volume 1. MERL Series, Report no. 3, The University of Rhode Island, Kingston, RI, 176p.
2	Frithsen, J.B., P.A. Lane, A.A. Keller and M.E.Q. Pilson. 1985. Effects of inorganic nutrient additions in coastal areas: A mesocosm experiment data report. Volume 2. MERL Series, Report No.4, The University of Rhode Island, Kingston, RI, 330p.
3	Frithsen, J.B., A.A. Keller, and M.E.Q. Pilson. 1985. Effects of inorganic nutrient additions in coastal areas: A mesocosm experiment data report. Volume 3. MERL Series, Report no. 5, The University of Rhode Island, Kingston, RI, 244p.
4	Keller, A.A., J.B. Frithsen, C.A. Oviatt, J.T. Maugham, B.K. Sullivan, S.W. Nixon, and M.E.Q. Pilson. 1987. Marine ecosystem responses to sewage sludge and inorganic nutrient additions: A mesocosm experiment data report. MERL Series, Report No. 6, The University of Rhode Island, Kingston, RI, 237p.
5	Frithsen, J.B., C.A. Oviatt, and A.A. Keller. 1987. A comparison of ecosystem and single-species tests of sewage effluent toxicity: A mesocosm experiment data report. MERL Series, Report no. 7, The University of Rhode Island, Kingston, RI, 187p.
6	Fulweiler, R.W. 2007. The impact of climate change on benthic-pelagic coupling and the biogeochemical cycling of Narragansett Bay, RI. Ph.D., University of Rhode Island, Narragansett, RI.;
	Fulweiler, R.W. and S.W. Nixon. 2009. Responses of benthic-pelagic coupling to climate change in a temperate estuary. <i>Hydrobiologia</i> 629(1):147-156.
7	Hale, S. 1974. The role of benthic communities in the nutrient cycles of Narragansett Bay. M.S., University of Rhode Island, Narragansett, RI.;
	Nixon, S.W., C.A. Oviatt, and S. Hale. 1976. Nitrogen regeneration and the metabolism of coastal marine bottom communities. In: Anderson, J.M. and A. Macfadyen (ed.). <i>The Role of Terrestrial and Aquatic Organisms in Decomposition Processes</i> . Blackwell Scientific Publications, London.
	Nixon, S.W., J.R. Kelly, B.N. Furnas, C.A. Oviatt, and S. Hale. 1980. Phosphorus regeneration and the metabolism of coastal marine bottom communities. In: Tenore, K.R. and B.C. Coull (ed.). <i>Marine Benthic Dynamics</i> . University of South Carolina Press, Columbia, SC.
8	S.W. Nixon, unpublished data
9	MERL mesocosm experiments

D-2. PROVIDENCE RIVER ESTUARY DATA

Table D-3. Past measurements of benthic fluxes in the Providence River Estuary. Sediment oxygen demand (SOD) is in $\text{mg m}^{-2} \text{h}^{-1}$, and all nutrient fluxes are in $\mu\text{mol m}^{-2} \text{h}^{-1}$. Fluxes in the same row were not measured simultaneously in the same cores. 1980s data are from S. Nixon and B. Nowicki (unpub. data), and 2005-2006 data are from Fulweiler et al. (2010).

Date	Temp	Station	SOD	DIP Flux	NH_4^+ Flux	NO_x Flux
9/19/83	21	CON	42.0	-26.1	-258.0	-267.8
9/19/83	21	FIE	18.0	123.2	653.0	-50.9
9/19/83	21	GAS	65.0	29.4	118.0	78.0
12/14/83	9.5	CON	4.0			
12/14/83	9.5	FIE	19.0			
12/14/83	9.5	GAS	7.0			
3/15/84	4	CON	18.0	-1.1	-36.0	-89.4
3/15/84	4	CON	20.0	-10.3	86.0	-38.2
3/15/84	4	FIE	21.0	23.3	358.0	42.3
3/15/84	4	FIE	20.0	8.6	422.0	102.9
3/15/84	4	GAS	18.0	2.5	14.0	-7.4
3/15/84	4	GAS	16.0	0.4	41.0	-1.0
4/13/84	7	CON	30.0	-1.0	-39.0	-34.7
4/13/84	7	CON	27.0		-37.0	3.4
4/13/84	7	FIE	17.0	3.2	68.0	-14.7
4/13/84	7	FIE	24.0		100.0	-13.7
4/13/84	7	GAS	29.0	0.6	48.0	-14.8
4/13/84	7	GAS	12.0		74.0	2.2
5/3/84	10	CON	34.0	-0.7	-60.0	-46.9
5/3/84	10	CON	27.0		-32.0	-27.4
5/3/84	10	FIE	22.0	0.5	98.0	3.5
5/3/84	10	FIE	13.0		112.0	19.8
5/3/84	10	GAS	22.0	23.1	6.0	1.3
5/3/84	10	GAS	7.0		30.0	4.1
6/18/84	19	CON	38.0	32.9	63.0	-9.6
6/18/84	19	CON	31.0	16.0	202.0	0.0
6/18/84	19	FIE	40.0	104.6	142.0	-40.4
6/18/84	19	FIE	25.0	24.8	219.0	24.0
6/18/84	19	GAS	37.0	76.5	91.0	0.5
6/18/84	19	GAS	25.0	49.5	231.0	7.4
7/26/84	21	CON	92.0	89.2	113.0	-42.5
7/26/84	21	CON	90.0	17.3	859.0	74.9
7/26/84	21	FIE	71.0	-20.0	-49.0	-107.9

Date	Temp	Station	SOD	DIP Flux	NH ₄ ⁺ Flux	NO _x Flux
7/26/84	21	FIE	78.0	45.0	107.0	-28.6
7/26/84	21	GAS	100.0	1.9	-261.0	-60.4
7/26/84	21	GAS	101.0	-38.3	-121.0	-21.2
8/3/84	20	CON	40.0	66.7	348.0	-9.5
8/3/84	20	CON	32.0	14.4	351.0	-3.6
8/3/84	20	FIE	57.0	174.7	571.0	-56.1
8/3/84	20	FIE	44.0	133.3	734.0	-21.5
8/3/84	20	GAS	61.0	93.0	82.0	-6.2
8/3/84	20	GAS	55.0		90.0	10.7
8/20/84	22	CON	97.0	18.5	114.0	18.8
8/20/84	22	CON			255.0	22.0
8/20/84	22	FIE			249.0	-44.6
8/20/84	22	FIE	63.0	91.4	593.0	3.6
8/20/84	22	GAS	62.0		-140.0	12.5
8/20/84	22	GAS	88.0	-21.5	-77.0	16.3
10/26/84	15	CON	24.0			
10/26/84	15	GAS	13.0			
8/22/05	23	C	87.8	-10.8	777.7	-69.0
8/22/05	23	C	59.3	11.9	483.9	-67.9
8/22/05	23	C	106.5	-29.9	632.3	-38.6
11/22/05	13	C	30.2	-3.4	5.6	-6.1
11/22/05	13	C	14.8	1.2	12.6	-3.0
11/22/05	13	C	5.8	-2.5	0.6	-24.9
11/22/05	13	PRU	37.7	-3.0	38.8	-11.9
11/22/05	13	PRU	32.7	-3.1	-24.9	1.2
11/22/05	13	PRU	39.5	0.5	-0.1	37.5
4/19/06	6	C	17.7	2.2	20.9	-3.6
4/19/06	6	C	19.9	-0.2	0.1	-6.5
4/19/06	6	C	13.9	-0.4	5.3	-4.0
4/19/06	6	PRU	28.2	3.4	80.6	7.1
4/19/06	6	PRU	14.3	2.8	17.1	8.6
4/19/06	6	PRU	27.9	4.5	29.3	14.0
7/10/06	18	C	47.5	5.9	97.4	14.3
7/10/06	18	C	28.3	2.5	-7.3	0.5
7/10/06	18	C	37.9	1.2	54.7	5.4
7/10/06	18	PRU	57.0	41.8	169.2	-9.7
7/10/06	18	PRU	40.3	-3.8	162.5	-16.3
7/10/06	18	PRU	46.7	8.1	72.9	32.8
9/1/06	22	PRU	29.5	28.0	442.0	-24.7
9/1/06	22	PRU	23.9	32.5	290.8	-28.7
9/1/06	22	PRU	17.2	30.6	294.4	-31.0

Date	Temp	Station	SOD	DIP Flux	NH ₄ ⁺ Flux	NO _x Flux
1984	4	SAB		37.5		
1984	20	SAB		233.3		
1984	20	SAB		54.2		
1984	21	SAB		37.5		